The Constitution of Paleobiological Data

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For my parents

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Introduction

This dissertation investigates the features of the paleobiological epistemic thing by historicizing and seeking the grounds of validity of the paleobiological practice. Paleobiology is a new approach to the fossil record born during the 1970s. First and foremost, its epistemic thing is the fossil record. By following the changing meanings of the fossil record, I will investigate the social and philosophical conditions that make up the genesis, the constitution, and the early establishment of paleobiological data. I will investigate how and to what extent paleontologists can *de facto* and *de jure* impose formal constraints on their data to obtain biological knowledge. I will focus on i) the genesis of paleobiological data as it emerges in German stratigraphy and paleontology between the mid 19th and the early 20th century and ii) how the conceptualization of the paleontological data was reformulated and taken as the starting point for studying the patterns of the diversity of life in deep time between the 1940s and 80s. By tracing the various meanings of the fossil record, I will characterize what changed in the transition between paleontology and paleobiology. I argue that a different categorial framework differentiates the former from the latter.

What, however, is the fossil record? This is not a simple question because it is both the paleontological datum and an epistemic thing. Intuitively, the fossil record is a material object entombed in rock layers, which can be admired in a museum. It is a petrified organism and as such provides marvelous insights into the biological features of the remote past. The intuitive comprehension of the fossil record was not always formulated in these biological terms. A long effort of thought was required in order to perceive a material object entombed in a rock as a biologically relevant entity. I will not focus on this historical development, but rather on how it was possible to treat a material object as a valuable datum for paleontological and paleobiological inquiries. In the next pages, I will point out various definitions of the fossil record as well as their qualities and deficiencies to historically trace their genesis and philosophically reflect on their validity. One remark needs to be anticipated however: the fossil record, i.e. the paleontological datum, is always imperfect and incomplete. It is extremely rare to find a well-preserved fossil. In fact, it is subjected to what have been called taphonomic processes. For instance, it is extremely rare to find fossils with soft-parts preserved and even the hard-parts are rarely completely preserved. Hence for the most part, paleontologists deal with incomplete and imperfect data: generally only a small part of the original organism generally is fossilized and preserved. As Charles Darwin famously wrote in the ninth chapter of his *Origin of Species*: fossils are extremely imperfect entities.

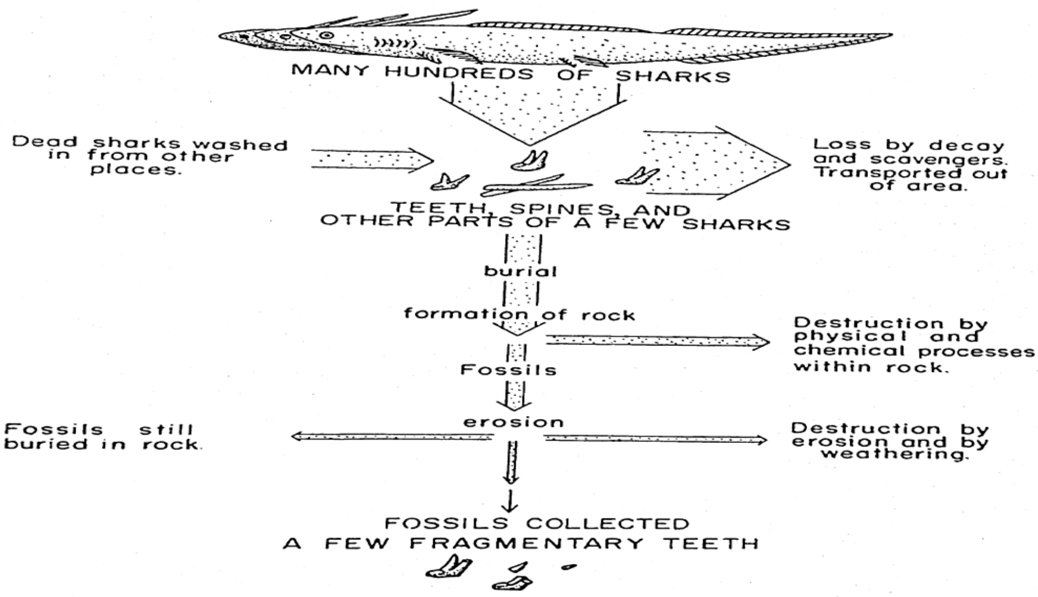


Figure 1 Possible taphonomic processes

By carrying out an historical epistemology in conjunction with a meta-reflection, I will reconstruct in detail how it was possible to transform an incomplete and misleading material object — the fossil record that can be admired in a museum — into a source of knowledge (misleading no longer). In fact, I will argue that paleobiological data are not given at all. They are, on the contrary, the end product of a complex activity of construction and deconstruction of the observational features of the material fossil record. For a paleobiologist, the fossil record is not something which can be admired in a natural museum; it is rather a stabilized version of the past. To obtain these kinds of epistemic things, paleobiologists have stepped back from their former position of metaphysical realism, concerning the nature of reference and truth in the past. Both from a factual and logical point of view[1], I will describe and historicize step by step the levels of this constitution emphasizing the elements of continuity and fracture with German paleontology of the 19th century. In Germany the fossil record was conceived in at least two different ways: on the one hand, it was identified as a set of facts, on the other as an event in deep time. Over the next chapters, I will examine the origin of these approaches and the extent to which they were important for the later American 'paleobiological revolution'.

[1] I.e. I will investigate both the matters of fact (quid facti) and the grounds of validity (quid iuris) of this process.

Why is data so central?

Data are things that are given. They are not merely material objects, but also starting points for epistemic investigations. Famously, Immanuel Kant writes in his *Critique of pure Reason* that "there is no doubt whatever that all our cognition begins with experience […] **As far as time is concerned**, then, no cognition in us precedes experience, and with experience every cognition begins" (Kant, 1999, p. 136, B1). Kant's *Critique of pure Reason* was a complex attempt to analyze the general conditions of possibility for our epistemic knowledge. He concludes that "for it could well be that even our experiential cognition is a composite of that which we receive through impressions and that which our faculty (merely prompted by sensible impressions) provides out of itself." (Ibid.) Hence, epistemic knowledge is possible only through a synthesis between our a priori cognition and our impressions, these in the form of amorphous data.

Kant studied the configuration of our a priori cognition, but he left the structures of data to one side. This was a precise and informed move. He was, in fact, convinced that the investigation of how our understanding can legitimately impose schemes and constraints on data, is the essential element in philosophical analysis. After Kant, many philosophers criticized this move harshly. Among them, Edmund Husserl founded his phenomenology on the motto "zurück zu den Sachen selbst!" By returning to things themselves, Husserl aimed to emphasize the complexity, richness, and the power of data. Data are structured and meaningful entities which enable every epistemic activity before (logically and temporally meant) any categorial activities. These intervene in a second moment, in fact, as Husserl affirms "Through a method of idealization and construction which historically has long since been worked out and can be practiced intersubjectively in a community, these limit-shapes have become acquired tools that can be used habitually and can always be applied to something new—an infinite and yet self-enclosed world of ideal objects as a field for study." (Husserl, 1970, p. 34) Within the scientific enterprise, data are limit-shapes which by means of a method of idealization and construction—practiced intersubjectively in a community—then become the epistemic object. In all his work, Husserl strongly emphasized the differences between the object of the life-world and that of the scientific investigation. The experiential object is given: it is a product of a passive synthesis in which the perceiver's activity has no role. It has an internal genesis that licenses it to be ready-made for further epistemic idealizations and constructions. On the contrary, the epistemic object is not given, but is patiently constructed. Hence, even according to one of the most severe critics of Kant's philosophy, once we step into the stage of the scientific inquiry, data are not ready-made entities, but are subjected to a strenuous process of constitution and idealization. To put it differently, the epistemic world does not consist of ready-made entities.

In the last decades however, historians, philosophers, scientists, and sociologists with different environments and interests have questioned the nature of data and their mind-dependent status. First, the infinite debate between realists and antirealists has reopened a broader discussion on the nature of data. Michael Devitt, one of the champions of realism, argues that "the general doctrine of realism about the external" is "committed not only to the existence of this world but also to its 'mind-independence': it is not made up of 'ideas' or 'sense data' and does not depend for its existence and nature on the cognitive activities and capacities of our minds" (Devitt, 2007, p. 768). Data are mind-independent entities and do not depend for their existence on the cognitive activities of the scientist. Indeed, these can be used as valuable starting points, since they are ready-made out there. Devitt also uses the same argumentative schema to deal with broader philosophical topics like the theory of truth and the notion of reference. Roughly speaking, terms are able to refer to something, since there are ready-made stable entities given out there that endorse this reference. The same can be said for the notion of truth. A statement is truth because it has a constant or absolute relationship between its elements and the objects given in the world. Other prominent philosophers and scientists agree on this realist stance. For instance, Steven Weinberg asserts that "What drives us onward in the work of science is precisely the sense that there are truths out there to be discovered, truths that once discovered will form a permanent part of human knowledge." (Weinberg, 2001, p. 126) There is a common position shared by this realist approach: according to Hilary Putnam, all proponents share the idea that "There is exactly one true and complete description of 'the way the world is.'" (Putnam, 1981, p. 49) This is independent from the cognitive activities of the scientists.

Hence, data is important since it can be used to study how we *de facto* and *de iure* know and investigate the world. The first alternative to the dependent nature of data and, more broadly, which supports a realistic position, arises from the philosophical debate of the last decades. Besides this philosophical debate, other scholars underline the same point from another perspective. The notion of data has indeed become central in the comprehension of the new Big Data sciences: Biology, Paleontology, Informatics, just to cite a few of them, use a huge amount of data, statistical techniques, and databases to come up with well-grounded conclusions. Following the growth and development of new epistemic approaches and techniques based upon a huge amount of data—the so-called Big Data—scientists, historians, and sociologists have argued in favor of a theory-free status for the disciplines. For instance, Viktor Mayer-Schönberger and Kenneth Cukier recently argued that "Before big data, our analysis was usually limited to testing a small number of hypotheses that we defined well before we even collected the data. When we let the data speak, we can make connections that we had never thought existed." (Mayer-Schönberger, 2013, p. 14) Both

IBM's Data expert Jeff Jonas and Chris Anderson, the editor in chief of Wired, claim that the data deluge makes the scientific method obsolete: "with enough data, the numbers speak for themselves." (Anderson, 2008) Hence, according to them, Big Data sciences are hypotheses free: their logic of discovery is based upon a massive presence and use of data. By putting them to work, the epistemic explanans and explanandum appears as two epiphenomena. Big Data are seen thus as something that has an internal structure independently from the theory chosen to describe them: they are theory-free.

However, from a factual point of view, Big Data Sciences are not theory free. The practices of informatics, biologists, and paleontologists are based upon and guided from many theoretical assumptions. As Werner Callebaut rightly notices, "We know from Kuhn, Feyerabend, and (Lorenz's friend) Popper that observations (facts, data) are theory-laden. Popper […] rejected the 'bucket theory of knowledge' in favor of the 'searchlight theory,' according to which observation 'is a process in which we play an intensely active part.' Our perceptions are always preceded by interests, questions, or expectations" (Callebaut, 2012, p. 74). The statement about the theory-free status of Big Data sciences should not be too quickly dubbed as naïve. In fact, from a logical point of view though, this claim might characterize the Big Data disciplines. The grounds of validity of these sciences can be seen in the notion of data as ready-made, albeit structured and dynamical (à la Husserl), entities. As Goethe expresses it "Das Höchste wäre, zu begreifen, daß alles Faktische schon Theorie ist. Die Bläue des Himmels offenbart uns das Grundgesetz der Chromatik. Man suche nur nichts hinter den Phänomenen; sie selbst sind die Lehre" (Goethe, 1907, p. 76) Phenomena are already theory because according to the already mentioned scholars they are ready-made entities. Hence, Big Data sciences force us to reflect on the relationship between data, phenomena, and the experimenter's activity.

Famously Kant asserted that "one has already gained a great deal if one can bring a multitude of investigations under the formula of a single problem. For one thereby not only lightens one's own task, by determining it precisely, but also the judgment of anyone else who wants to examine whether we have satisfied ours or not" (Kant, 1999, p. 146 B 119). By affirming that the notion of data is central, we have therefore gained a great ideal. In fact, we know which kinds of question can be addressed and legitimately answered by investigating this notion. The study of the features of data is indeed pivotal to comprehending how Big Data sciences work *de facto* and to addressing deeper philosophical questions about the notion of scientific knowledge, truth, and reference. Thus not only the description of how science works but also theoretical questions on the nature of our knowledge is at stake. The analysis of the functions and structures of data is therefore essential if we are to disentangle these problems.

Is there something important in paleontological data? Nomothetic, idiographic and the dark abyss of deep time.

The epistemic and historical importance related to the study of the notion of data is even greater if we take paleobiology into consideration. This is a science which, by means of a great deal of data, aims to reconstruct what happened in the past and so bring out biological patterns and processes. It is therefore a historical and biological discipline and the analysis of its data can provide useful insights into both the development of this discipline and into the broader epistemic issues previously raised.

Furthermore, both the paleontological and paleobiological data have an ontological peculiarity. The temporal dimension involved in their nature is so vast that the human spirit seems to *lose its way* (Rossi, 1984). Deep time is immense: in quantities no mind had yet conceived (McPhee, 1981). This immense quantity of time destroys the evidences of events that happened in the remote past. As a result, what happened in the past is underdetermined by its data and, consequently, paleontological data is always imperfect and incomplete. Furthermore, scientists are challenged in the search for valuable methods of dealing with deep time without loosing their way. That means that representational tools and instruments were created to obtain a reliable degree of knowledge within the deep past. In other words, paleontologists have struggled for centuries to make something invisible, visible, by using incomplete and imperfect data. They came up with representational techniques to manage, shape, and constitute their historical data in order to save the invisible phenomena. The history of paleontology can be in fact written in answering a simple question: how is it possible to overcome the abyss of deep time?

Paleontological and paleobiological data are extremely interesting because unlike another big data discipline, for instance, bioinformatics, they are *prima facie* incomplete and imperfect. Furthermore, they are difficult to manage. In fact, before the paleontologist deals with his data in a bulk, he has to overcome the destructive role of deep time: he has to find a way in it. However, despite these epistemic difficulties, paleontology has been able to provide reliable, valuable, and global knowledge as to what happened in the past, and how. This is indeed a fact. Paleontology, in the form of paleobiology, legitimately contributes to the theory of evolution: it has a seat at the high table of evolution. (J. M. Smith, 1984) The historical and philosophical question is then how was that possible? Or to put it in different words, upon which factual, contingent, and essential conditions is this fact—meant in its *fieri*—grounded in its historical development? And how was the transition from paleontology to paleobiology *de jure* possible? Answering these questions implies *ipso facto* providing essential insights into the nature of the different Big Data disciplines and taking a stance in the broader philosophical debate about the notion of data, reference, and truth.

What is then paleobiology? And what kind of difference is there between it and paleontology? As I have mentioned, paleobiology is a new approach to the fossil record developed during the 1970s in in the United States. It aims at “1) making paleontology more theoretical and less descriptive; 2) introducing models and quantitative analysis into paleontological methodology; 3) importing ideas and techniques from other disciplines (especially biology) into paleontology; 4) emphasizing the evolutionary implications of the fossil record” (D. Sepkoski, 2012, p. 386). Or as Derek Turner puts it in five slogans, “1) Paleontology has more to contribute to biology than to geology; 2) Study fossils in bulk — individual specimens don’t tell you much about evolution; 3) Paleontology needs theories; 4) If you can’t experiment, then simulate.” (Turner, 2011, p. 7) Of course, this does not mean that all of these features are literally invented by paleobiologists. One of the aims of my dissertation is to show the roots of some of these characteristic points. For example, Sepkoski’s first, third, and fourth points as well as Turner’s first, second, and third slogans characterized the paleontological practice in Germany between the end of the 19th and the beginning of the 20th century. It is nevertheless undeniable that although the origins of the paleobiological revolution are deeply rooted in the past, these roots were consciously re-elaborated by the supporters of that revolution.

The numerous elements of novelty can be pointed out by reflecting on the classical distinction between nomothetic and ideographic disciplines. The Kantian philosopher Wilhelm Windelband (1848-1915) gave his rectoral address on the methodological differences between History and Natural Science on May 4, 1894 at the Kaiser-Wilhelms-Universität Strassburg. During that address, he distinguished historical from natural sciences by focusing on the “formale Charakter ihrer Erkenntnisziele” (Windelband, 1900, p. 144). The nomothetic disciplines aim at general laws and general apodictic judgments; whereas the ideographic sciences collect historical facts. The former are sciences of laws, the latter sciences of events: “jene lehren was immer ist, diese was einmal war” (Ibid.). This distinction is not about the contents of the two sciences, but is about the differences in the treatment of these contents. That means that the main difference between nomothetic and ideographical disciplines is methodological. One of the results of the paleobiological revolution of the 1970s was to fill this methodological gap. One letter sent by Stephen J. Gould to Jack Sepkoski offers an excellent example of this change.

Nine months after his article *The Paradox of the first Tier: an Agenda for Paleobiology* (1985) was submitted to Paleobiology, Gould wrote to the journal’s editor, Sepkoski, explaining the necessity of an interaction between different and autonomous layers of the evolutionary theory:

> “Hierarchy, as here discussed in its genealogical context, is an ‘internalistic’ theory about evolution dynamics. And we need to formulate it

> properly if we are to tackle this internal dynamic with the other great mover of life's patterns—the externals of geological history especially mass extinctions, that so impact life's history...in other words, all the data the you and your colleagues are treating in such new and exciting ways. Hierarchy confronts the geological dynamic, and we will not get it right until we reformulate both sides" Gould to Sepkoksi, 13 August 1985 in (D. Sepkoski, 2012, p. 382).

In this letter, Gould clearly affirms the importance of reformulating the hierarchical model of evolution in the light of the momentous and exciting research techniques used in the investigation of mass extinctions. The reformulation Gould had in mind however concerned the entire paleontological discipline. He suggested a "nomothetic and idiographic" approach to the fossil record based upon David Raup and Sepkoski's studies on the structure of the mass extinction (Raup & Sepkoski, 1982, 1984): it is namely meant to be an union of stretching and modeling the fossil record. To accomplish the reformulation of the entire paleontology however, another reformulation was essential. Paleobiologists should start to accurately fix and define their epistemic object: the fossil record. As I have said, this is an *incomplete and imperfect* material object and paleobiologists would redefine its features during the paleobiological revolution. The hiatus between ideographic and nomothetic discipline can be thus overcome by a reconceptualization of the fossil record. Gould clearly suggested this in commenting on Sepkoski's study on Phanerozoic diversity. He affirms that

> "Here we see an interesting and fruitful interaction of nomothetics and ideographics. The form of the model remains nomothetic – the ''real'' pattern arises as an interaction between two general curves of the same form, but with different parameters. Ideographic factors determine the parameters and then enter as boundary conditions into a nomothetic model" (Gould, 1980, p. 115)

The ideogeographic factors mentioned by Gould derive from Sepkoski's famous *Compendium*. It gives the required data for Sepkoski's mathematical treatment of data. This in turn makes visible what is invisible: the structure and development of the Phanerozoic diversity. This approach is one of the main results of the paleobiological revolution, but upon which conditions is it founded? What does 'ideographic factors' mean? And how can historical facts determine the mathematical frame of the curve? To answer this question requires in-depth study of the notion of paleontology, i.e. paleontological data, as a mere ideographic discipline; also, study of how the proponents of this science used their data.

Indeed, most of my dissertation is dedicated to the practices of paleontology between the end of 19th and the beginning of the 20th centuries. This span of time is crucial for the establishment of paleontology as an autonomous science and thus for the consequent paleobiological revolution. In the German speaking-area, paleontologists used, at least, two different approaches to support the study of deep time. At the same time, they were deeply convinced about the biological nature of their investigations: paleontology is a biological discipline and it contributes to the theory of evolution, not to geology. The decisive issue was then how an ideographic discipline could contribute to biology. The answer is based on the two diverse notions of the fossil record proposed during that period. These in turn characterized the two main paleontological methods at the end of 19th century. On the one hand, the fossil record was identified with an event in deep time which could be narrated. This approach marked the growth of important techniques for reading and narrating the fossil record in the remote past. For instance, some paleontologists developed statistical tools for reading and tracing it. They aimed at making statements about what happened in deep time, and how, thus overcoming it. Others emphasized stratigraphic techniques to refine the temporal dimension of the story. On the other hand, the majority of paleontologists decided that the correct paleontological aim was to accurately describe historical facts of deep time. These facts can be useful for understanding the features of evolution. This is not, however, the primary task of paleontology. First and foremost, paleontology describes the morphological features of extinct animals and plants: paleontology is a descriptive and classificatory discipline. By doing so, it fixes the referential borders of natural kind terms of extinct animals and plants. Symbolically, Heinrich Georg Bronn (1800-1862) epitomized the first approach; whereas Karl Alfred von Zittel (1839-1904) the second one. Although both these two approaches were extremely influential and achieved numerous results, the latter overcame the former and emerged as the main paleontological method. Zittel's morphological approach was established as the main paleontological approach: paleontology aims to accurately depict the organisms and plants of the deep past. It does not seek to come up with biological processes or laws and as such it is a pure ideographic discipline. Zittel was even named the first "paleontologist of the contemporaneity", "the master of the paleontology, and the teacher of the paleontologists"[2]. He profoundly influenced the development of paleontology with both his *Handbuch der Paläontologie* and *Grundzüge der Paläontologie* (Zittel, 1876, 1895c)[3].

[2] "Begeistert nennen ihn seine Schüler, mit Überzeugung und neidlos auch die deutschen, englischen und amerikanische Fachgenossen der erste Paläontologe der Gegenwart" (Heigel, 1904, p. 8); "Hier [in Munich] wurde Zittel der, als welchen neidlos die wissenschaftliche Welt ihn anerkannte: Der Meister der Palaeontologie, der Lehrer der Palaeontologen" (Pompeckj, 1904, p. 7)

[3] Othenio Abel (1875-1946) asserts that "für die Entwicklung der Paläozoologie und Paläobotanik ist ein Werk von grundlegender Bedeutung geworden, nämlich das Handbuch der Paläontologie von K. A. von Zittel". And again "Wenn auch seither sich vieles geändert hat, neue Formen bekannt geworden und alte von neuen Gesichtspunkten aus untersucht worden sind, so daß 'der große Zittel' heute bereits veraltet ist, so ist dieses Werk doch noch heute die Grundlage des modernen Lehrbetriebes und von keinem anderen Werke erreicht oder übertroffen worden; für die Entwicklung der Paläozoologie ist das Handbuch Zittels von größter Bedeutung." (Abel, 1914, p. 346)

In the next chapters, I will analyze these two approaches by emphasizing the nature of data used. By choosing to represent one of the several lines of paleontological development, I am aware of the degree of abstraction of which my analysis might be accused. In fact, paleontology is a complex and polysemantic enterprise. It belongs to different disciplines and it lies between geology and biology. It has been developed in various ways in the course of the 19th and 20th century. My analysis has therefore a necessary degree of abstraction. But by preventively asserting the level of abstraction upon which I will be moving, I am be able at the same time to narrate completely the cycle of life of my chosen lines of development.

The paleobiological movement is a reaction against the concept of data established by the collective enterprise embodied in Zittel's works. The problem with this approach is—as the paleontologists Derek Ager puts it—that "paleontology [is done] by the telephone book" (Ager, 1983). Zittel established a great amount of data without specifying how the paleontologist can operate with them. If we carrying out this method, we understand paleontology as a pure and merely ideographic science.

Paleontological sciences in German-speaking area during the 19th century

The publication of Charles Darwin's *Origin of Species* (1859) left a deep mark on the paleontological sciences. In German-speaking countries, Darwin's book was even more influential because the translator of the first two editions of the *Origin* was Heinrich Georg Bronn. He was considered the most important paleontologist of the period. In fact, as the German paleontologist Melchior Neumayr (1845-1890) has observed:

> *"Wer die biologische Literatur in diesem Zeitraum verfolgt und prüft, wird fast auf jedem Gebiete einen merkbaren Unterschied finden zwischen Auffassung und Darstellungsweise derjenigen, welche zur Zeit des Erscheinens von Darwin's Werk schon als fertig gebildete wissenschaftliche Individualitäten dastanden, und zwischen der Anschauung der jüngeren Generation, welche ihre Studien unter dem Einflüsse der Darwin'schen Lehre begonnen und diese vom Anfange an in sich aufgenommen haben" (Melchior Neumayr, 1889, p. III)*

Darwin's masterpiece was pivotal in the shaping of the scientist's mind. A good methodological division is thus necessary to take into account whether the paleontologist under investigation in this chapter began his studies by reading and studying Darwin's *Origin*.

Second, I will take into consideration the space for discussion and research in Germany and in German-speaking countries. It is extremely difficult to separate the names of Heinrich Bronn, Alfred Zittel, Melchior Neumayr, Albert Oppel, and Othenio Abel from the fortune of the Universities in which they grew up and taught. Not only were they considered authorities in their own field, but they also obtained titles of nobility and high academic position, thus increasing the cultural power of their country[4]. Bronn, for instance, became *Prorektor* at the *Heidelberger Universität* and Zittel even *Rektor* at *Ludwig-Maximilians-Universität München*.

This entails a deep difference between the spread and the development of paleontological thought in German and in English speaking countries between the 19th and 20th centuries. In America and in England the academic status of paleontology was similar to the British one. In fact, while in Germany the prominent paleontologists were occupying outstanding academic and social positions, in American universities and curricula vertebrate paleontology were regarded only peripherally[5]. Friedrich Paulsen notices that:

> "Nach der deutschen Auffassung ist der Universitätsprofessor zugleich Lehrer und wissenschaftlicher Forscher. [...] In dieser Einheit von Forschung und Lehre besteht nun der eigentümliche Charakter der deutschen Universität. In Oxford und Cambridge gibt es vortreffliche Gelehrte, aber niemand wird die englischen Universitäten die Träger der wissenschaftlichen Arbeit des Landes nennen." (Paulsen, 1902, p. 5)

All the key figures of this dissertation maximally represent and develop a solid unity between research and teaching. This unity, derived from Humboldt, Fichte and Schleiermacher's reform of university at the beginning of the 19th century, is fundamental and it should be taken carefully into

[4] Charles E. McClelland observes that "the German university system had an unusually significant place in the history of Germany, as well. The impact of the German universities on the society was surely deeper than that of their American or British counterparts. Moving directly from lecture hall to government bureaux or professional offices, university graduates commanded the modernization of the German lands; the men who shaped its cultural and scientific life were also closer to universities than in most other parts of Europe. It was in Germany, around the beginning of the nineteenth century, that scientific investigation moved out of the overburdened academies of science and into the universities, beginning a process still perceptible today. More than in the relatively open societies to the West and the closed ones to the East, the German universities served as the breeding ground for a peculiar social stratum, an academic bourgeoisie [00'] the recruiting pool for both cultural and administrative elites" (McClelland, 1980, pp. 2-3)

[5] See (Conn, 1998; Rainger, 1991). I will deal with American vertebrate paleontology and its social and academic context in the third chapter. It is worth, however, quoting Reinger to better mark this difference. In *An Agenda for Antiquity*, he asserts that "may colleges maintained their collections and around the turn of the century a number of the new college museums were established. Yet it is questionable to what extent the collections in those museums were used by students. Courses on biology and geology included material on fossil vertebrate, but few students chose or were encouraged to choose that subject as a field of specialization. At Yale, where over fifty students obtained Ph.D. degrees in geology between 1900 and 1925, only three specialized in vertebrate paleontology. At Columbia University where 144 Ph.D. degrees were granted in zoology in the years 1895-1942, fourteen were in vertebrate paleontology. The story was the same at Princeton, the University of Chicago, the University of California, at Berkeley, and other schools." (Rainger, 1991, p. 21).

account, since it also shapes epistemic unities and virtues in other disciplines[6]. This reform emphasized the importance of discovery and research in the universities - meant as centres of research in which teaching and research were indissolubly connected. This union plays a fundamental role in the creation of new epistemic objects and it contributed to the scientific supremacy of Germany during the second half of 19th century. Syllabi, textbooks and *Leitfäden* can therefore reveal something about the features of the paleontological epistemic object. The flourishing of paleontology in Germany was highly supported by both the universities and the regional states, guaranteeing thus an indispensable condition for its possibility. In my analysis, I will take these important social factors into account. In fact, by focusing on the ways in which scientific facts can be transmitted and are thus able to survive over generations, I will argue that the teacher-student relationship is fundamental. A teacher-student relationship connects the main German paleontologists presented in my historical epistemology. For instance, Heinrich Bronn, the symbolic initiator of the first approach, was teacher of Zittel, the symbolic founder of the second method, at Heidelberg. Zittel developed his method by rejecting Bronn's teaching. I will therefore consider all these social factors in order to delineate the meaning of the paleontological data between the end of the 19th and the beginning of the 20th centuries[7].

Summary

By adopting an historical epistemology in conjunction with a meta-reflection, I will describe and analyze how the fossil record has been used to come up with biological knowledge. I will namely analyze the epistemic achievements of German paleontology between the last decades of the 19th and the beginning of 20th century to point out the contingent and necessary premises behind the notions of data used in that period. In the last part of my dissertation, I will concentrate on the notion of paleobiological data by historicizing it. I will specifically connect this notion with the two approaches emerged in German academia. Consequently, I will carry out a meta-reflection upon these notions to discover their philosophical implications and commitment. The main finding of my dissertation is that the paleobiological movement was able to use data to come up with biological knowledge since, according to Kant, they comprehended that "reason has insight only into what it itself produces according to its own design" (Kant, 1999, p. 109 B XIII). I describe the layers of this

[6] See Reinhard Riese (1977) for the development of chemistry and physics in Germany during the same period. (Riese, 1977, p. 136)

[7] As Zittel noticed, "Vergleicht man die Einrichtungen an unseren Deutschen Universitäten für das Studium der Geologie und Paläontologie mit denen in den Nachbarländern, so dar behauptet werden, dass sie nicht hinter den letzteren zurückgeblieben, dass vielmehr unsere Institute und Lehrmethoden vielfach als Muster nachgeahmt worden sind". (Zittel, 1895a, p. 17)

production and its metaphysical and empirical costs. For instance, paleobiologists abandon defence of the ready-made nature of their data and phenomena. On the contrary, they commence actively constituting their data and constructing their phenomena. Furthermore, I will historicize this practice and I will delineate the differences between the paleontological categorial framework and the paleobiological one. The paleontological framework is founded upon a realist foundation. This framework requires an object ready-made out there not to lose its way in deep time. This implies that the space for empirical possibilities (Friedman, 2001) is restricted to the availability of well-preserved data. By adopting this framework, knowledge in deep time is extremely narrow. The paleobiological categorial framework, on the contrary, considered its data not as something given out there, but as the product of an active reading of the observer: "the given is now divided into wider and narrower circles of objectivity, which are distinctly separated and arranged according to [a] definite point of view." (Cassirer, 1923, p. 291) By abandoning metaphysical realism, the paleobiologists do not lose their ways in the deep time because they define what can legitimately appear in it.

Chapter I. *Patterns and History: The Fossil Record into the Flow of deep Time*

This chapter investigates Heinrich Bronn's concept of the fossil record. Bronn identified the fossil record with events in the deep past and developed important statistical techniques to read them. As a result, he came up with biological patterns and processes. In this chapter, I argue that Bronn's education in *Kameralwissenschaft* plays a key role in shaping this particular and fundamental concept of the fossil record. The main result of this chapter is the description of the first meaning of the fossil record presented in German-speaking area. Bronn's identification of fossils with event was, in fact, pivotal to the development of the future paleontology. On the one hand, stratigraphy will strengthen the identification of fossils with events in deep time; on the other, Zittel's notion of the fossil record is a reaction against the imperfect, incomplete, and metaphysical results derived from the historical and statistical treatments proposed by Bronn.

Chapter II. *The Making of Paleontological Data*

This chapter analyses the coming into being of pure ideographic paleontological data. Zittel made and spread through the scientific community this particular concept of data between the end of the 19th century and the beginning of the 20th century. He identified the fossil record not with events in the deep past, but with stabilized facts that share an isomorphic relation with the material fossil record conserved in a museum. This different notion of data was made possible only by excluding from paleontology the geological inorganic world with its temporality. The fossil record is no longer a time-maker. On the contrary, it is a stable morphological entity that supports biological investigations emancipating thus paleontology from the geological and inorganic world. I historically trace the development of this notion as well as stress the social conditions that contributed to its making. As a result, I elucidate the differences between Zittel's and Bronn's concept thus pointing out the qualities and the deficiencies of the former. Furthermore, I show how the establishment of the paleontological epistemic thing, embodied in Zittel's works, was able to open an epistemic space in which the union of vertebrate and invertebrate paleontology found its validity.

Chapter III. *A strenuous Effort of Thought: Zittel's Heredity*

This chapter focuses on the effects of the coming into being of the paleontological thing established by Zittel. I deal with both the generations of paleontologists contemporaneous with Zittel and with those paleontologists working the beginning of the 20th century and the 1940s. I illustrate how and to what extent the coming into being of the pure paleontological data has been established. I examine three significative case studies to study the reception of Zittel's work by his contemporaries: Nicholson's works (1872; 1877; 1889), Neumayr's *Die Stämme des Thierreiches* (1889), and Stromer's *Lehrbuch der Paläozoologie* (1907). Successively, I examine how American paleontologists received Zittel's data. I argue that Zittel's concept of data was fully accepted by the new generations of paleontologists. It became in fact the established paleontological research program. Moreover, the identification of fossils with a-temporal facts was one of the causes of the American paleontological "crisis of identity" (D. Sepkoski, 2012, p. 52) during the 1940s. By placing invertebrate fossils at the same level with vertebrate fossils, Zittel unified *de facto* these disciplines - creating in this way a crisis in their own aims and functions.

Chapter IV. *How to observe?*

This chapter provides a first answer to an important issue raised during the second part of the 19th century: the question is how to use the fossil record for investigating the theory of evolution without falling, on the one hand, into metaphysical pitfalls (à la Bronn) and, on the other, into a useless collection of facts (à la Zittel)? To overcome this stalemate, some paleontologists proposed to refine the temporal dimension. In fact, this was one of the disturbing factors in Bronn's statistical analysis. Instead of putting it aside, they tried to develop epistemic tools in order to correctly frame the deep past. Carl Albert Oppel's work on the *Jurassic formation in England, France and south Germany* (1856-57) is the most representative work on this subject. It considers how to perceive rocks strata to obtain a temporal dimension. His concept of zone as faunal assemblage was pivotal. By means of this concept, paleontologists started to better find their way in time. Although Oppel's notion of the fossil record is very close to that one proposed by Bronn, he did not develop any techniques to read the fossils through time. He did not attempt to narrate a biological history. His notion of zone however gave the right impetus for developing these techniques.

Chapter V. *How an Epistemic Practice shaped its Data: Formenreihen and Evolution*

This chapter gives a second answer to the question raised in the previous chapter: how should the fossil record be used for coming up with biological knowledge without falling into metaphysical pitfalls or working as a mere collection of facts? I argue that Oppel's concept of zone had a pivotal role in answering this question. In fact, by using the Oppelian notion of zone, paleontologists read the flow of time represented in these zones as ordered changes in the morphology and thus in the development of fossilized organism. This is the notion of *Formenreihen* [series of forms] as proposed by Wilhelm Heinrich Waagen (1841-1900) and Melchior Neumayr (1845-1890). These two paleontologists identified fossils with events in deep time and came up with a method for reading it. Following Zittel, they put aside any statistical treatment of data. As a consequence, they found a secure foundation for their analysis in the visible recognition of well-preserved fossils. I argue that the paleontological epistemic objects are thus the *Formenreihen*. They provide the local data from which the Darwinian mechanism of evolution can be inferred. Nevertheless, this epistemic object is locally limited. Although the paleontologists struggled for a global degree of knowledge, they could not obtain it. This is due mainly to the fact that the construction of a series of forms is merely a practice of reading the fossil record and it does not take into account or investigate the ontological nature of this data. The paleontological data remained imperfect and incomplete and therefore they relied only on well-preserved data. However, these are only locally available. As a consequence, paleontology can assert judgments whose validity is local.

Chapter VI. *Paleontology and Darwinian Theory of Evolution: The dangerous Role of Statistics*

This chapter provides the last answer to the question how to use the fossil record. It examines the dangerous role of statistics in paleontological sciences at the end of the 19th and the beginning of the 20th centuries. I argue that in paleontology, the quantitative method was abandoned by the first decade of the 20th century because as its opponents noted—when the fossil record is treated statistically, it was found to generate results openly in contrast with the Darwinian theory of evolution. Essentially, statistics questions the gradual mode of evolution and the role of natural selection. The main objections to statistics were addressed during the meetings at the *Kaiserlich-Königliche Geologische Reichsanstalt* in Vienna around 1880. After having introduced the statistical treatment of the fossil record, I will use the works of Charles Léo Lesquereux (1806-1889) and Henry Shaler Williams (1847-1918) to compare the objections raised in Vienna with how the statistical treatment of the data worked in practice. Successively, I will deal with Melchior

Neumayr's (1845-1890) criticisms to show why, and to what extent, statistics were questioned in Vienna. The final part of this paper considers what paleontologists can derive from a statistical notion of data: in particular a) the necessity of opening a discussion about the ontological nature of the paleontological data, and b) the requirement for broader reflection upon the quantity and quality of the paleontological data.

Chapter VII. *On the Notion of Paleontological Representation: The Levels of Constitution of Paleobiological Data*

This chapter analyzes four diverse, simple, and concrete paleontological representations to study their conditions of possibility and the assumptions behind them. It namely aims to describe the levels of constitution of the paleobiological data in order to shed light on what can *de facto* and *de jure* be done with them. The historical development of paleontology shows that as soon as the paleontologist has abandoned defence of a metaphysical and "naïve realism", he is able to *represent* the fossil record in order to come up with evolutionary explanations. Based on it, the relevant questions of this chapter concern the notion of paleontological representation: i) which notion of representation is required in order to use the fossil record to identify evolutionary patterns and processes? ii) Which assumptions and conditions are necessary to represent the fossil record in a biological framework? iii) Which kinds of functions does the paleobiological self need to identify, find, and determine to use paleontological data? iv) How has the paleontological categorial framework changed over time? I answer these questions by examining Zittel's description of *Psiloceras planorbis*, Waagen's *Formenreihe*, Williams' representation of fauna, and Raup and Sepkoski's representation of the periodicity in mass extinctions within geological time. The study of these four representations allows me to draw general philosophical conclusions about the notion of paleontological and paleobiological data and about the differences between the paleontological categorial and paleobiological framework.

Chapter VIII. *Paleobiological Data and Phenomena*

This chapter gives a second look at the notion of paleobiological data and phenomenon to see their limits, how they should be understood, upon which assumption they are based, and what relationship there is between these two elements. All these reflections contribute to understanding why, *de jure*, the paleobiologists need to construct their phenomena: paleobiologists construct their explananda to overcome the dark abyss of deep time. This chapter starts recalling the famous data-phenomena distinction proposed by Bogen and Woodward. After having modified it in the light of the paleontological notion of data, I introduce the difference between construction and constitution. Successively, I illustrate the notion of paleobiological phenomena and its line of continuity and rapture with the paleontological one. I will namely analyze under which circumstances the layers of meaning examined in the first chapters have influenced the paleobiological notion of data and phenomena. I will look at the context of applicability of Zittel and Oppel's data and how these have been connected with the paleobiological revolution of the 1970s. The results of this analysis will help me in explaining why the paleobiologists need to construct their phenomena. To achieve this aim, I will go backwards from the historicized *Faktum* of the paleontological phenomena to its conditions of possibility continuing thus the meta-reflection started in the previous chapter. I specifically follow the changes in the notion of the fossil record and phenomenon by looking and studying three important textbooks between the beginning of 20th century and 1978. These textbooks are Lull's *Organic Evolution* (1917), Moore's *Historical Geology* (1933), and Raup and Stanley's *Principles of Paleontology* (1971, 1978). As a result, I point out that paleobiology is able to investigate the trends and patterns of evolution, because a) it decides what a datum is, b) how it can be read, and c) it constructs on them working versions of the past, i.e. the targets of its models. By *de facto* stretching the fossil into a database and treating them statically, the paleobiologist is *de jure* able to impose formal constrains (for instance, temporal, spatial limitation, a hierarchal notion of nature, or a particular causal dimension) on it. That means that, "to know a content means to make it an object by raising it out of the mere status of givenness and granting it a certain logical constancy and necessity." (Cassirer, 1923, p. 303) As a consequence, the ready-made nature of data proposed both by some defenders of metaphysical realism and by advocates of the theory-free nature of Big Data sciences is rejected. Both from a factual and logical point of view, paleobiological data and phenomena are constituted and constructed: "every empirically given particular is already determined through the form of the whole of experience." (Cassirer, 1996, p. 194)

Chapter I. Patterns and History: The Fossil Record into the Flow of deep Time

Introduction

A few sentences from Karl Emil von Schafhäutl's (1803-1890) inaugural lecture at the University of Munich (1843) provide proper starting point for my historical epistemology. Schafhäutl was the first professor of Geology in Bayern and the subject of his lecture the relation between geology and the other natural sciences. In outlining these relationships, Schafhäutl says something significant about the role, aims, and status of geological science as commonly understood in that period. He asserts that "die Geologie, die heutige Lehre von der Bildung der Welt [...] eine Doktrin [ist], vom Anfang her verwandt mit dem erhabensten Thema, mit jenem der Theogonie, an welchem der erste, geistig erwachende Mensch, seine jugendlichen Seelenkräfte übte, und da, herab durch Denker aller Nationen gebildet hat." (Schafhäutl, 1843) Geology is related to theogony where both disciplines try to narrate the origin of something which, in principle, is not accessible to our experience. The only way to overcome this difficulty is to narrate a history as Hesiod did with his *Theogony*. Both theogony and paleontology, Schafhäutl suggests, position their data in the flow of time and attempt to narrate a story through this. This procedure inevitably generates both a low degree of knowledge and metaphysical speculation. This precise notion of geology would be refuted in the last decades of the 19th century, thus opening up space for a new concept of data and fossils constituted and spread thorough the scientific community by the German paleontologist Karl von Zittel.

At the same time, this identification would be subject to innumerable changes in the course of the 19th century. The paleontological narration of metaphysical origin was steadily converted into a rigorous history of patterns of local diversity. Theogony would be transformed into historical geology and afterwards into biostratigraphy and paleogeography. Within these disciplines the theory of evolution would be discussed and set to work. There are deep, ancient roots to this transformation. By the beginning of the 19th century, Alexandre Brongniart (1770-1847), Karl Ernst Adolf von Hoff (1771-1837), Giovanni Battista Brocchi (1772-1826), Augustin Pyrame de Candolle (1778-1841), Gérard Paul Deshayes (1795-1875), and Charles Lyell (1797-1875) had begun to direct paleontological and "theological" investigations towards the rigorous researching of patterns in time. The German paleontologist Heinrich G. Bronn would prove the key figure in this development of the paleontological sciences: geologist and paleontologist Werner Quenstedt (1809-1889) calls him "nicht nur der erste allgemeine Paläontologe, sondern [der] Wegbereiter der Abstammungslehre in der Paläontologie" (W. Quenstedt).

In this chapter, I will deal with Bronn's works so as to point out his crucial concept of the fossil record. Bronn conceives the fossil record as an event in deep time. An event is generally something which takes place in the flow of time. It has a relatively well-defined temporal border and many events can take place at the same time. According to the philosopher David Hugh Mellor, events can have split appearances, just as a fossil can occur at time t_1 and, due to gaps in its preservation, reappear at time t_3. Furthermore, an event has a precise historical position: either it occurs or it does not, there is no a middle way (Wittgenstein, 2001). An entire narrative story can be obtained from its occurrences: confined in precise temporal boundaries.

Bronn sees the fossil record as events and he develops important epistemic tools to read this notion in the course of the deep past. He does not seek metaphysical archetypes, but he draws what have been called "systematic-chronologic-diagnostic tables" (Schumacher, 1975, p. 77) to frame and narrate an event in the course of deep time. As I will argue, these tables provide the essential space for the narration of events constituted in the fossil record. In fact, by situating the found fossils under the temporal and spatial entries of the tables, Bronn is able to indicate the temporal and spatial frame in which the event occurred. Consecutively, he invented a new discipline for the purpose of tracing and narrating historical patterns from the framed events. Called *paläontologische Statik*, this aims to give numerical and quantitative treatment to the fossils previously only listed in bio-chronologic tables. This quantitative treatment enables narration of a complete history of past events. The incomplete and imperfect material objects—i.e. fossils—are inserted into tables; by virtue of a quantitative reading, Bronn is then able to use the tables to produce biological patterns and processes. In perceiving fossils as events, he hoped—vainly—to overcome their biased, ontological nature. As I will argue in the next chapter, Karl Zittel, one of Bronn's best students, refuted both Bronn's method and identification. The history narrated from these records is related to an unstable and changing notion of truth and it obtains only a low degree of reliability and knowledge. Consequently, it became necessary to provide both a new concept of the fossil record and different techniques for reading it.

In this chapter, I will argue that Bronn's education plays a pivotal role in forming his concept of the fossil record. Thanks to his studies in *Kamerlawissenschaft*[8], he was very well trained in mathematics and *Statistik*[9]. He used these methods to read the fossil record in order to discover historical patterns and biological processes. As I have mentioned, the use of statistics to uncover historical processes and patterns did not initiate with Bronn's. He was deeply influenced by

[8] Friedrich Wilhelm I. established this discipline to educate his future public servants.

[9] I will use the term statistics exactly as Gottfried Achenwall (1719–1772) used it: a descriptive and comparative study of particular objects presented in a specific area.

Brocchi, Brongniart von Hoff, Deshayes and Candolle's methods. After receiving his *venia legendi* (1821), Bronn travelled twice (1824, 1827) to Switzerland, southern France and Italy to gather important information, data (mainly material exemplars of fossils), and especially to meet important personalities of that period. From the published reports of these travels, the pivotal importance of these naturalists in constituting Bronn's own method becomes clear. The proceeding sections of this chapter will indicate the key steps in Bronn's education as well as novel elements of his method.

The key finding of this chapter is the delineation of one important meaning of the fossil record as it emerges from Bronn's analyses. In fact, the identification of the fossil record with an event in deep time will play an essential role in the development of paleontological science in at least three directions. On the one hand, Karl Alfred von Zittel will intentionally refuse this identification. He will remove disturbing temporal factors from the concept of the fossil record. As a result, he will be able to separate paleontology from both metaphysical speculation and deep time - so securing its epistemic and biological value. To achieve this, he shifts the main goal and target of paleontology: this discipline does not aim to make declarative statements (what happened and how), but to fix the reference of past and extinct entities. On the other hand, stratigraphy will strengthen the identification of fossils with events in deep time. Carl Albert Oppel, for instance, will use the fossil record as an event to describe the Jurassic fauna in Europe. Following Oppel, other biostratigraphers will re-adopt Bronn's idea to pave the way for further statistical treatments of the fossil record. Lastly, the paleobiological revolution will unconsciously support its claim by adopting a notion of the fossil record very close to Bronn's. As the conclusions of my entire dissertation show, there is a clear continuity between Bronn's analysis and the growth of the paleobiological revolution. Bronn anticipated many techniques and philosophical attitudes which would be *in auge* almost one hundred year later.

Bronn's Education: The Importance of Kameralwissenschaft

"Mit ihm erlosch einer der hellsten Sterne am Himmel deutscher Wissenschaft" (von Gümbel, 1876). Using these words, the *Allgemeine Deutsche Biographie* announces the death of Heinrich Georg Bronn. Indeed, Bronn was considered the most important German paleontologist of the 19th century[10]. He was the first Professor of Zoology at the University of Heidelberg[11] and translator in German of the first two editions of the *Origin of Species*. Bronn not only found mathematical patterns in the distribution of fossils, but he also sought out processes that might explain these

[10] Among others, I would like to recall these words of Wilhelm Salomon's (1868-1941): "Er [Bronn] wandte der Paläontologie noch mehr Aufmersamkeit und Zeit als der Zoologie zu und galt mit Recht als einer ihrer allerhervorragendsten Vertreter."(Salomon, 1911, p. 138)

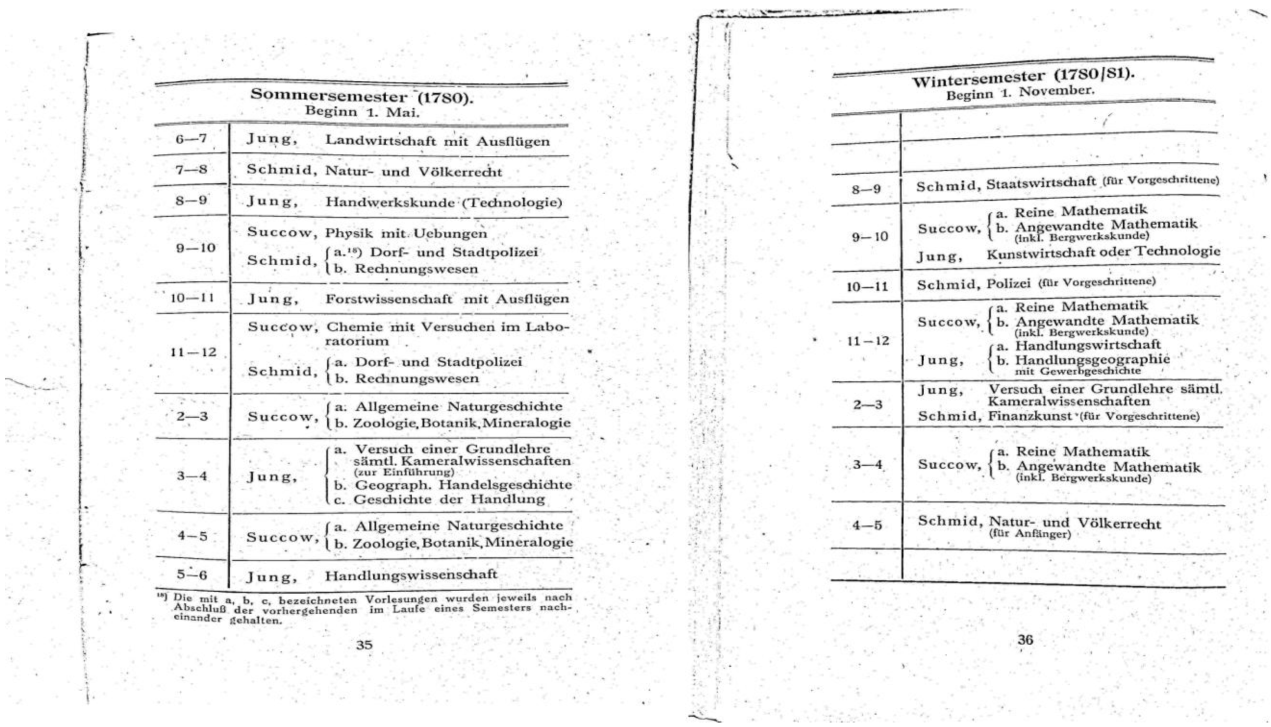
[11] The Heidelberger Institut für Zoologie was the fifth such in Germany. See (Nyhart, 1995)

patters. A Humboldtian concept of science—in the air in that period—influences his results. Nevertheless, as Sander Gliboff has recently asserted in his book on *The Origins of German Darwinism*[12], Bronn's practices overcame the contingency of his age. If we are to understand both the genesis of Bronn's thought and the further birth of pure paleontological data as a reaction against Bronn's history of nature, it is essential that we examine Bronn's education and academic career, following Ludwig Fleck's insights (Fleck, 1929, 1979).

Bronn studied Cameral Studies and Natural History at the university of Heidelberg from the summer semester 1818. As I have shown in the introduction, in German-speaking countries universities exemplified an inseparable unity of teaching and research, particularly in the period from 1809 to early 20th century. The German philosopher Friedrich Paulsen even claimed that "Man wird sagen dürfen: wenn in einer Geschichte der Wissenschaften in Deutschland alles gestrichen würde, was von Universitätslehrern geleistet worden ist, dann wäre der verbleibende Rest nicht gar groß" (Paulsen, 1902, p. 7). It is therefore crucial to study the academic environment of German servants and scholars to understand what they accepted, refused, and transmitted, always bearing in mind the indissoluble unity of teaching and research that characterises German society. To understand the importance of education for the development of Bronn's thought, I will attempt to reconstruct what he possibly learnt in that period.

Friedrich Wilhelm I. established the chair of *Kameralwissenschaft*, i.e. "Cameralia, Oeconomia und Polizeisachen" (Wissenschaften, 1908), at the university of Halle on the 27th July, 1727. In the same year, he established a further chair of *Kameralwissenschaft* at the University of Frankfurt, Oder. The first Institute for Cameral Studies in South Germany was opened in Kaiserslautern in 1774. The head of school was the botanist and doctor Friedrich Casimir Medicus (1736-1808). The lecture timetable of the *Kameral Hohe* gives many important insights into the structure of *Kameralwissenschaft*. The timetable for the academic year 1780/1781 is as follows:

[12] Sander Gliboff has listed the points in contact between Bronn's approach to the history of life and the ideal of Wissenschaft presented in that period in Germany. Those points are 1) "the rule of law in biology; the unity of the biological and physical realms, the generation of *Maennigfaltikgeit* and historical change by the complex interactions among biological laws and forces and environmental factors; functional rather than transcendental types; and quantitative biogeography." (Glidoff, 2008, p. 62)



Sommersemester (1780).
Beginn 1. Mai.

6–7	Jung, Landwirtschaft mit Ausflügen
7–8	Schmid, Natur- und Völkerrecht
8–9	Jung, Handwerkskunde (Technologie)
9–10	Succow, Physik mit Uebungen Schmid, a.[18]) Dorf- und Stadtpolizei; b. Rechnungswesen
10–11	Jung, Forstwissenschaft mit Ausflügen
11–12	Succow, Chemie mit Versuchen im Laboratorium Schmid, a. Dorf- und Stadtpolizei; b. Rechnungswesen
2–3	Succow, a. Allgemeine Naturgeschichte; b. Zoologie, Botanik, Mineralogie
3–4	Jung, a. Versuch einer Grundlehre sämtl. Kameralwissenschaften (zur Einführung); b. Geograph. Handelsgeschichte; c. Geschichte der Handlung
4–5	Succow, a. Allgemeine Naturgeschichte; b. Zoologie, Botanik, Mineralogie
5–6	Jung, Handlungswissenschaft

[18]) Die mit a, b, c, bezeichneten Vorlesungen wurden jeweils nach Abschluß der vorhergehenden im Laufe eines Semesters nacheinander gehalten.

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Wintersemester (1780/81).
Beginn 1. November.

8–9	Schmid, Staatswirtschaft (für Vorgeschrittene)
9–10	Succow, a. Reine Mathematik; b. Angewandte Mathematik (inkl. Bergwerkskunde) Jung, Kunstwirtschaft oder Technologie
10–11	Schmid, Polizei (für Vorgeschrittene)
11–12	Succow, a. Reine Mathematik; b. Angewandte Mathematik (inkl. Bergwerkskunde) Jung, a. Handlungswirtschaft; b. Handlungsgeographie mit Gewerbgeschichte
2–3	Jung, Versuch einer Grundlehre sämtl. Kameralwissenschaften Schmid, Finanzkunst (für Vorgeschrittene)
3–4	Succow, a. Reine Mathematik; b. Angewandte Mathematik (inkl. Bergwerkskunde)
4–5	Schmid, Natur- und Völkerrecht (für Anfänger)

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Figure 2 Lecture timetable for the academic year 1780/1781. From (Webler, 1927)

The subjects taught at the *Kameral-Hohe-Schule* were various: from pure mathematics to zoology and mineralogy. Hence, the student acquired a complete and in-depth overview on various scientific practices and methods. Webler lists the textbooks used to support the lectures at the same school:

> for the *pure mathematics* the "Lehrbuch [was] Büchs „Mathematik zum Nuzen und Vergnügen des bürgerlichen Lebens" […] Die *angewandte Mathematik* umfaßte Mechanik, Hydrostatik, Aerometrie, Optik, Cataptik, Dioptrik und Pyrobolik, vorgetragen nach einem Lehrbuch von Wolf [...] Hydrotechnik, Bergbau und angewandter Maschinenkunde, [...] die wichtigsten Grundbegriffe von Astronomie, Geographie, Zeitrechunng und die Gnomonik, wobei Eberhards „Beitrage zur mathesi applicata" und Büchs oben erwähntes Lehrbuch benützt wurden.
>
> [...] Unter den „Grundwissenschaften "betrachtete man die *Naturgeschichte* […] Er [Succow] gab hier zunächst einen Gesamtüberblick über „die Körper der drei Naturreiche" im Hinblick auf ihre Bedeutung für di Oekonomie, wobei er Erxlebens „Anfangsgründe der Naturgeschichte„ benutzte. Naturgemäß trat hier die Zoologie zurück hinter Botanik und Mineralogie, die eingehende Würdigung erfuhren. Für seine Vorlesung in der *Botanik* hatte Succow ein eigenes Lehrbuch, die „ökonimische Botanik", verfaßt.
>
> [...] Die *Mineralogie* lag Cronstedts „Versuch einer Mineralogie" zu Grunde." (Webler, 1927, pp. 119-121)

Even the textbooks were chosen to educate the students in every aspect of the natural and life sciences. This was indeed the main goal of the *Kameralwissenschaft*: since its foundation, in fact, this discipline was conceived as a practical, economical, and statistical science able to educate and support the public servants of the absolute state governed by Friedrich Wilhelm I. As Wilhelm

Bleek notices “Erstes Ziel aller Verwaltungstätigkeit im absoluten Staat und damit auch der Kameralwissenschaften war die Erhöhung des fürstlichen Etats” (Bleek, 1972, p. 66) Thus, *Kameralwissenschaft* was not a mere juridical science, but a means of instructing valued servants in practical and statistical sciences with the end of conserving absolute power.

Ten years after its foundation, the Kaiserslauterner cameral school was moved to Heidelberg and incorporated into the philosophical faculty of that University in 1822. Ludwig Wallrad Medicus (1795-1849) was Friedrich Casimir Medicus’s son. He was professor of *Staatwirtschafts* at the *Kameral Hohen Schule* in Heidelberg. In a letter about the unification of the University of Heidelberg and the cameral school, we learn what he used to teach:

> “Seit meiner Anstellung … habe ich über folgende Fächer Vorlesungen gehalten: Enzyklopädie der Staatswirtschaft. Wissensch[aft], ... Landwirtschaft, Forstwissenschaft, Bergwerkswissenschaft. In Hinsicht de lezteren Faches habe [ich] nicht sowohl Bergbau in Specie vorgetragen, sondern es in hiesiger Lage für zweckmäßiger gefunden, meine Zuhörer mit dem ganzen der bergmännischen Wissenschaften bekannt zu machen, wobei ich jedoch die Hauptrücksicht auf Geognose <Gebirgskunde> und Bergbau selbst nehme. Handlungswissenschaft habe [ich] ebenfalls schon einigemale vorgetragen. Den für das kameralistische Fach so wichtigen integrierenden Theil der Rechnungswissenschaft habe ich mehrmalen angekündet, aber noch zu Stande gebracht. Über Anfangsgründe der reinen Mathematik habe [ich] dreimal Vorlesungen gehalten und bin dazu, so wie Unterrichte in der praktischen Geometrie und auch in der Mineralogie erbötig“ (Drüll, 1991, p. 101)

The list gives us a rough idea of the composition of this study in Heidelberg: the most important subjects taught are calculation, mathematics, and—especially—measurement. This is particularly interesting, as it implies that *Kameralstudium* did not lose sight of its practical and statistical goals even after the Prussian administrative reform of the years 1807/1811. The reform aimed to give more power to jurisprudence in the *curriculum* of future public servants. Nevertheless, “keineswegs die kameralistische durch eine rein juristische Vorbildung ersetzt werden.” (Bleek, 1972, p. 102) The practical and statistical backbone of cameral studies appears evident in the form of Medicus’ successor at Heidelberg.

Ludwig Wallrad Medicus held the professorship in Heidelberg until 1804. His successor was Karl Christian Langsdorf (1757-1834)[13]. Leinsdorf emphasized the importance of natural sciences and particularly mathematics for the education of the *Kameralisten*. In fact, he wrote in an introductory book on mathematics for *Kamerlisten* (1817) that he teaches mathematics inasmuch as it can be used in everyday work:

> “Die höchste Stufe, bis zu der ich hier den Schüler der Analysis begleite, liegt also *unter* der, zu welcher die Werke eines *Euler, Lacroir, Lagrange, Laplace*

[13] To be precise, he was Professor für Mathematik, Technologie, Wasser, Straßen- und Brückenbau.

> u. a. führen; aber sie liegt hoch genug, um von ihr ins praktische leben zu schreiten; hoch genug, um alles, was mir irgendwo in Schriften anderer Analytiker brauchbares für die Ingenieurswissenschaften und gesamte Kameralistik vorgekommen ist, und was ich selbst seit 38 Jahren dahingehöriges geschrieben habe, ohne Schwierigkeit lesen zu können" (Langsdorf, 1817, p. 6)

This brief survey of the nature and the subjects of the *Kameralwissenschaft* shows the key role of mathematics and statistics in the discipline: Bronn studied the same subjects and consequently was very well trained in calculation and measurement. Cameral sciences and particularly statistics constitute the essential core of his further paleontological method. He applied this bureaucratic structure to natural science.

Bronn's attendance of Einrich Eschenmayer's lectures (1763-1845) supports my previous point. Eschenmayer was professor of *Staatwirtschaft*[14] and author of various important books and textbooks concerning state finance. In the preface of *Über Staats-Aufwand und die Bedeckung desselben* (1806), Eschenmayer describes his notion of state science. *Staatwirtschaft* tries to depict "wie [es] möglich ist, eine systematische Ordnung und eine pünktliche Richtigkeit in das Finanz-System und der Rechnungs-Wesen zu bringen, und diese Ordnung zu handhaben." (Eschenmayer, 1806, p. IV) The key words in this quotation are *Ordnung zu bringen* and *zu handhaben*. Firstly, *Staatwirtschaft* is a science and as such it aims at systematically bringing order to chaotic matter. Secondly, order is a necessary condition for the fruitful handling of state financial problems and not the principal aim of the science. Thirdly, the central question that the *Staatwirtschaft* seeks to answer is quantitative and not qualitative. It is about "wie viel, wovon und wann sie [die Nation] zu bezahlen habe?" (Ibid.)

Eschenmayer thus conceives the *Staatwirtschaft* as a science that provisions order by means of mathematical tools. The achieved order is then represented in tables to better facilitate reading of the acquired results[15]. Bronn absorbed these considerations; he had the especial opportunity to reflect on the importance of order in the development of every science and on the essential function of tables. This became an important mental schema within which he would build his natural system: paleontological data should be orderly listed and disposed in tables exactly as if objects of a census.

The second professor with an essential role in Bronn's scholarship was Karl Cäsar Ritter von Leonhard (1779–1862). Leonhard was an eminent mineralogist and geologist. He founded the *Taschenbuch für die gesamte Mineralogie* and Bronn himself become co-editor of the Journal[16]

[14] As Bleek notices "Nationalökonomie und Staaatswirtschafslehre erwuchsen beide aus der alten Kameralwissenschaft, sprengten sie und gliederten sich zu selbständigen Wissenschaften auf." (Bleek, 1972, p. 96)

[15] See, for example, his *Anleitung zu einer systematischen Einrichtung des Staats-Rechnungswesens*, 1807.

[16] The journal was named *Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaken-Kunde* in 1830 and it took its current name—*Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaken-Kunde*—in 1833.

from 1830, assuming therefore a “strategic position that not only gave him great influence within the profession, but also enabled him to keep pace with the unprecedented ‘information explosion’ in the science.” (Martin J. S. Rudwick, 1972, p. 220) Bronn attended Leonhard’s lectures on natural history and mineralogy in Heidelberg. To help our understanding of what Bronn could have learnt from those courses, we can turn to Leonhard’s *Leitfaden akademischer Vorlesungen* in natural history (1819). Here we can infer that Bronn learnt that natural history is meant to be a chronology of what happened on the earth surface. It is a *chronologically ordered list of events and phenomena*. The prerequisite for writing such a history is an almost complete catalogue or index of what appeared on the earth’s surface. As Leonhard wrote in the guidelines of the course, natural history is made possible only by enumerating what appeared and by chronologically ordering these phenomena. Chronology is thus fundamental; how, however may we carry out a chronology of events in deep time? Bronn would answer this question in his masterpiece: *Index palaeontologicus oder Übersicht der bis jetzt bekannten fossilen Organismen* (1848-9).

The importance of chronology and order is mirrored in Leonhard’s S*ystematisch-tabellarische Übersicht und Charakteristik der Mineralkörper* (1806). It is a systematic work that aims “die Gesamtheit der Kennzeichen aller bisher bekannten Produkte der anorganischen Natur in einer leicht zu übersehenden Ordnung so darzustellen” (Leonhard von, 1806, p. I) by the means of tables. Tables are the *medium* whereby the natural elements previously classified can be orderly listed and comprehended. A facilitated view expressed in tables and an accurate classification (by using all the natural disciplines) is thus central to Leonhard’s lectures on natural history, geology, and mineralogy. This element would also prove fundamental in the shaping of Bronn’s investigation.

To summarise, I have shown so far that Bronn’s scholarship is based upon a solid mathematical education and a quasi-obsessive research into order through use of classificatory and statistical tools. The union between mathematics and the struggle for order is expressed in tables as both *Kameralwissenschaft* and Leonhard’s natural history suggest. Independent from the direct influences on Bronn during his studies, the statistical and tabular method was commonly applied to botany by the servants of that period. It was pejoratively named *Tabellenstatisktik*. Bronn was perfectly aware of this botanical variant. In fact, when he first travelled to Switzerland, Italy and southern France, Bronn met the great Swiss botanist De Candolle with the intent of sharing various problems encountered in botanical arithmetic[17]. As Bronn reported, “I found great satisfaction in the fact that De Candolle assured me that I was correctly using the philosophical-botanic calculus”

[17] Janet Browne shows in his *The secular Ark* (1983), “botanical arithmetic was to natural history what mathematics was to the study of electromagnetism, heat”. I will return to this point in the sixth chapter.

(Bronn, 1826, p. 58). Moreover, in the reports of these travels, Bronn listed important statistical works by von Hoff and Brocchi. The following sections show how Bronn used this bureaucratic structure in the natural sciences.

Historical Roots of Bronn's Data

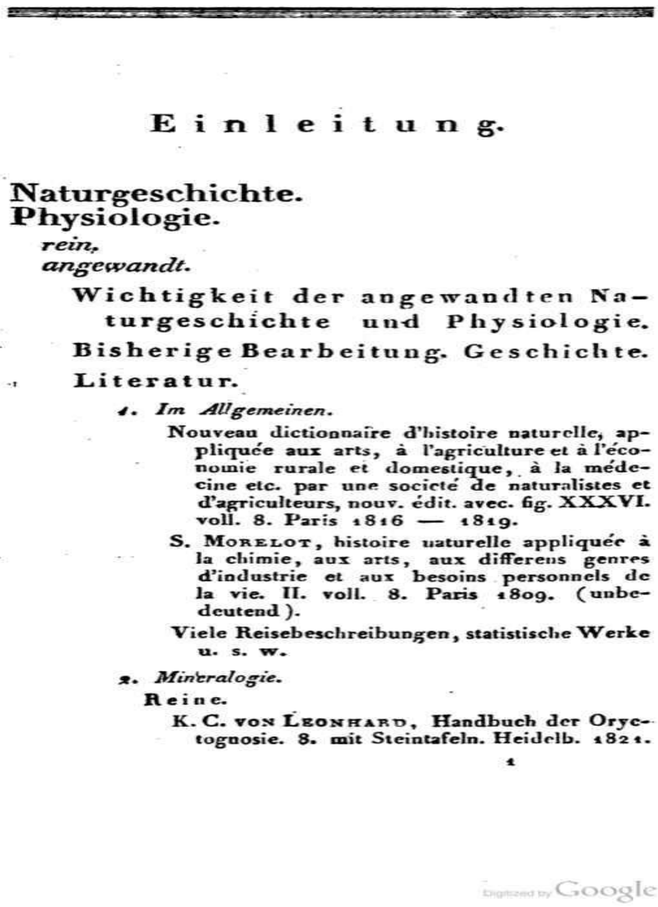
This section does not deal with Bronn's place in the history of evolutional thought[18], but rather provides historical framework for his notion of the fossil record. I will illustrate the roots of both Bronn's *paläontologische Statik* as well as his identification of fossils with events.

A brief glance at Bronn's list of lectures give us a proper starting point for discussing Bronn's method and thoughts because, as Ingrid Schumacher has noticed, "die Vorlesungen, die BRONN ankündigte, dienten ihm zur Vorbereitung seiner größeren Veröffentlichungen und umfassenden Werke." (Schumacher, 1975, p. 17) Looking carefully at that list, we can see that Bronn's courses cover three 'eras': a) until circa 1830, we see Bronn narrowing his focus and sharpening his conception of science; b) until 1850 he studied and taught fossil collections and taxonomy; c) in later life, he taught the application of his system of law to natural history.

This point leads into another. We see Bronn implementing this tri-partition in every academic year as well: he always offered a course on the methodological aspect of science (cameral studies), on taxonomy and collection of the specimens, and on the zoological history of earth. Bronn clearly considered these three courses essential not only for the formation of future paleontologists, but also for his own paleontological research. Indeed, as I have anticipated above, "der Universitätsprofessor hat nach deutscher Auffassung eine doppelte Stellung und Aufgabe: er ist zugleich Gelehrter oder wissenschaftlicher Forscher und Lehrer der Wissenschaft" (Paulsen, 1902, p. 203). Research and teaching are inseparable in German academia. These activities mirror themselves and therefore the topics chosen for lecturing are also those preferred for researching.

We can obtain other information from this list of courses. For instance, the choice of books can reveal a particular intellectual inclination in Bronn's teaching. In fact, these textbooks are meant to complete the *Vorlesungen* by offering wider and deeper insights into the discipline. To support his lectures on applied natural history and physiology, he published a little *Leitfaden:*

[18] See for example (Baron, 1961; Gitelman, 2013; Glidoff, 2008; Junker, 1991; Schumacher, 1975; D. Sepkoski, 2013)



Einleitung.

Naturgeschichte.
Physiologie.
rein,
angewandt.
Wichtigkeit der angewandten Naturgeschichte und Physiologie.
Bisherige Bearbeitung. Geschichte.
Literatur.
1. Im Allgemeinen.
Nouveau dictionnaire d'histoire naturelle, appliquée aux arts, à l'agriculture et à l'économie rurale et domestique, à la médecine etc. par une société de naturalistes et d'agriculteurs, nouv. édit. avec. fig. XXXVI. voll. 8. Paris 1816 — 1819.
S. Morelot, histoire naturelle appliquée à la chimie, aux arts, aux differens genres d'industrie et aux besoins personnels de la vie. II. voll. 8. Paris 1809. (unbedeutend).
Viele Reisebeschreibungen, statistische Werke u. s. w.
2. Mineralogie.
Reine.
K. C. von Leonhard, Handbuch der Oryctognosie. 8. mit Steintafeln. Heidelb. 1821.
1

Figure 3 From (Bronn, 1824c)

The first page of Bronn's *Leitfaden* shows that even in applied natural history statistical works are important.

Bronn would almost always use Johann Christian Hundeshagen's *Encyclopädie der Forstwissenschaft, systematisch abgefasst* (1821) as textbook in his cameral studies lectures (on *Forstwissenschaft* and *Landwissenschaft*). In the encyclopaedia introduction we read (it is worth quoting entirely):

"Die fortwissenschaftliche Theorie in ihrem ganzem Umfange, begreift

A. Die Vorbereitungs- oder Hilfswissenschaften
B. Die haupt- oder eigentliche Fort-Wissenschaft
C. Die fortwissenschaftlichen Nebenfächer.

A. Zu den Vorbereitungs- Wissenschaften zahlt man diejenigen, aus welchen die theoretischen Grundsätze der Fortwissenschaft entweder entlehnt, oder zu Erläuterung derselben notwendig sind. Hierher gehören also

Vorkenntnisse:

1.) Mathematische,
a. Arithmetik und Algebra
b. Reine Elementar-Geometrie ebene Trigonometrie und Polygonometrie
c. Angewandte Geometrie und Trigonometrie

d. Plan- und Bauzeichnung
2.) Naturwissenschaftliche,
a. Allgemeine Einleitung in die Naturwissenschaft,
b. Experimental- [sic]
c. Chemie
d. Mineralogie
e. Botanik
f. Zoologie
3.) Rechtliche,
Kameralrechte.
4.) Stattswissenschaftliche."
(Hundeshagen, 1821, p. 5)

This list is extremely important because it shows the pre-requisites for a student in silviculture. Bronn entirely agreed with this list and pushed the intersection of disciplines that we see here, even further. Particularly significant is the strong connection between *Forstwissenschaft* and both mathematics and the natural sciences. In fact, Bronn taught *Forstwissenschaft* every year, since this discipline provides a good mechanism for combining different aspects or layers of knowledge. In particular – and as above – *Forstwissenschaf* provides good means of combining mathematics with natural sciences. This is interesting because, as I will show later, a synthetic-constructivist methodology plays a key role in Bronn's approach to the fossil record. This synthetic method is anticipated and shaped in his lectures on cameral studies. A student attending Bronn's lectures on cameral studies would need proficiency in mathematics and calculation – bringing these skills to the series or, potentially, learning these through the lectures. As a final remark on the lecture list, Bronn's most famous student Karl Alfred von Zittel attended only the last period of Bronn's courses on geology and zoology, not his *Forstwissenschaft* lectures. That means that Zittel's *forma mentis* was not shaped by the cameral studies.

It is also important to stress the nature of the statistics used in *Kameralwissenschaft*. Not only was Bronn very well trained both in statistics and in the "philosophisch-botanischen Kalkus", but he also taught this Kalkus to his students during his *kameralwissenschaften* courses. But what exactly was *Statistik* during this period? As is well known, Gottfried Achenwall (1719-1772) considered statistics or *Staatbeschreibung* a descriptive discipline that aims to numerically describe the objects in a particular area. We find August Ludwig von Schlözer (1725-1809) the successor of Achenwall in Göttingen. In his *Theorie der Statistik* (1793), he emphasized that "statistics is history without motion; history is statistics in motion". Statistics is a synchronical treatment of historical facts; history narrates those facts in time. This statement sets the canon for further statistical treatment of the fossil record and would play an essential role in the course of the next decades until the abandonment of the statistical method by the 1910s. For instance, Eduard Baumstark (1807-1889)—an important politician and professor of cameral studies in Heidelberg between 1825 and

1838—backed up Schlözer's statement (quasi-literally) in 1835. In his monumental *Kameralistische encyclopädie* (1835), he argues that the *Kameralwissenschaft* is not only about a mere statistical treatment of data: it is not a mere compilation of dry statistics. It is rather a historical reflection based upon historical principles:

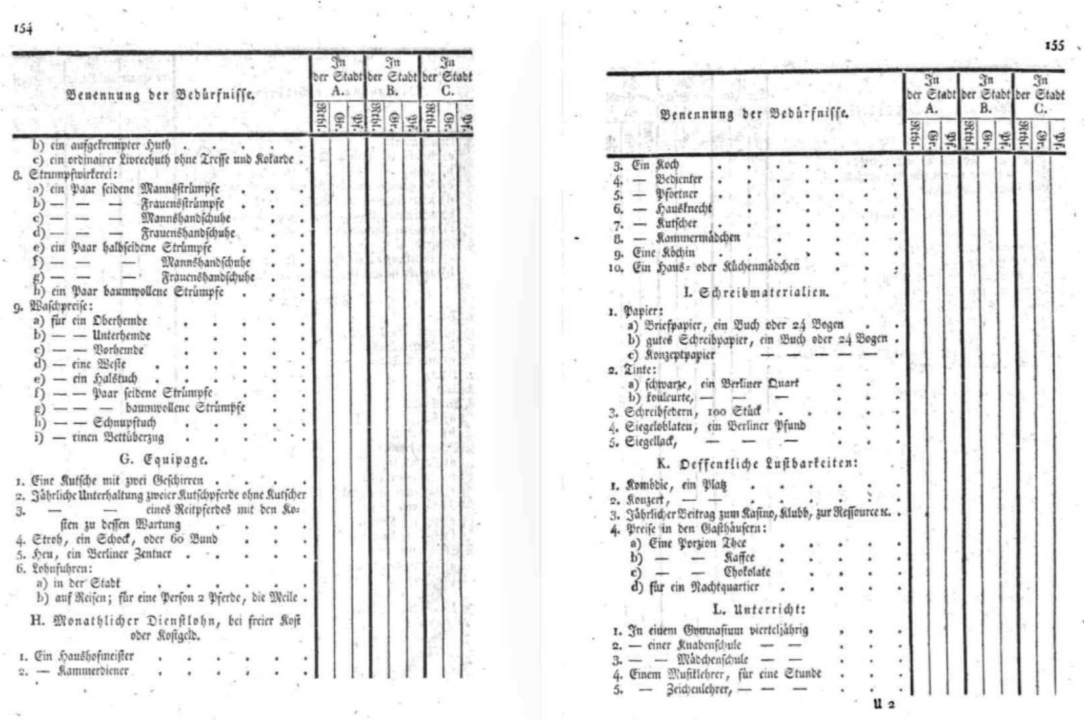
> „Ich meine hiermit nicht, daß bei jeder Doctrin der Finanzwissenschaft mit Jahrzahlen und kalten-statistischen Daten eine magere geschichtliche Einleitung gegeben, sondern die ganze öffentliche Wirthschaftslehre in ihrem Zusammenhange auf historische Grundlage, anstatt auf bloße Dogmatik, gestellt und als ein Ergebniß von Forschungen in der Geschichte des Verkehrs, der Kvltur, des Staats und der Menschheit überhaupt entwickelt werde." (Baumstark, 1835, p. viii)

"Dry statistical data" are useless if they are not connected with, and based upon, historical principles[19]. Baumstark may have spoken with Bronn concerning this—crucial—point since both were teaching in Heidelberg during the same period. The entry in both the *Allgemeinen deutschen Real-Encyklopädie* or *Konversations-Lexikons* and *Allgemeines Handwörterbuch der philosophischen Wissenschaften* confirms this description of statistics: "Zwei große Kreise bilden den Umfang der geschichtlichen Wissenschaften: der Kreis der Vergangenheit und der Kreis der Gegenwart. Von jenen beiden Kreisen der Zeit aber wird der Kreis der Vergangenheit durch die Geschichte, der Kreis der Gegenwart durch die Statistik und Geographie dargestellt. " ("Statistik," 1827) Statistics is therefore connected with history. It aims at acquiring a quantitative historical knowledge. Moreover, Prussia established *statische Bureaus* in order to set up statistical tabular works [*statistiche Tafelwerke*] to measure the state objectively in 1805. In a little work meant as an introduction to setting up the *statische Bureaus*, Leopold Krug (future head of the Prussian *statische Bureaus*) reflects extensively on the nature of statistics and on the statistical investigation of Prussia, from which I will draw the following points. First, although statistics deals with a collection of fragmentary data [*eine Sammlung von Bruchstücken*], "die Wissenschaft der Statistik lehrt, aus diesen Bruchstücken mit möglichster Wahrscheinlichkeit ein Ganzes zusammenzusetzen" (Krug, 1807). That means that Krug was perfectly aware of the fragmentary nature of statistical and historical data, but did not see this as inhibiting acquisition of knowledge. Second, Krug accomplished a statistical examination of Prussia, not simply because Prussia was his country, but also "daß in diesem Staate gewiß mehr als in vielen andern auf tabellarische Übersichten der staatswirthschaftlicheu Verhaltnisse gehalten wird." Tables are the raw data for Krug's statistical investigation; only if data are already present in form of a table, can a statistical investigation take place. Third, statistics is understood as a historical discipline which simply presents how objects are, not how they are supposed to be:

[19] The American paleontologist Williams will underline this same point about sixty years later.

> Die Statistik darf, als historische Wissenschaft, die Gegenstände nur darstellen, wie sie sind, und muß sich alles Urtheils über dieselben, oder aller Vorschlage, wie sie seyn sollten, enthalten; sonst greift sie in das Gebiet der Nazionalökonomie und Staatswirthschaft; aber sie muß eben dem Staatswirth und dem Nazionalökonomen vorarbeiten, und die in das Gebiet dieser Wissenschaften gehörenden Gegenstände von so vielen Seiten und auf so vielerlei Art darstellen, als es ihre Quellen erlauben, und da diese Quellen in vielen Ländern und bei vielen Gegenstanden arm sind, so muß sie durch Kombinazionen oder Zusammenstellungen einzelner Notizen nach Wahrscheinlichkeitssätzen zu Resultaten zu kommen suchen, welche vielleicht bei dem Mangel an historischen Angaben anfanglich nur Hypothesen sind, deren Widerlegung oder Bestätigung aber den Staatsmann auffordern kann, der Wissenschaft mehr historische Data zu verschaffen, oder deren Betrachtung ihm doch einen Fingerzeig giebt, auf welche Gegenstände er vorzüglich seine Aufmerksamkeit zu wen den habe.(Krug, 1807)

Fourth, since data are not always perfectly gathered and statistical data are historical [*historische Data*], the conclusions derived from a statistical analysis can only be probable. However, at the same time they can provision statesmen valuable suggestions. Bronn developed a statistical treatment of the fossil record strongly influenced by these points.


154

Benennung der Bedürfnisse.	In der Stadt A. Rthl.	Gr.	Pf.	In der Stadt B. Rthl.	Gr.	Pf.	In der Stadt C. Rthl.	Gr.	Pf.
b) ein aufgekrempter Huth									
c) ein ordinairer Livreehuth ohne Tresse und Kokarde .									
8. Strumpfwirkerei:									
a) ein Paar seidene Mannsstrümpfe . . .									
b) — — — Frauensstrümpfe . . .									
c) — — — Mannshandschuhe . .									
d) — — — Frauenshandschuhe . .									
e) ein Paar halbseidene Strümpfe . . .									
f) — — — Mannshandschuhe . .									
g) — — — Frauenshandschuhe . .									
h) ein Paar baumwollene Strümpfe . . .									
9. Waschpreise:									
a) für ein Oberhemde									
b) — — Unterhemde									
c) — — Vorhemde									
d) — eine Weste									
e) — ein Halstuch									
f) — — Paar seidene Strümpfe . . .									
g) — — — baumwollene Strümpfe . .									
h) — — Schnupftuch									
i) — einen Bettüberzug									
G. Equipage.									
1. Eine Kutsche mit zwei Geschirren									
2. Jährliche Unterhaltung zweier Kutschpferde ohne Kutscher									
3. — — eines Reitpferdes mit den Kosten zu dessen Wartung									
4. Stroh, ein Schock, oder 60 Bund . . .									
5. Heu, ein Berliner Zentner									
6. Lohnfuhren:									
a) in der Stadt									
b) auf Reisen; für eine Person 2 Pferde, die Meile .									
H. Monathlicher Dienstlohn, bei freier Kost oder Kostgeld.									
1. Ein Haushofmeister									
2. — Kammerdiener									

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Benennung der Bedürfnisse.	In der Stadt A. Rthl.	Gr.	Pf.	In der Stadt B. Rthl.	Gr.	Pf.	In der Stadt C. Rthl.	Gr.	Pf.
3. Ein Koch									
4. — Bedienter									
5. — Pfortner									
6. — Hausknecht									
7. — Kutscher									
8. — Kammermädchen									
9. Eine Köchin									
10. Ein Haus- oder Küchenmädchen . . .									
I. Schreibmaterialien.									
1. Papier:									
a) Briefpapier, ein Buch oder 24 Bogen . .									
b) gutes Schreibpapier, ein Buch oder 24 Bogen .									
c) Konzeptpapier — — — — — .									
2. Tinte:									
a) schwarze, ein Berliner Quart . . .									
b) kouleurte, — — — . . .									
3. Schreibfedern, 100 Stück									
4. Siegeloblaten, ein Berliner Pfund . . .									
5. Siegellack, — — — . . .									
K. Oeffentliche Lustbarkeiten:									
1. Komödie, ein Platz									
2. Konzert, — —									
3. Jährlicher Beitrag zum Kasino, Klubb, zur Ressource rc. .									
4. Preise in den Gasthäusern:									
a) Eine Porzion Thee									
b) — — Kaffee									
c) — — Chokolate									
d) für ein Nachtquartier									
L. Unterricht:									
1. In einem Gymnasium vierteljährig . . .									
2. — einer Knabenschule — — . . .									
3. — — Mädchenschule — — . . .									
4. Einem Musiklehrer, für eine Stunde . . .									
5. — Zeichenlehrer, — — — . . .									

U 2

Figure 4 Example of historical data in a tabular form, from (Krug, 1807).

Bronn, however, used the term *statics*: how do we understand this term? In the *Allgemeinen deutschen Real-Encyklopädie* we find entries for both statistics and statics. Statics is "die Lehre vom Gleichgewicht der festen Körper" ("Statik," 1827). This mechanical theory was applied to some disciplines presented in the classical cameralistics *curriculum*. It was used as a valuable technique to balance the levels of State income and expenditure. As the Agricultural chemistry Eduard Heiden (1835-1888) put it "Statik ist die Lehre vom Gleichgewichte. Dieser wichtige Satz der Mechanik hat seine hohe Bedeutung für alles staatliche und bürgerliche Leben" (Heiden, 1872, p. 1) Statics was, for instance, successfully applied to *Forstwirtschaft*

> "Ich habe Seite 150 des 16. Hefts dieser Jahrbücher wiederholt die Aufmunterung zur Bearbeitung der forstlichen Statik durch einen reichlich auszustattenden Preisfonds vorgeschlagen und sowohl darum, als weil ich dieses Fach zuerst als besonderen Zweig unserer Wissenschaft (im ersten Hefte dieser Jahrbücher Mainz 1828) zur Sprache brachte, einem näheren Beruf, durch nachstehende Zergliederung anzugeben, was ich darunter verstehe und in welcher Ordnung ich dieses ausgebreitete Feld bearbeitet zu sehen wünsche. Die forstliche Statik soll Hand in Hand mit der Theorie gehen, sich jedoch nicht auf Beschreibungen und in Erörterungen der wissenschaftlichen Lehren einlassen, hingegen diesen dadurch, dass sie überall wo im forstlichen Leben und Weben Größen vorkommen deren Verhalten in Zahlen auszudrücken sucht, zur wesentlichen Grundlage dienen, dem wissenschaftlichen Forscher aber, wie dem ausübenden Praktiker, eine reichhaltige Fundgrube von Anhaltpunkten darbieten. Man könnte die forstliche Verhältnißkunde daher auch *forstliche Stöchiometrie* nennen. Sie ist übrigens in ihrer Art mehr als diese und jeden falls weit umfassender, als die landwirtschaftliche Statik, deren Begriff man seither auf die Verhältnißkunde der Bodenkräfte beschränkte." (Wedekind, 1840, p. 146)

Wedekind conceives the *forestliche Statik* as an essential branch of *Forestwissenschaft* Rather than being a merely descriptive discipline, it should go hand in hand with theory (i.e. contra the first formulation of statistics). For Wedekind, *forestliche Statik* expresses important numerical relations and so offers "*Fundgrube von Anhaltpunkten*" for further investigations. Moreover, Wedekind proposes that statics fits *Forestwissenschaft* better rather than *Landwirtschaft*, implying therefore that statics was developed within many disciplines and contributed—as a method—to their growth. However, statics was originally conceived and applied to *Landwirtschaft*. In 1809, Albrecht Daniel Thaer (1752-1828) wrote *Grundsätze der rationellen Landwirtschaft*, founding the *Ackerbaustatik* or *landwirtschaftliche Stati*k. This was defined as "die Lehre über das Verhältniß, in welchem die Kraft des Bodens, der Ertrag der Ernten und die Erschöpfung gegen einander stehen" (Thaer, 1810, p. xv). This discipline then studies the relationships between the various elements of agriculture. However, to avoid possible errors:

> "So werde ich insbesondere die Lehre von den einzelnen vegetabilischen Produktionen mehr aphoristisch und gewissermaßen tabellarisch vortragen, da bei selbiger Missverständnisse weniger zu besorgen sind, und sie nur zu oft und zu weitläufig von andern behandelt ist. Ich hoffe gerade dadurch das Wesentlichste und Wissenswürdigste hervorzuheben, was unter dem Wortschwall bisher dem Auge entrückt war." (Ibid.)

The use of tables to present the data of the *Landwirthschaft* and tabular representation appears fundamental to the avoidance of possible errors.

Werthschätzung eines Landguts. 53

Art des Bodens.	Klasse.	Tragt nach dem Dünger.	Einsaat per Morgen. Schfl.	Mtz.	Das wievielste Ertragskorn.	Ganzer Ertrag per Morgen. Schfl.	Mtz.	od. Schfl.	Mtz.	Kornart.
Weizenboden	Erste	Erste	1	6	7 bis 8	9	10	11	—	Weizen.
— —	—	Zweite	1	4	7 — 8	8	12	10	—	Gerste.
— —	—	Dritte	1	4	6	7	8	.	.	Weizen.
— —	—	Vierte	1	2	5 — 6	5	10	6	12	Gerste.
— —	Zweite	Erste	1	6	6 — 6½	8	4	8	15	Weizen.
— —	—	Zweite	1	4	6	7	8	.	.	Gerste.
— —	—	Dritte	1	4	5 — 6	6	4	7	8	Rocken.
— —	—	Vierte	1	2	5 — 6	5	10	6	12	Gerste.
Gerstboden	Erste	Erste	1	4	6 — 6⅓	7	8	8	2	Rocken.
— —	—	Zweite	1	4	6 — 7	7	8	8	12	Gerste.
— —	—	Dritte	1	2	5	5	10	.	.	Rocken.
— —	—	Vierte	1	—	5	5	—	.	.	Gerste.
— —	Zweite	Erste	1	4	6	7	8	.	.	Rocken.
— —	—	Zweite	1	4	6	7	8	.	.	Gerste.
— —	—	Dritte	1	2	4¾	5	1	.	.	Rocken.
— —	—	Vierte	1	—	4½	4	8	.	.	Hafer.
Haferboden	—	Erste	1	2	5	5	10	.	.	Rocken.
— —	—	Zweite	1	2	5	5	10	.	.	Hafer.
— —	—	Dritte	1	—	3½	3	8	.	..	Rocken.
— —	—	Vierte	1	—	3½	3	8	.	.	Hafer.
— —	—	Fünfte	—	14	3	2	10	.	.	Rocken.
— —	—	Sechste	wird	öko	nomisch	nicht	beste	llt.		
Rockenboden	—	Erste	1	—	3	3	—	.	.	Rocken.
— —	—	Zweite	—	14	2½	2	3	.	.	—
— —	—	Dritte	—	12	2	1	8	.	.	—

Figure 5 One of the tables presented in (Thaer, 1810)

Bronn was perfectly aware of Thaer's reflections. In fact, during his travels in Europe, Bronn extensively quoted Thaer's works. Julius Adolph Stöckhardt (1809-1886) developed the more mature definition *landwirtschaftliche Statik* which better defines the nature of this discipline. In the second volume of his *Chemische Feldpredigten für deutsche Landwirthe* (1857), he writes that "Statik zieht die Bilance zwischen 'haben' und 'sollen' in Ganzen und Generellen, ohne die einzelnen Contis der Einnahme und Ausgabe zu berücksichtigen. Die Agrikulturchemie dagegen hat jedes *einzelne Conto* in Betracht zu ziehen." (Stöckhardt, 1857, p. 203) Statics aims at achieving general conclusions on how to balance what there is with what there is supposed to be; on the contrary, *Agrikulturchemie* is a discipline of particulars, and which takes into account every single factor.

Hence, the main difference between statistics and statics is that latter "soll Hand in Hand mit der Theorie gehen" (Wedekind, 1840) and "zieht die Bilance zwischen haben und sollen" (Stöckhardt, 1857, p. 203), whereas the former helps the statesman to support his further investigations. In the only work dedicated to cameral studies (broadly meant) entitled *Ueber Zweck* *und Einrichtung landwirthschaftlicher Vereine überhaupt, und mit besonderer Beziehung auf Baden*, Bronn characterizes the *landwirtschaftliche Statik* as follows

> "*die landwirthschaftliche Statik*: oder die Bestimmung dessen, wie viel Nahrungstheile ein Acker an jede darin angebaute Fruchtart abzieht, wie viele ihm bleiben, und welche Fruchtarten und in welcher Menge erste nun noch zu tragen fähig ist; oder wie viele Theile man ihm wieder zusetzen müsse, damit er einen gewünschten Ertrag gebe. Solche Versuche lassen sich nur auf größeren Gütern machen, ihre Resultate aber sich mit vielem Vortheil auch auf kleine Besitzungen anwenden. Es muß sich zuletzt ergeben, wie viele ihrer Bestandtheile eine jede Fruchtart bis zu ihrer Reife aus dem Acker zu ziehen pflege, in wie ferne die Größe der Aerndte vom Düngervorrathe des Bodens abhängig seyn, und wie weit sich der reine und der Roh-Ertrag durch vermehrte Düngung und Arbeit erhöhen lasse." (Bronn, 1830, p. 17)

For Bronn *landwirthschaftliche Statik* is a quantitative and arithmetic discipline. It determinates *wie viel* there was, there is, and there will be; it further balances these quantities. There is thus a strong similarity between the *landwirthschaftliche Statik* and what Bronn will call *palaeontologische Statik*.

As mentioned, looking at Bronn's teaching activity can give useful insights into the historical roots of his thinking. To support his lectures, Bronn started using his own books in conjunction with two other textbooks[20], as soon as they were published. The peculiarity of the textbooks[21] chosen is that they mainly provide a detailed and precise description of the three natural kingdoms. The question is accordingly why Bronn used such books to sustain his lectures. I think that the answer can be found in Bronn's own conceptualisation of the fossil record. The key elements for its understanding are presented in Bronn's mature idea of the history of nature. As I have shown above, Bronn series of lectures on paleontology was entitled *history of nature*, whereas the 'classical *Erdgeschichte*' is confined to courses about special zoology.

In the preface of the monumental *Naturgeschichte der drei Reiche*, he writes that "es ist das erste Mal, dass der Versuch gemacht wird, eine Geschichte der gesamten Natur durch systematisches Ordnen und wissenschaftliche Beleuchtung rein thatsächlicher Beobachtungen ohne vorgefasste Theorie zu entwerfen" (Bischoff, et al., 1841, p. VI). These words are linked both with those commonly used to describe the aims of the *Staatswissenschaft* and with Leonhard's *Agenda Geognostica* (1829). Indeed, the history of nature is concerned to bring order to chaotic matter exactly as is *Staatswissenschaft*. By handling the created order disposed in tables, a fruitful history of nature can be obtained and consequently the paleontologist is able to express scientific laws and

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[20] Especially (Bronn, 1834, 1841-1849).

[21] They are namely, *Handbuch der Zoologie* by Arend Friedrich Wiegmann and Johann Friedrich Ruthe (1831); and *Schul-naturgeschichte: eine analytische Darstellung der drei Naturreiche* by Johannes Leunis (1851).

explanations. The history of nature thus aims to be a new science [*neue Wissenschaft*] and "zur Geschichte wird diese Wissenschaft dadurch, dass man die Veränderung in ihrer Chronologischen Aufeinanderfolge betrachtet" (Querner, 1985, p. 536). Order is an essential feature for further investigations and a list of all the objects is required to sort nature systematically. This list can be constructed only by means of collection of purely factual observations [*rein thatsächlicher Beobachtungen*] and their chronological disposition.

The words in the preface of the *Naturgeschichte der drei Reiche* are connected also with Leonhard's assertions in his *Agenda Geognostica*. In that book Bronn's teacher argues that nowadays "man beschränkt sich mehr darauf, der induktiven Beobachtung Folge zu leisten, einsehend, dass Systeme nur Resultate oder Schlussfolgen von Thatsachen sein dürfen." (Leonhard von, 1829, p. 4) Geology and geognosy must therefore follow the method of finding and collecting facts and observations ["*Thatsachen auffinden lassen*"] and applying an inductive practice on them.

This method is necessary because:

> "Die Gebirgskunde – ein Wissen, das uns nicht, gleich der Geometrie, finden, sondern nur suchen lehrt, eine Scienz, in deren Bereich ohnehin mit mehr Ruhe, Umsicht und einem Grade von Ausdauer geforscht werden muss, wie dieses vielleicht bei keinem andern Zweige naturgeschichtlicher Doktrinen der Fall, – hat mit Schwierigkeiten zu kämpfen, welche den übrigen Theilen beobachtender Naturwissenschaften mehr oder weniger fremd sind." (Ibid.)

Theories and laws result from a collection of pure facts necessary in order to overcome the difficulties presented in geological sciences. The pursued empiricism is however very particular, because although it is influenced by the Humboldtian concept of science, it leads—at the same time—to speculative outcomes[22]. Hence, the important question is, how is it possible to list the events of the deep past and consequently to apply statistical techniques to them? The answer to this question characterizes Bronn's mature concept of the fossil record.

Bronn's mature Conceptualisation of the Fossil Record: How to put Events in Deep Time

After having explained the historical assumptions behind Bronn's investigation, I can deal with Bronn's mature works. First of all, it is crucial to identify what should be the object of natural history:

[22] The great anatomist, pathologists and physician Friedrich Gustav Jacob Henle (1809-1885) researched and taught in Heidelberg in the same years. He published an important paper in roughly the same period in which he criticises the speculative systems based upon numerical and statistical methods. I will return to Henle's paper in the next chapter.

> "Als um 1830 die Heidelberger Professoren der Botanik (Gottlieb Wilhelm Bischoff, 1897-1854), der Mineralogie (Johann Reinhard Blum, 1802-1883), der Geologie (K. C. v. Leonhard) sowie der Zoologie (Friedrich Sigismund Leuckart, 1794-1843) beschlossen, eine 'Naturgeschichte der drei Reiche' herauszugeben, hatte Bronn wahrscheinlich die Paläontologie übernommen." (Querner, 1985, p. 536)

Natural history is about all the tree kingdoms and Bronn specifically deals with what can be learnt from the fossil record. This aspect is crucial because "das Studium dieser Reste (dieser Denkmünzen der Schöpfung, wie sie Cuvier nennt) ist für uns der einzige Weg zu ermitteln, welche Thiere und Pflanzen in der verschiedenen Zeiten seit Beginn der Bildung der neptunische Erdrinde gelebt haben." (Bronn, 1854, p. 86) By studying the fossils, it is possible to access which kinds of organisms lived in the different epochs of the earth; the aim of the paleontological investigation is to narrate the history of nature by using this data. There is nevertheless a methodological problem in the treatment of the fossil record. The fossil record is always incomplete and imperfect: "es gibt ganze Familien, Ordnungen und selbst Klassen von organischen Wesen, die vermöge ihrer chemischen Zusammensetzung oder ihrer unbedeutenden Größe durchaus nicht geeignet sind sich im fossilen Zustande zu erhalten. Wir haben keine Hoffnung jemals Reste von Horn-Spongien […] zu entdecken." (Bronn, 1858, p. 4) To better highlight the incompleteness of the fossil record, Bronn uses the famous image of the book of nature:

> "die Erd-Rinde ist ein großes Buch; ihre Schichten sind die Blätter desselben, Versteinerungen die Buchstaben des Alphabets, womit es geschrieben, und der Inhalt ist die Geschichte der Schöpfung, von der uns kein lebender Augenzeuge Nachricht geben kann. Aber jene Blätter liegen unvollständig, zerrissen, durcheinander-geworfen und verblichen vor uns […] Das Alphabet, worin das Buch geschrieben, war uns lange fremd […] Wir bekommen daraus eine mehr und weniger vollständige Kenntnis von den Wesen, welche damals existierten, von ihrer Zahl und Organisation" (Bronn, 1858, p. 75)

Fossils are not exactly as the typical targets of the *kameralwissenschaftlichen* presents: normally a census records a stable, un-misleading object. On the contrary, paleontological data is always incomplete and imperfect. The methodological question is, accordingly: how may these records be fruitfully studied (becoming a part of the new science named history of nature) if they are only incompletely preserved and can only be partially gathered?

The answer lies in the enormous and lengthy work Bronn presented in his *Index palaeontologicus* (1848-9). In the preface, Bronn asks himself "was hat uns zu diesen Unternehmen wohl vermögen können?" The answer is direct: "die Unmöglichkeit im paläontologischen Gebiete selbst ohne solche Arbeit weiter voranzukommen!" (Bronn, 1849d, p. V). The work Bronn is talking about is a particular *Hülfsmilttel* for palaeontologist's effort. It enables recognition of the kind of fossils, genera, species and families found in the epochs of the earth. This compilation can resolve the difficulty of acquiring a minimal degree of knowledge within the paleontological field. Bronn himself takes up this task. Harnessing botanical arithmetic on the one hand and the role of statistics on the other, in *Kameralwissenschaft* Bronn ordered the collected fossils in tables under their geological and geographical expansion - roughly from 1839[23]. The results of this exhausting work are the *Enumerator* (a list of all plant and animal fossilised species chronologically and systematically ordered in tables) and the *Nomenclator* (an alphabetic list of the fossils record).

Hence, the fossil record can be represented in at least two different ways independently from its material structure. In fact, Bronn's data does not constitute material and perceptive features of the fossil record, but entries in his *Nomenclator* and *Enumerator*[24]. The *Nomenclator* is meant as preliminary work which cooks and prepares the raw data of the *Enumerator*. The Enumerator then chronologically and systematically lists the fossils cooked in the *Nomenclator*. How is it possible to chronologically list the fossils given that deep time has a destructive nature? Bronn's answer is significant and already revealing of his mature concept of natural history and the fossil record. He affirms that paleontology can accomplish a chronological investigation "1) nach der Zeitfolge, 2) nach den Klassen, 3) nach den Weltgegenden." (Bronn, 1849f, p. 939) Although the temporal dimension is the most fundamental, paleontology can also carry out chronological studies by following a systematic or geographical order. As I have said, in this short quotation we find Bronn's mature concept of natural science and the fossil record already present. Natural history is a complex and synthetic discipline. It proceeds by putting together diverse standpoints on the same epistemic object. For Bronn, this object is the fossil record. It is meant as an event to be narrated in order to obtain valuable knowledge. In fact, a history can be narrated by reading it through its temporal disposition, systematic position or geographical dispersion.

All these point of readings are then put to work in Bronn's tabular systems. Tables are essential for his investigation. Indeed, following his cameral studies and Leonhard's teaching, Bronn explicitly recognized the importance of tables as raw material for further studies. An example of Bronn's "systematic-chronologic-diagnostic tables" (Schumacher, 1975, p. 77) can be seen in Figure 2. This table lists all the found species of the class *Cephalopoda* by sorting them according to the place, i.e. time, in which they were found. The last column indicates how many living species have been found.

[23] To be precise, Bronn had been working on this massive and monumental work since his first trip to Italy (1824).

[24] Although Bronn collected many fossils during his travels, it is evident that his data are not the material exemplars collected and bought during his travels, but the entries in his tables.

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Benennungen.	Weltgegend. $H^{1,2}$ Europa. $S^{1,2,3}$ Asien. $F^{2,3,4}$ Afrika. $M^{1,2,3,4}$ Amerika. $U^{3,4}$ Australien. E S F M U kein Zeichen: bedeutet E^2.	KohlenP. U.-Silurische F. O.-Silurische F. Devonische F. Bergkalk. Kohlen-Gebirge. Todtliegendes. Zechst.-Kupfer. a b c d e f g	SalzP. St. Cassian. Bunt-Sandstein. Muschelkalk. Keuper. h i k l	OolithP. Lias. Unter-Jura. Ober-Jura. Wealden. m n o p	KreideP. Neocomien. Grünsand. Kreide. q r f	MolasseP. Nummulit.-Gest. Untere Mittle (Molasse.) Obere Diluvial. s t u v w x	Neu Alluvial. Lebend. y z
Cl. XV. CEPHALOPODA Cuv.: **Kopffüsser.**							
I. TETRABRANCHIA Ow., Vierkiemer.							
a Ammonitina.							
Bactrites G. Sandb. 2	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	. 0
† subconicus Sndb. .	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
† *sp.* 2. Sndb.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
Goniatites DeH. 194	. . . . .	. . . .	. . . .	. . . .	. . .	. . . . . .	. 0
(Ellipsolithes So.; Nautellipsites Park.)							
α Bactrites Sndb.							
Schlotheimi Qu. . .	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
β Goniatites.							
(* *lobo dorsali simplici.*)							
? angustiseptatus Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
auris Qu.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
Beaumonti Mü. . . .	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
Becheri Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
biferus Phill.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
biimpressus Bu. . .	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
Bronni Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
Buchi AV.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
canalifer Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
ceratitoides Bu. . .	. . . . .	. . ?(?). . .	. . . .	. . . .	. . .	. . . . . .	. .
clymeniiformis Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
compressus AV. . .	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
‡ Cottai Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
cucullatus Bu. . . .	. . . . .	. . ?(?). . .	. . . .	. . . .	. . .	. . . . . .	. .
Dannenbergi AV. .	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
divisus Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
falcifer Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
globosus Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .
Haueri Mü.	. . . . .	. . c	. . . .	. . . .	. . .	. . . . . .	. .

Figure 6 An example of Bronn's systematic-chronologic-diagnostic table

The first conclusion is that

> "um die *Geschichte der organischen Wesen im Einzelnen*, die Fragen von ihrer Verbreitung; ihre Aufeinanderfolge oder Gleichzeitigkeit ihrer gegenseitigen Beziehungen und alle Gesetze zu studieren […] müssen wir Schicht um Schicht die

> ganze Erd-Rinde sorgfältig durchforschen und aus den darin eingeschlossenen organischen Resten die Familien, Genera, Arten früherer Lebenswesen nach der jedesmaligen Bildungs-Zeit jener Erdschichten zu bestimmen suchen." (Bronn, 1849f, p. 1)

The paleontologist can answer important questions on the history of the nature by relying on his lists of fossils. He has to scan the earth layer by layer and to note the time and geographical position of the fossils in the tables of this powerful *Hülfsmilttel*[25]. This action generates an ordered list that supports the paleontologist's work. In other words, it provides foundation for his search for the laws of the history of nature. The drawing up of such a catalogue is a long and meticulous process, often very difficult and boring[26], but the final result is the establishment of paleontological raw data. To complete this task a further condition is required. The *construction* of such a list is made possible only by using the knowledge borrowed from the zoologists and botanists[27]. Only by borrowing this bulk of information can fossils be classified and the comparison between these species and those currently existing, begin.

As I have said, this combined knowledge results in "systematic-chronologic-diagnostic tables" (Schumacher, 1975, p. 77), tables that facilitate biostratigraphic recognition, i.e. a chronological history of the earth. Such are constructed paleontological raw data. In his *History of Geology and Paleontology* Karl Zittel underlines this precise point. He observes that

> "the first attempt at a Chronological Succession of fossil organism is to be found in H.G. Bronn's *Lethaea Geognostica*. This word is a masterpiece of scholarship […] it was followed by an *Index Palaeontologica* and these books exerted a great influence on the development of paleontology, and were for several decades the chief books of reference for all the more comprehensive paleontological works." (Zittel, 1901, p. 365)

[25] This task would be taken up by the next generations of paleontologists. Zittel and Neumayr realised that such support is essential to fruitfully carry out any paleontological investigation. Neumayr proposed to draw up an *Enumerator palaeontologicus* during the International Geological Congress held in Berlin in 1885. See the next chapter.

[26] In drawing up the compendia of fossil marine animals, Jack Sepkoski stresses the same characteristic. See the chapter 7.

[27] Bronn asserts that "Um die organischen Reste nach Geschlechtern und Arten zu bestimmen und sie unter sich und mit den lebenden Wesen vergleichen zu können, müssen wir die Kenntnisse der Zoologen und Botaniker zu Hülfe nehmen." (Bronn, 1849f, p. 1) This is indeed and interesting point, because it has been attempted to apply the botanical and zoological classification to mineralogy without any result since the late 18th century. This implies an increasing conviction in treating the fossil records as part of the biological kingdom. Bronn has been endorsing this point since 1824. In his *System der Urweltlichen Konchylien durch Diagnose, Analyse und Abbildung der Geschlechter erläutert*, he asserts that "die nähere Beschreibung der Thiere sowohl als ihrer Gehäuse, ist ein Gegenstand der Zoologie, und die Terminologie zu Beschreibung der letztern wird von daher in der Petrefactenkunde entlehnt." (Bronn, 1824a) It is worth noticing that this little book is an introductory guide for the students.

These works are thus a chronological representation of the fossil records and as such useful for narrating the history of the earth. Zittel supports this in a paper published in 1985. He argues that Bronn's *Lethaea geognostica* forms a "supporting pillar for historical geology and paleontology; while his *Geschichte der Natur* with the *Index Paleontologicus* has served as essential support for every paleontologist through these years"[28]. By using this data, Bronn was able to win the prestigious prize of the *Acedémie des Sciences* in 1857. In 1850, the *Acedémie des Sciences* announced the prize-question as follows:

> "Etudier les lois de la distribution des corps organises fossiles dans les différents terrains sédimentaires suivant leur ordre de superposition. Discuter la question de leur apparition et de leur disparition successive ou simultanée. Rechercher la nature des rapports qui existent entre l'état actuel du règne organique et ses états antérieurs."

The question fit perfectly with Bronn's research since 1831 – it is unsurprising that he would go on to win the prize seven years later. It is interesting to note, however, that no one won the prize in 1850. This observation is astonishing, since if we agree with Sandra Herbert,

> "The dominant cognitive goal of English geology at this period [between 1827 and 1843] was to discover, using fossils, the true order of succession of the strata. Success in achieving this goal carried with it possibility of reconstructing the history of life on its surface. The secondary goal of English geology at this period was to make geology a comprehensive science by insisting that it complement and draw from other sciences and that it be, in principle, a science of causes as well as of description and classification." (Kohn, 1985, p. 490)

Neither English nor French paleontologists were able to win the prize because it required the reordering of cognitive goals within the discipline at the time, i.e. prioritising the concept of geology as a comprehensive science and as a science of causes. Only Bronn was able to do as such. In fact, the system of tables and the lists of dates are the only materials required for further etiological elaborations. They are, so to speak, history without motion. Bronn's paleontology however implies something more: it is a "science of causes as well as of description and classification". This is a key point. If we consider the main aim of *Staatswissenschaft* and of Leonhard's works again, we see that the order acquired in tables is only the staring point for deeper causal investigations. Tables and statistics are useless without historical principles: statistics has to

[28] "dessen [of Bronn] Lethaea geognostica einen Grundpfeiler der historischen Geologie und Paläontologie bildet, während die Geschichte der Natur mit dem Index Paleontologicus lange Jahre hindurch jedem arbeitenden Paläontologen als unentbehrliches Hilfsmittel diente." (Zittel, 1895a, p. 15)

be put in motion. The constituted raw data require another treatment[29] so that they can narrate a natural history.

The synthetic-constructivist practice generates 'raw material' upon which paleontology can finally work. This is the task of the new discipline called *palaeontologische Statik*. It aims to discover causes and laws in the history of life, working with the data listed in the *Index palaeontologicus*. Bronn used this *palaeontologische Statik* in 1840s, but the aims of the discipline and its methods had been clearly present in his mind since his second trip to Switzerland, Italy, and south France. Specifically, p*alaeontologische Statik* deals with numerical relations between the fossils given in lists, charts, and tables so that these events can be put into a narrative frame. By using simple statistical tools, the paleontologist compares the records presented in the tables to give a solid and unified structure to his narration. Before mathematically handling the records listed in tables, it is fundamental to clarify the relations between species and the higher taxonomical levels. Figure 2 indicates that the species are Bronn's epistemic objects. In fact, as he wrote in 1831, "so würde sich die Verwandtschaft eines tertiären Beckens mit einem anderen mathematisch ausdrücken lassen, wenn man voraussetzen dürfte, dass man alle fossile Arten einer Gegend genau kenne, und wenn man zuvor noch für jedes dieser Momente den relative Werth noch in Aufrechnung gebracht hätte" (Bronn, 1827, p. 663). Although the species are the fundamental unities in Bronn's system, the Heidelberger paleontologist follows Edward Forbes (1815-1854) in providing positive answer to a much debated, key questioning in these years: "hat jedes Genus, so wie jede Species ein Verbreitungs-Centrum?" (Edward, 1848) Bronn's answer affirms: genus and species share the same characteristics and the mathematical treatment can be applied to both of them. The result is a graph in which the developments of various genera are depicted. In fact by

[29] Bronn's method is therefore based upon a complex synthesis of various disciplines. This union is essential to the generation of paleontological data. His practice is reflected also in his zoological investigations. In the *Neue Enzyklopädie der Wissenschaften und Künste für die deutsche Nation (1850)*, he followed indeed the same synthetic and constructivist practice. Zoology is meant to be the natural history of the animal in a broader sense ["*Naturgeschichte der Thiere im weiteren Sinne*"]. It is thus a historical discipline whose subject is represented by animals. The question is thus what is an animal? Animals are natural bodies that live a limited span of time under the influence of the environment. "They consist of soul and bod, of energy and substance, of form and material." Therefore many disciplines study them. The task of the *Naturgeshichte* is thus to explain what the concept of 'animal' is. This aim can be accomplished only "*wenn wir schliesstlich die Endergebnisse aller diesen Wissenschaften vereinigen, so werden wir nicht nur eine schärferen sondern auch vollständigeren und umfassenderen Begriff von 'dem Thiere' erlangen, als jetzt vorläufig aufzustellen möglich ist*." (Bronn, 1850) A constructivist approach characterizes both the data and the aims of scientific investigations. This metaphysical ideal shapes Bronn's enterprise and only by neglecting it, or rather only by posing another metaphysical instance, has the genesis of pure paleontological data been possible.

operating mathematically on the records of the *Enumerator,* Bronn comes up with biological patterns and processes on the species, genus, and family levels.

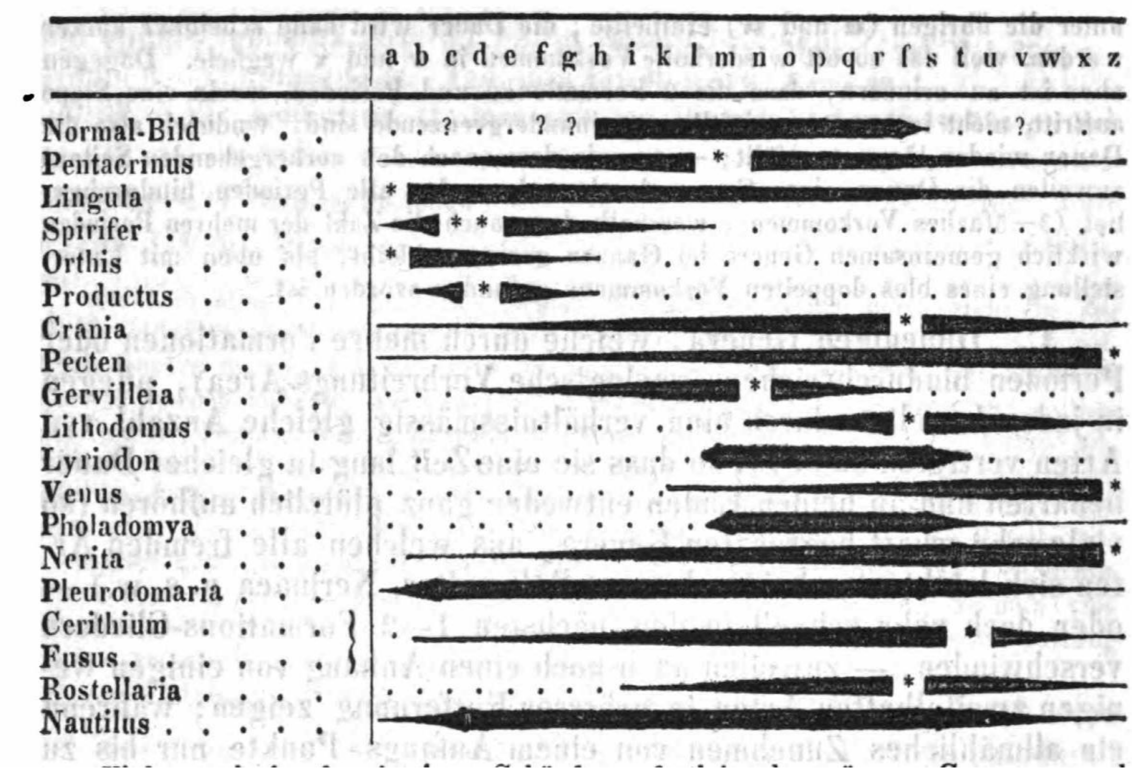


Figure 7 Bronn's table of development and distribution of various genera.

As Bronn did in his *Handbuch der Geschichte der Natur*, in adopting a statistical treatment of data the paleontologist is able to compare the number of plant and animal fossils with the living specimen (§ 7); count the total number of family (§ 8); determine the ratio between families and species (§ 10). In other words, the paleontological static is a mathematical treatment of data; it not only cooks and redefines the paleontological starting points, but also chronologically narrates the history of nature. As a result, the paleontologist is able to obtain historical patterns from the fossil record. These, in turn, have a biological meaning.

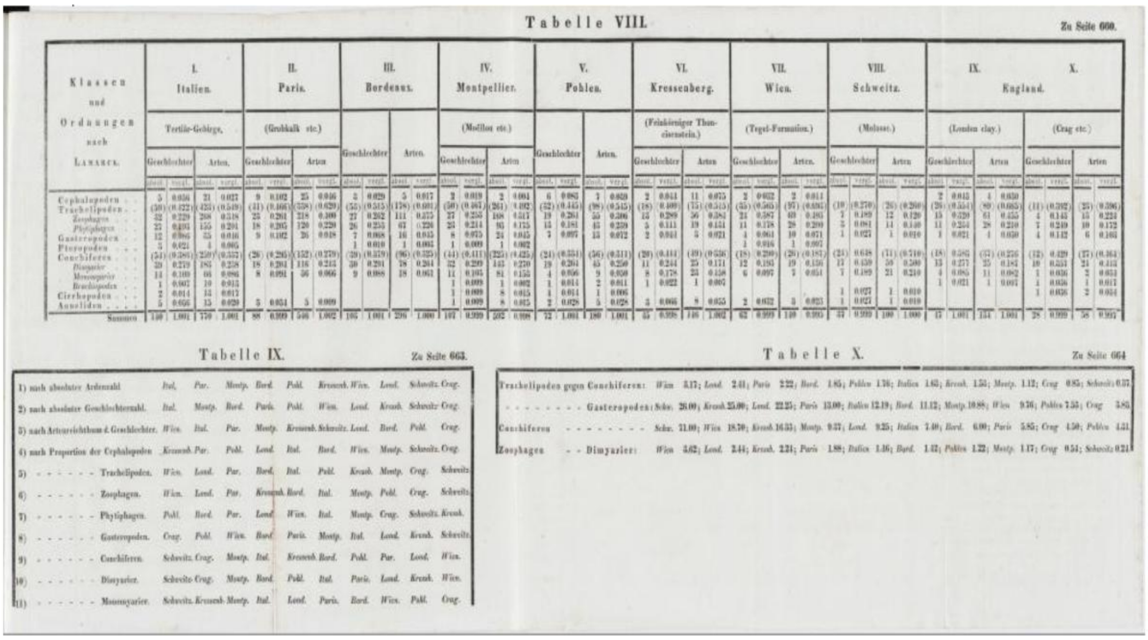


Tabelle VIII. Zu Seite 660.

Tabelle IX. Zu Seite 663.

1) nach absoluter Artenzahl	Ital.	Par.	Montp.	Bord.	Pohl.	Kressenb.	Wien.	Lond.	Schweitz.	Crag.
2) nach absoluter Geschlechterzahl.	Ital.	Montp.	Bord.	Paris.	Pohl.	Wien.	Lond.	Kressb.	Schweitz.	Crag.
3) nach Artenreichthum d. Geschlechter.	Wien.	Ital.	Par.	Montp.	Kressenb.	Schweitz.	Lond.	Bord.	Pohl.	Crag.
4) nach Proportion der Cephalopoden	Kressenb.	Par.	Pohl.	Lond.	Ital.	Bord.	Wien.	Montp.	Schweitz.	Crag.
5) - - - - - - - Trachelipoden.	Wien.	Lond.	Par.	Bord.	Ital.	Pohl.	Kressb.	Montp.	Crag.	Schweitz.
6) - - - - - - - Zoophagen.	Wien.	Lond.	Par.	Kressenb.	Bord.	Ital.	Montp.	Pohl.	Crag.	Schweitz.
7) - - - - - - - Phytiphagen.	Pohl.	Bord.	Par.	Lond.	Wien.	Ital.	Montp.	Crag.	Schweitz.	Kressb.
8) - - - - - - - Gasteropoden.	Crag.	Pohl.	Wien.	Bord.	Paris.	Montp.	Ital.	Lond.	Kressb.	Schweitz.
9) - - - - - - - Conchiferen.	Schweitz.	Crag.	Montp.	Ital.	Kressenb.	Bord.	Pohl.	Par.	Lond.	Wien.
10) - - - - - - - Dimyarier.	Schweitz.	Crag.	Montp.	Bord.	Pohl.	Ital.	Paris.	Lond.	Kressb.	Wien.
11) - - - - - - - Monomyarier.	Schweitz.	Kressenb.	Montp.	Ital.	Lond.	Paris.	Bord.	Wien.	Pohl.	Crag.

Tabelle X. Zu Seite 664

Figure 8 Bronn' s statistical treatment of the data gathered in Italy. From (Bronn, 1826)

	in Deutschland. Sippen.	in Deutschland. Arten.	in England. Sippen.	in England. Arten.
Pflanzen	18	50	7	11
Konchylien	17	82	15	33
Kruster	2	10	2	5
Sechsfüßer-Insekten	—	—	48	60
Fische	8	14	14	27
Reptilien	3	4	11	13
	48	160	97	149

Figure 9 An example of Bronn's *Palaeontologische Statik*: Bronn statically compares the number of diverse species and genera in Germany and England. From (Bronn, 1849d)

Therefore, the natural history of the earth is based upon statistics in motion. P*alaeontologische Statik* plays exactly the same function in paleontology as statistics does in *Kameralwissenschaft*: both describe historical trends. The former, unlike the latter, uncovers the casual laws responsible for the detected trends. These laws, nevertheless, are mere abstractions based upon an incomplete induction. They have no mathematical value and "neue Beobachtungen können sie modifizieren oder umstoßen" (Bronn, 1849f, p. 809). Bronn underlines this process of abstraction and the probable consequent results not only in the practice of enumerating the laws of the history of nature, but also in the mathematical treatment accomplished by the paleontological static. In fact, the paleontologist should keep always in mind that

> "wenn wir auch die Resultate dieser Vergleichungen mir mathematisch scharfen Ausdrücken hinstellen, Diess dennoch nur annähernde ungefähre Werthe nach dem jetzigen augenblicklichen Stande unsrer Kenntnisse sind […], dass das Bild, welches wir geben, sich auf die Summen der bisherigen Betrachtungen gründet, und dass neue Beobachtungen im Laufe der Jahre es sehr bedeutend umgestalten können, wenn auch viele Ergebnisse darin als für immer feststehend bereits betrachtet werden dürfe*n*." (Bronn, 1849a, p. 137)

The final results of the complex and statistical works carried out by the *palaeontologische* remain only probable. Therefore, paleontology obtains only a low and unstable degree of knowledge. Further observations and data can change both the nature and contents of the paleontological narration. Although Bronn's epistemic practice is able to list the events which happened in the past and to narrate them, these narrations have a narrow utility: they cannot pretend to overcome the mere *hic et nunc* derived from the gathered data. This instable nature of Bronn's conclusion is based upon the nature of deep time. Indeed, Bronn recognized its key role in any mathematical treatment: in order to compare the

> "numerischen Reichthum ehemaliger Bevölkerung mit dem der jetzigen […], so darf man weder unsre ganze jetzige Fauna und Flora mit der ganzen fossilen noch mit derjenigen fossilen des kleinen Theiles der Erd-Oberfläche […] noch auch die lebende eines einzelnen Landes mit der fossilen desselben Landes im Ganzen oder aus einer Periode desselben, sondern höchstens au seiner einzelnen Formationen neben einander stellen. Solcher Formationen wird man etwa 15 zählen" (Bronn, 1849f).

Only by using the temporal dimension as a fundamental unity, can mathematical comparisons be made. However, "eine genaue Vergleichung der Zahlen der zu verschiedenen Zeiten lebenden Thier- und Pflanzen-Formen ist nicht möglich" (Bronn, 1849f, p. 783). Bronn provides many reasons in arguing for the impossibility of an exact knowledge based upon mathematical techniques. The first is particularly important. Bronn affirms that this exact knowledge is not possible "weil wir 1) nicht bestimmen können, in wie ferne sich die den einzelnen Schichten, Formationen, Perioden entsprechenden Zeit-Abschnitte unter sich gleich verhalten; oder nicht der eine derselben 2-3-4- mal länger als der andere in gleiche Kategorie gestellte Abschnitt ist" (Ibid.). Deep time thus plays a destructive role. It does not enable exact and stable knowledge of the past. As a result, Bronn claims that "diese neuen Untersuchungen der statischen Paläontologie [...] sind Ergebnisse noch sehr unvollkommener Hülfsquellen, deren Mängel wie später zu beleuchten Gelebenheit finden werden. Indessen geben sie wenigstens ein Bild der Wissenschaft [...] und dürften in soferne immer einigen Werth behalten" (Ibid.). Bronn's paleontological statistics is meant—despite all its flaws and defects—to provide a valuable image and example for further paleontological investigation[30].

Conclusion: Bureaucratic Statistik into paleontological data

The conclusion that emerges from this first chapter is threefold. First, I have argued that only previously constructed data can be fruitfully used to write a history of nature. This data is based upon a synthetic union of different disciplines, such as stratigraphy, zoology and mathematics:

> "So find die Naturwissenschaften überhaupt noch sehr jung; den mächtigsten Anstoß erhielten die Chemie zu Ende des vorigen, die gesammte Naturgeschichte zu Anfang des jetzigen Jahrhunderts, mithin von kaum 50 Jahren, und es hat sich überall gezeigt, dass die Ausbildung der Naturwissenschaften nur gemeinsamen Schrittes mit einander möglich ist, indem jede von der andern Licht empfangt und ihr Licht ertheilt." (Bronn, 1854, p. 188)

The formation of the sciences of nature is possible only if they proceed together, constructing their data step by step. Bronn would have claimed that the paleontological data are not ready made, out there but, that the paleontologist needs to make and shape them. Bronn's ability to draw biostratigraphic tables—a chronology of the specimens appeared on the earth surface—was conditional on the help of zoology and botany. Only by borrowing their respective knowledge, was Bronn able to find patterns among the fossils. He thus—as above—understands the secondary aim of English-speaking geology as the primary aim. The kind of construction Bronn is talking about is *de facto* only a synthetic and systematic view: he transmitted a scientific practice to the next generation of paleontologists based upon an accumulation and a statistical treatment of data. He applied his knowledge of bureaucratic statistics to paleontology. His paleontological method is based upon training in *Kameralwissenschaft* acquired during his studies. Through the historical element of the *Staatbeschreibung* he accentuated that the paleontologist is able to describe and narrate a history.

This method nevertheless obtains only provisional, imperfect, and probable conclusions: Bronn himself recognised that new observations can modify and nullify the validity of his inferences. From a pedagogical point of view, this first point is particularly important. In fact, the structures of the German universities *quasi* oblige a theoretical confrontation with their teachers. The next immediate generation of paleontologists would refuse the mathematical treatment of the fossil record, since it implies weak and imperfect results. Zittel argues that paleontology can obtain strong and certain results if this discipline adopts a descriptive method without statistics. This

[30] It is not by chance that in Charles Knight's *English Cyclopaedia* (1870) the paleontology entry is entirely dedicated to the mathematical treatment of the fossil record.

method has the ability to fix the referential burden of extinct animals. It does not aim at making statements about the past.

Secondly, the product of the synthesis between stratigraphy, zoology and mathematics is fundamental for the further development of historical geology and not for the realization of the paleontological data. What Bronn was able to offer was a constructivist practice – entailing a reading of a material object (the fossil record) in the light of the history of nature. This is the central point: if we consider the fossil record as incomplete words in a book, then we need to develop a practice for reading those words, whereas if we lay aside this metaphor, we can fruitfully treat them as pure facts. In other words, if we take the fossils as data that ontologically require a diachronic reading, i.e. as events, then the paleontologist has to develop a practice for advancing step-by-step in this reading. This practice is, and it could not have been otherwise, inductive. Induction, in fact, tries to obtain from many singular cases at time t_0 a degree of knowledge at the time t_1, thus overcoming the decay of information through time. That is to say, by identifying the fossil record with events, Bronn at the same time supports an inductive practice to narrate a story from those events directly: he "professed a purely inductive ideal of scientific reasoning and said he was making the first attempt to develop a comprehensive history of nature directly from facts, without any preconceived theory." (Glidoff, 2008, p. 65) In Bronn's thought, facts are subordinated to the narrative functions they can play in the system of nature. They are events that seek a function in a wider system of knowledge. They need to be inductively read to acquire a diachronic dimension[31].

Zittel's notion of paleontological data, i.e. the secure paleontological starting points required to come up with certain biological conclusions, would react against this historical reading of the fossil record: the reading can be only partial and should thus be avoided. What is important, on the contrary, is bringing the fossil record close to a set of facts and – consequently – developing the epistemological power hidden in its folds. In other words, the paleontologist should not treat material objects as events. But he should come up with mechanisms to transform material objects into more stable facts. A collective thought metaphysically embodied in Karl Alfred von Zittel would achieve this decisive step during the last decades of the 19th century.

Lastly, by asserting that the one of the main causes of the impossibility of exact knowledge in the deep past is the enormous timespan involved, Bronn provided the impetus for stratigraphical studies. In fact, he suggested that a precise dimension of time is fundamental to the reaching of

[31] This practice will be extensively used in historical geology—as I will show in next chapters. Furthermore, it will generate a new discipline: paleogeography. Bronn is clear about this point: "die ganze Entwicklung und Lebensgeschichte der Thiere erwartet noch eine vergleichende Bearbeitung. Über Thiergeographie haben wir noch nicht einmal einen allgemeinen Versuch. Die Erforschung der Geschichte des Thierreiches hat eben erst begonnen." (Bronn, 1850, p. 44)

stable and certain conclusions. Albert Oppel would undertake this line of research, in complete opposition to Zittel's investigation. He would be able to re-observe time in the form of space - and thus guarantee a firm basis for further statistical analyses.

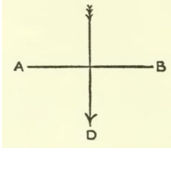
Chapter II. The Making of Paleontological Data

Introduction

Between the end of the 19th century and the beginning of the 20th century we see the genesis of a collective enterprise within the domain of paleontological research. We can define this enterprise as an intellectual community committed to the exchange of ideas. Its object was to establish what I will call the pure paleontological epistemic thing, and was conceived to support paleontological investigations by emancipating them from stratigraphical and geological inquiry. Accordingly, the fossil record could be biologically treated - thus providing a stable set of explananda for paleontology independent from previous geological investigations. Paleontological epistemic objects are conceived as unmixed paleontological explananda - freeing paleontology from historical speculation and bringing it into contact with biology. Both morphological and atemporal data, these objects have a close relation to the material records exhibited in a museum or a lecture. In turn, these material records are the metaphysical essences which support further paleontological representations of the data. The paleontologist has only to see that the fossil record has certain particular morphological features and to represent them accordingly.

Hence, the paleontological data established in the final decades of the 20th century does not refer to past events, (à la Bronn), but constitutes stable fact. These facts are characterized by an element of a-temporality[32]. Events happen in a particular time; facts, on the contrary, are atemporal:

[32] My claim should not be misunderstood. Within the paleo-biological sciences, a-temporality means only synchronicity. The linguist and semiotician Ferdinand de Saussure (1857-1913) proposed—in his lectures in Geneva, published posthumously as *Course in General Linguistics* (1916)—theoretical distinction between the synchronic and diachronic. Saussure's starting point is a common one for that period. He asserts that the "intervention of the factor of time creates difficulties peculiar to linguistics and opens to their science two completely divergent paths". In fact, it is important for all sciences to specify the co-ordinates along which they move, as per the following illustration.



Saussure explains that "between (1) the axis of simultaneities (AB), which stands for the relations of coexisting things and from which the intervention of time is excluded; and (2) the axis of successions (CD), on which only one thing can be considered at a time but upon which are located all the things on the first axis together with their changes" (de Saussure, 1959, p. 80) The axis AB defines the concept of synchronicity in time and the corresponding discipline is synchronic linguistics, whereas from the axis CD emerges the concept of diachronicity in time and the subsequent it is a fact that the bodies of trilobites are divided into three parts both now and in the Cambrian past, for example; mass-extinction, as an event, has a validity only within a certain temporal frame. This point can be better stressed using a slightly modified version of Ramsey's example (Ramsey, 1927). The phrase 'the extinction of trilobites' can function in two different ways. Firstly, it describes an event. Both 'the extinction of trilobites' and 'an increase of carbon dioxide killed the trilobites' constitute descriptions of this event. Secondly, that same phrase can be used to describe a fact. In the sentence 'he was aware of the extinction of trilobites', 'the extinction of trilobites' does not stand for an event. Otherwise, it should be substituted by 'an increase of carbon dioxide killed the trilobites'. But, as Ramsey notices, one could be aware that trilobites were extinct, without knowing that they had been killed. Ramsey concludes his distinction by asserting that the *event* 'the extinction of trilobites' or "'the death of Caesar'" should not be confused with the *fact* that the trilobites became extinct or that Caesar died. These two categories have two separate meanings and as such should be treated differently.

Hence, we find a linguistic, epistemic, and ontological difference between facts and events[33]. Consequently, an identification of paleontological data with events or facts establishes an epistemic difference: data, i.e. paleontological starting points can assume another meaning, a different function, and more complex ontological features when they are assimilated with events or facts. As I have explained in the previous chapter, Bronn identified the fossil record with facts; this chapter argues that Karl von Zittel successfully assimilated the fossil record with stable facts.

Zittel's starting point is clear. To put it concisely, scientific truth, which is the product of declarative statements, is a very changeable concept; therefore, paleontology should deal with atemporal facts rather than unstable and partial truths. Facts are both paleontological starting points and explananda; as atemporal entities, they provide required source for securely establishing paleontology as an autonomous discipline. Any attempt to discover biological laws in deep time must be abandoned where—as Bronn had already noticed—they have no mathematical value and "neue Beobachtungen können sie modifizieren oder umstoßen" (Bronn, 1849f, p. 809)

Zittel firmly held that the scientific truth "ein wechselnder Begriff, abhängig vom Umfang unseres Wissens. Was heute für wohlbegründete Wahrheit gilt, ist häufig nach wenigen Jahrzehnten

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diachronic linguistics. De Saussure warns linguists that "evolutionary [diachronic] facts are more concrete and striking; their observable relations tie together successive terms that are easily grasped; it is easy, often even amusing, to follow a series of changes" (Ibid.). It is therefore extremely important "to put each fact in its own class and not confuse the two methods". (Ibid.)

[33] This difference appears evident if we recall that the philosophers Russell or Wittgenstein supported a correspondence theory of truth based upon the notion of fact. I will return to this point in the chapter 7.

als grober Irrtum erkannt" (Zittel, 1902, p. 13) The acknowledgement of a changing and dynamic truth has its roots in Zittel's education as well as being a common trope in the science of that period. Between the end of the 19th and the beginning of the 20th century both philosophers and scientists stressed the anti-metaphysical and experimental nature of the scientific enterprise. The scientist and philosopher Ernst Mach (1838-1916), among others, emphasized in his *Die Mechanik in ihrer Entwickelung* (1883) that science describes natural phenomena:

> "thence is imposed the task of everywhere seeking out in the natural phenomena those elements that are the same, and that amid all multiplicity are ever present. By this means, on the one hand, the most economical and briefest description and communication are rendered possible; and on the other, once a person has acquired the skill of recognising these permanent elements throughout the greatest range and variety of phenomena, of seeing them as the same, this ability leads to a comprehensive, compact, consistent and facile conception of the facts. [so fuehrt dies zur uebersichtlichen, einheitlichen, widerspruchslosen und munhelosen Erfassung der Tatsachen.]" (Mach, 1893, p. 5)

Scientific theories are economic versions of descriptions and are able to record observational facts excluding metaphysical speculations. I will argue in this chapter that Zittel founded the notion of pure paleontological data: he was able to shift the focus from mere speculative theories - as we see with Bronn for instance - to "something, which usually survives." (Poincaré, 1913, p. 351) Zittel faced, in fact, a pressing problem: after Bronn's investigations, it seemed that paleontology produced only incomplete and imperfect results and was unable to deepen our knowledge of the past. Zittel proposed an epistemic and radical turn: instead of focusing on contingent methods and theories, paleontologists should come up with methods to strengthen their data and widen its field. This data is what survives from the changing and inconstant progress of science, whereas the various truths claimed after complex and statistical procedures are designated to disappear. Zittel would have agreed with Poincaré in asserting that "what succumbs are the theories, properly so called those which pretend to teach us what things are." (Ibid.) What survives is the relation and "it will be found again under a new disguise in other theories which will successively come to reign in place of the old" (Ibid.). Zittel understood[34] how to separate theories, namely historical geology as Bronn conceived it, from data and their relations in order to secure the value of paleontology. Data usually survives because it can be found out there, or to put it differently, although this data is the final result of a complex representational activity, its epistemic status is preserved in the metaphysical and morphological essence conserved in a museum and exhibited during a lecture. In

[34] It is important to stress that Zittel was not the only one to use this notion of data. It was a commonplace in that period. Friedrich Mohr in his *Geschichte der Erde* (1875) used the same notion of fact to construct a new history of the earth.

fact, the paleontologist can always refer his data to the morphological features of the fossil record carefully conserved in museums and collections: these morphological features are the metaphysical essence which support his investigations. Furthermore, Zittel implicitly proposed that a declaration of past events is not the main paleontological goal. As I have argued, truth is *ein wechselnder Begriff* and it is not paleontology's brief to deal with a changing and sloppy concept. On the contrary, it is tasked to provide and to fix the referential burden of extinct entities. This, not the making of declarations, constitutes the main paleontological aim[35].

In order to establish enduring data – and so a secure space for paleontology – it is essential that disturbing factors are kept separate. Bronn identified his data with events in the flow of time and it was precisely this which was responsible for producing provisional and probable conclusions. Not only were Bronn's results imperfect, but neither was his data able to overcome both the abyss of time and the impact of future observations: new observations may demolish the extant work. Therefore, another concept of the fossil record was sought—and discovered—by Zittel.

To summarize, Zittel identified the fossil record not with events in the deep past, but with stable facts that share a relation with their material starting points. This different notion of data was made possible only by excluding from paleontology the inorganic geological term 'event', and its attendant temporal associations (time had presented a disturbing factor in Bronn's analysis.) This new notion implies the coming into being of what I have named pure paleontological data, i.e., fossils understood as stable morphological entities that support biological investigation, thus emancipating paleontology from the geological and inorganic world: "Nachdem *Karl Alfred v. Zittel* das gesamte Material unserer Wissenschaft, wie einst *Linné* das der lebenden Organismen, kritisch durchgesehen und einheitlich geordnet hatte, sind der Paläontologie wenigstens die Kinderschuhe zur selbständigen Bewegung angezogen." (Jaekel, 1907) Before dealing with the genesis of this notion however, a preliminary observation of the use of the term 'paleontological data' is due.

On the Notion of 'paleontological Data'

The label 'paleontology' can be applied to many disciplines during the 19th and the early 20th century: from geological to biological sciences. We can note how paleontological professorships were initially found within both geological and biological departments, once instituted,. If however we look closely at paleontological professorships in German speaking countries, mid 19th century,

[35] I will return to the philosophical consequences of this statement in the next chapters.

we can see that there was only one chair of paleontology in Munich[36]. The second was established in Vienna in 1873[37]. From a sociological point of view therefore, paleontology only emerged as an autonomous chair, i.e. discipline, in the late decades of the 19th century. There are numerous reasons for this. Indubitably – as I will show – the establishment of pure paleontological data plays a fundamental role in the shaping of this discipline. But other social factors are important also. In fact, political and economical decisions facilitated the establishment of new professorships throughout Germany. One must bear in mind that the universities in Germany were restricted, on the one hand, by the promotion of a unity between teaching and research—the Humboldtian 'teaching-research' model—and on the other by the "intellectual power of the state." In my introduction, I have emphasized the importance of the former; I will now deal briefly with the latter.

It is difficult to do so however, since the economic-political situation[38] of the German states is complex. Following in part Charles E. McClelland, I differentiate between two periods where relations between government and academia were strictly maintained. Roughly between 1819 and 1840, universities were "beset by confusion and contradiction. It was an age in which universities had to work quietly under the watchful eye of political commissars […] yet it gave birth to the first generation of 'scientists'" (McClelland, 1980, p. 152) such as Bronn, Johannes Peter Müller (1801-

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[36] Zittel also noticed that "Munich University was the first in Germany to institute a full or 'ordinary' Professorship for Geology and Palaeontology." (Zittel, 1901) Martin even claims that the professorship of Paleontology in Munich was the first to be created. He asserts that "Die Tatsache, daß es bereits 1832 ganz offiziell einen Professor der Paläontologie an der Universität München gab, wird zumeist übersehen, wenn hervorgehoben wird, daß d'ORBIGNY 'bereits' 1853 den eigens für ihn geschaffenen Lehrstuhl für Paläontologie in Paris besteigen konnte und daß der paläontologische Lehrstuhl in Wien — als angeblich der erste dieser Disziplin in Mitteleuropa — 1873 errichtet worden ist."(Martin, 1965c, p. 8)

[37] Again Zittel reported that "in Austria and in Switzerland the majority of the more distinguished geologists and palaeontologists since the year 1820 have belonged to academic circles. The famous names of Eduard Suess, Ferdinand Hochstetter, and Melchior Neumayr are associated with Vienna." (Zittel, 1901)

[38] Industries also play a pivotal role in the shaping of epistemic things. For example, the growth of chemistry in German universities has been shaped by industrial necessities. What happened in Baden in the second half of the 19th century is a clear example. Reinhard Riese (1977) argues that the establishment of the Institute for Paleontology and Geology and especially a chair of Paleontology was difficult to implement since, during the same years, Chemistry and Physics had been asking a new institute and had priority, given the role they played in industry: "Die Erfolgsaussichten für das Projekt, im Etat 1896/97 eine solche Stelle zu beantragen, schwanden, als gleichzeitig Extraordinariate für mathematische Physik und organische Chemie von den o. Professoren der betreffenden Gesamtfächer verlangt wurden. Die traditionsreiche, in Heidelberg einst von Heinrich Georg Bronn gelehrte Paläontologie konnte ihren Prioritätsansprcuh gegenüber Chemie und Physik, deren Repräsentanten Quicke und V. Meyer einflussreiche Dozenten waren und auf die Bedeutung ihrer Disziplinen in Industrie und Technik verweisen konnten, in den kontroversen Fakultätsberatungen nicht behaupten." (Riese, 1977, p. 136)

1858) and Hermann Ludwig Ferdinand von Helmholtz (1821-1894). The second period is characterized by Prussia's growing supervision of German universities until, by 1870: "Prussia directly or indirectly controlled the policies of half the German universities from the 1870s onward." Outside Prussian control, only "Saxony, Bavaria, Württemberg and Baden had the resources to maintain first-rate universities" (Ibid.). These *Länder* had a huge interest in preserving their intellectual freedom from the Prussian central state: institutes, laboratories and professorships are powerful instruments promotional instruments for their respective countries. For example, "between 1850 and 1871 Baden spent over 450,000 gulden on the construction of new scientific institutes, an exorbitant sum for a small state […] Only Bavaria came close during this decade" (Ibid.)

Economic and political conditions are essential to understanding the development of a discipline. Munich became the most important centre for paleontology[39] in the world in the last decades of the 19th century. This was arguably owing to a desire to preserve and promote, its autonomy against the Prussian hegemony as embodied in the Humboldt University in Berlin. The instituting of outstanding professorships, laboratories, and institutes was a good means of attracting the best students from both Germany and abroad, thus drawing from the potential strength of other German states. In a letter to the Swiss paleontologist Charles David Mayer-Eymar (1826-1907), Zittel affirms in 1867 that "a substantial increase is established in the next budget by the ministry for the paleontological collection. This increase is approved by *Kammer* and therefore my finances are for the next are year quite secure."[40] (Zittel, 20.10.1867)

The institution of professorships of paleontology, however, does not mean that this discipline had found a definite place in the tree of knowledge. In fact, as above, paleontology belonged variously to geological and zoological institutions. It is nevertheless important to emphasize that paleontological professorships in continental Europe were established in that period. This implies that a collective enterprise was in place to define paleontology as autonomous, necessarily distinct from geological and biological sciences. The paleontological discipline has its data and although this may be applied to, and used within, other disciplines and contexts, that data

[39] Pompeckj confirms that this is the aim of the University of Munich. According to Pompeckj Zittel immediately realised what the paleontologist Moritz Hörnes said in 1866 about his hiring: "Durch Zittel wird die führende Rolle, welche Wien bisher auf dem Gebiete der Palaeontologie inne hatte, an München übergehen." (Pompeckj, 1904, p. 7)

[40] "In das nächste Budget ist nun allerdings eine sehr bedeutende Regie Erhöhung für di paläontologische Sammlung von Ministerium eingesetzt und wird dieselbe von den Kammern genehmigt, so sind meine Finanzen nächstes Jahr wieder ziemlich flott."

remains pure. They constitute the true starting points proper to paleontology. These and only these objects can endorse paleontological investigations, passed down from one generation to another.

Zittel's education and teaching

"Die Paläontologie hat längst aufgehört, sich als Lehre von den Leitfossilien ausschließlich in den Dienst der Geologie zu stellen. Sie ist allmählich zu einem selbständigen Zweig der biologischen Wissenschaften herangewachsen und nimmt an allen Bewegung und Strömungen der letzten Theil*."* (Zittel, 1897, p. 125) With these words, Karl Zittel opened his talk at the 6th International Geological Congress in Zürich, 1894. In 1894, Zittel status as a paleontologist was already realized. His masterpiece, *Handbuch der Palaeontologie*, had been published about twenty years before. He could therefore freely say what he meant under the label paleontology and geology, without fearing for his future academic career. The International Geological Congress was the right place to share his convictions on the nature of paleontology: paleontology as an autonomous branch of the biological sciences, and its stratigraphic age finished. Further, if the fossil record cannot mark an event in the past, it remains a useful tool for biological studies.

Zittel studied at University of the Heidelberg medicine and zoology under Heinrich Georg Bronn – as above. Zittel belongs to that group of scientists who began their academic career under the influence of Darwin's *Origin.* He obtained his Ph.D. in 1860 from Heidelberg and subsequently spent a year in Paris, going on to obtain his *Venia Legendi* in 1862 from the University of Vienna. In the Viennese period, he studied under Wilhelm Karl Ritter von Haidinger (1795-1871)—a talented mineralogist whose publications are characterized by extended and detailed descriptions of the inorganic world[41]—and, in particular, the famous Austrian geologist and paleontologist Eduard Suess (1831-1914). Having taught mineralogy at Karlsruhe for three years (between 1863 and 1866), Zittel took the only chair in Germany for Paleontology at the University of Munich, previously occupied by Carl Albert Oppel (1831-1865). Eduard Suess strongly supported Zittel's application. He wrote in letter on 10th January, 1865, "*Sie* [Wilhelm von Gümbel, the chief geologist in Munich] sollten, wenn Sie guten Ersatz für armen Oppel finden wollen, alle Anforderungen machen, um sich Zittel in Karlsruhe zu sichern, einen fleißigen und tüchtigen Paläontologen u., was fast ebenso vie list, einen herzensguten Cameraden. Er hat ein sehr Andenken hinterlassen." (Mayr, 1989, p. 14) Zittel was hired and, as Henry Fairfield Osborn reported, in those years "it is small wonder that Munich became the Mecca of paleontologists, young and old" (Henry Fairfield Osborn, 1904, p. 186). Many outstanding personalities would study in Munich under

[41] I would like to recall his *Anfangsgründe der Mineralogie. Zum Gebrauche bei Vorlesungen* (1829) and *Handbuch der bestimmenden Mineralogie* (1845).

Zittel. In 1885-86, Osborn himself "took a leave of absence from Princeton and studied in Zittel's laboratory." (Rainger, 1991, p. 34) In addition to the scholars already cited, we can also mention Wilhelm von Branca (1895-1928), Josef Felix Pompeckj (1867-1930), and Mario Canavari (1855-1928). Branca and Pompeckj would become professors of paleontology in Berlin some years later and although Canavari spent only one year in Berlin (1881), he was so impressed by Zittel that he decided to fund the Journal *Palaeontographica Italica* inspired by Zittel's *Palaeontographica*[42].

The historian Karl Theodor von Heigel (1842-1915) provides the following anecdoate in his memorial speech to Zittel. On the subject of his work:

> "Er [Zittel] wurde Mineraloge, und wen ein sonniger Tag ins Freie lockte, wanderte er über Berg und Tal, nicht mit der zerstreuten Neugier eines Naturschwärmers, sondern mit der Liebe zum Wissen, nicht als Spaziergänger, sondern als Sammler" (Heigel, 1904, p. 7).

Ever since the beginning of his career, Zittel had been a mineralogist and collector and those qualities provide foundation for his further work and teaching. Zittel mainly lectured on taxonomic paleontology and geology at the University of Munich. He was scheduled to lecture on "*Geologie, II. Teil (historische Geologie, Formationslehre)*", the summer semester of 1904 but he passed away prematurely. We can look to Richard B. Goldschmidt in his *Portraits from Memory* (1956); Goldschmidt also tells that Zittel's lectures were terrifically boring - essentially an enormous cataloguing of unknown fossils[43].

Zittel's Notion of paleontological Data

The structure and the methods of Zittel's lectures are reflected in both his books and papers. In the following, I will deal mainly with Zittel's *Grundzüge der Paläontologie*, arguing Zittel not only constructed but also spread pure paleontological data through the English-speaking countries through this textbook.

Zittel started drawing up his *Grundzüge der Paläontologie* in 1876. An updated version of his *Handbuch der Palaeontologie*, it immediately became the leading manual of paleontology at the end of the 19th century and at the beginning of 20th century. It was the "basis for most textbooks in

[42] This point corroborates my previous assertion: the constitution of a professorship for paleontology in Munich was also thought as a strategic move to attract students from Germany and abroad with the aim of increasing the prestige of Bavaria.

[43] August Rothpletz confirms this point. He reports that "Als Zittel im Winter 1867 auf 68 seine Vorlesungen begann, hatte er ganze 4 Zuhörer. Zwar hob sich diese Zahl bald auf gleiche Höhe wie bei Oppel [7-8 listeners], erreichte einmal sogar 14, aber das änderte sich in den ersten 10 Jahren seiner hiesigen Tätigkeit nicht wesentlich." (Rothpletz, 1905, p. 14)

invertebrate paleontology courses in the 20th century" (Schopf, 1972c, p. 23). *Grundzüge der Paläontologie* covers both vertebrates and invertebrates and "for each group, the morphology, geologic history and evolutionary relationships to other groups are shown with ample illustrations in the text."

As above, the importance of the book was felt not only in the German-speaking world, but also within the English community, following its revision and translation into English in 1903[44]. In reviewing the third volume of the book for *Nature*, which had just appeared in English translation, D. M. S. Watson writes "the 'Grundzüge' is the essential book to the working paleontologist, because it lists the great majority of genera of fossil vertebrates, indicating the more important synonyms and referring them to families" (Watson, 1946, p. 584).

Through the study of *Grundzüge der Paläontologie* the student is *ex abrupto* immersed in the complexity and the richness of paleontological data. In the preface to the first edition, Zittel points out that one of the main aims of paleontology is the realization of a natural systematic of morphological and phylogenetical observations[45], which may be applied within zoological and botanical systems. The natural systematic can—indeed—only be accomplished through pursuit of zoological and botanic methods. He goes further, characterizing paleontology as primarily

> "The science, which treats the life which has existed on the globe during former geological periods. It deals with all questions concerning proprieties, classification, relationships, descent, conditions of existence, and the distribution in space and time of ancient inhabitants of the earth, as well as with those theories of organic and cosmogonic evolution which result from such inquiries." (Zittel, 1900, p. 2)

The German and later the American student who opens the book and browses the index immediately receives the impression that paleontology is mainly a taxonomical and thus a descriptive discipline[46]. The book is an in-depth systematics manual for the major phyla that have appeared in the history of life. All the major phyla are patiently described and illustrated[47]. For

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[44] George Gaylord Simpson used the taxa collected in Zittel's Grundzüge to draw the survivorship curves for genera of, for instance, pelecypods and land carnivores. See (Simpson, 1944, p. 24)

[45] "Eine Hauptaufgabe der Paläontologie wird stets die Erzielung einer natürlichen, den morphologischen und phylogenetischen Erfahrungen entsprechenden Systematik bilden." (Zittel, 1876)

[46] The table of contents of the first edition is the following: Einleitung (p. 1), Systematik (p. 17), I. Stamm **Protozoa** (Urthiere) (p. 17), II. Stamm **Coelenterata** (p. 38), III. Stamm **Echinodermata** (Stachelhaeuter) (p. 112), IV Stamm **Vermes** (Wuermer) (p. 205), V. Stamm **Molluscoidea** (p. 208), VI. Stamm **Mollusca** (Weichthiere) (p. 250), VII Stamm **Arthropoda** (Gliederthiere) (p. 448), VIII. Stamm **Vertebrata** (Wirbelthiere) (p. 509).

[47] As I will argue in the following chapters and in the conclusion of this: in the end Zittel's data are the facts represented in the pictures.

instance, a typical entry of Zittel's textbooks is reproduced in figure 1. It describes the family of *Mollusca Bivalia Cardiniidae Zittel*. The entry offers an accurate image of the fossil and it is endorsed by a detailed description. The paleontological data are exactly such stabilized and represented images – not, then, incomplete and imperfect material fossils.

Hinter dem vorderen Muskeleindruck ein kleiner Fufsmuskeleindruck. In limnischen und brackischen Ablagerungen der Devon-, Steinkohlen-, Perm- und Triasformation.

Amnigenia Hall. Devon (Old red). Nordamerika und Rheinpreufsen.

Anthracosia King. (Fig. 635). Schale dünn, meist klein, länglich oval. Schlofsrand verdickt, jederseits mit einem stumpfen, länglichen Kardinalzahn und schwach entwickeltem leistenartigen hinteren Seitenzahn. In der produktiven Steinkohlenformation, im Rotliegenden und in den limnischen Permablagerungen von Rufsland häufig.

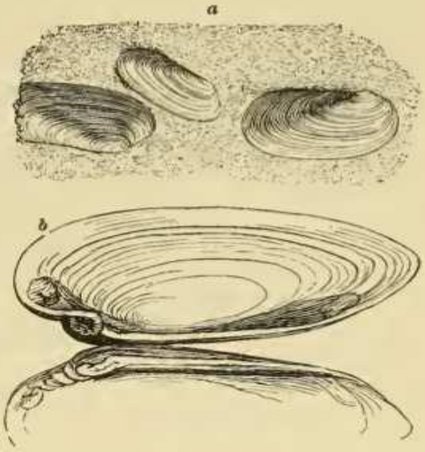


Fig. 635.
a Anthracosia (Unio) carbonaria Goldf. sp. Rotliegendes. Niederstaufenbach bei Kusel, Rheinbayern.
b Anthracosia Lottneri Ludw. sp. Steinkohlenschiefer. Hannibalzeche bei Bochum. (Nach Ludwig.)

Anthracomya Salter (*Nayadites* Dawson), *Asthenodonta* Whiteaves. *Carbonicola* M'Coy. Steinkohlenformation.

Palaeomutela Amalitzky (*Oligodon* Amal.). Schlofsrand mit zahlreichen, unregelmäfsigen Querzähnchen und Streifen bedeckt. In brackischen oder limnischen Mergeln der Permformation Rufslands.

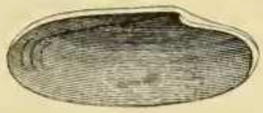


Fig. 636.
Anoplophora lettica Quenst. sp. Trias. Friedrichshall. (Nach Alberti.)

Anoplophora Sandb. emend. v. Koenen (*Uniona* Pohlig Fig. 636). Rechte Schale mit sehr stumpfem, dickem Schlofszahn, welcher sich in eine Einsenkung des linken Schlofsrandes einfügt. Linke Schale mit langem, hinterem Seitenzahn. Trias (Lettenkohle). *A. donacina* Schloth., *A. lettica* Quenst. sp.

2. Familie. **Cardiniidae.** Zitt.

Schale verlängert oder oval, glatt oder konzentrisch gestreift. Band äufserlich. Schlofszähne kräftig oder verkümmert. Hintere Seitenzähne lang, vordere kurz. Keine accessorischen Fufsmuskeleindrücke vorhanden. Nur fossil in marinen Schichten der Trias und im Lias.

Trigonodus Sandberger (Fig. 637). Oval bis trapezoidisch, hinten verlängert. Schlofsrand links mit einem starken dreieckigen, zuweilen gespaltenen Kardinalzahn, einem kurzen schrägen vorderen und zwei langen leistenartigen hinteren Schlofszähnen, rechts mit einem Schlofszahn, einem sehr kurzen schrägen vorderen und einem leistenartigen langen hinteren Seitenzahn. Trias, namentlich im Lettenkohlendolomit und in den Raibler Schichten.

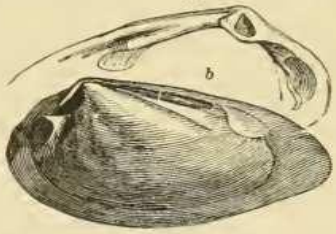
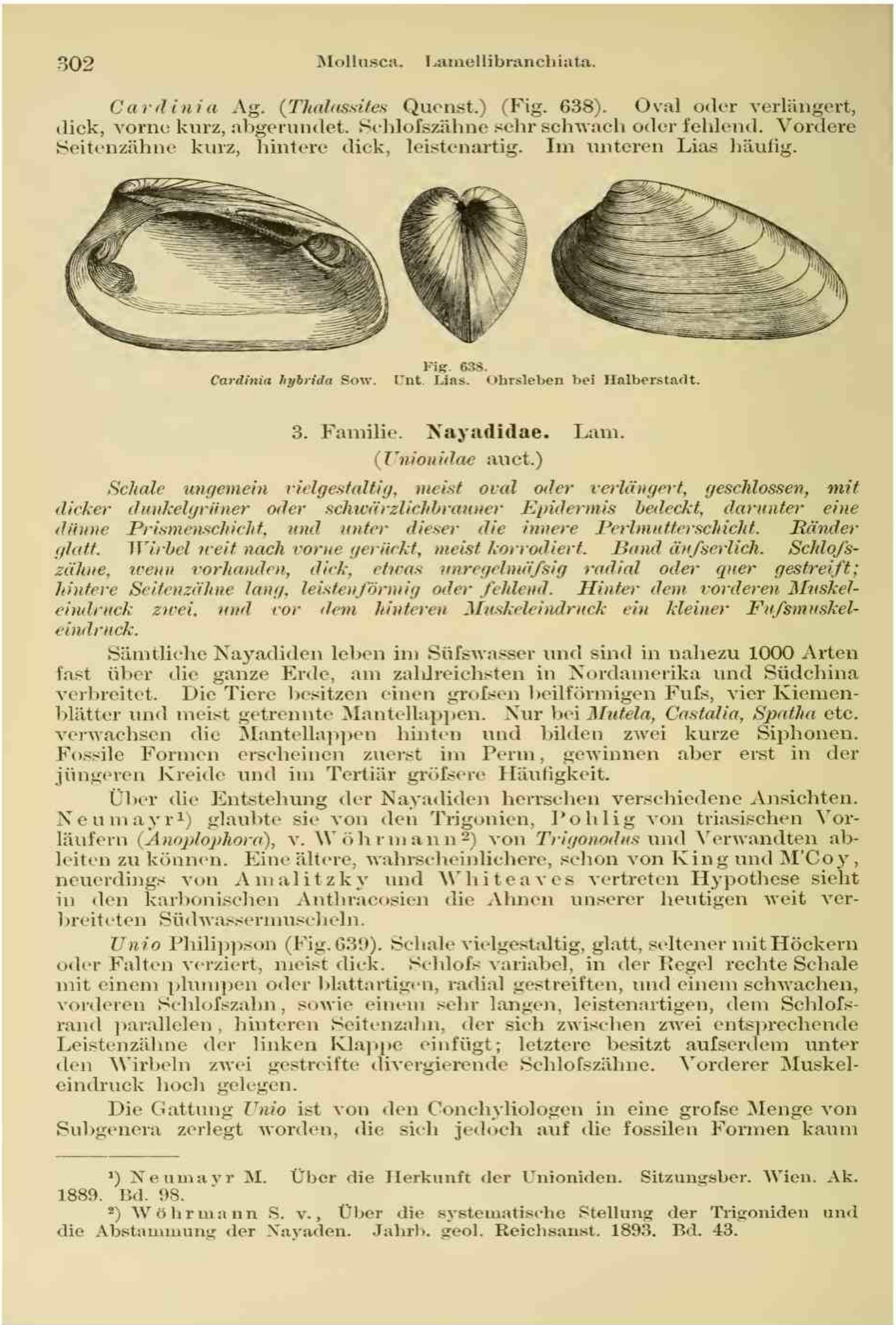


Fig. 637.
Trigonodus Sandbergeri Alberti. Trias (Lettenkohle). Zimmern, Württemberg. *a* Schlofs nach einem Guttapercha-Abdruck. *b* Steinkern. (Nat. Gröfse.)

Heminajas Neumayr. Trias. *H.* (*Myophoria*) *fissidentata* Wöhrmann.

Pachycardia Hauer. Länglich oval, fast dreieckig, konzentrisch gestreift oder glatt; Wirbel gekrümmt, fast terminal, sehr genähert; Vorderseite angeschwollen, steil abfallend, mit Lunula; Hinterseite verschmälert und etwas zusammengedrückt. Schlofszähne 2 : 2 kräftig, divergierend, der vordere rechts schwächer und fast marginal. Aufserdem ein verlängerter hinterer Seitenzahn in jeder Klappe. In der alpinen Trias. *P. rugosa* Hauer.



302 Mollusca. Lamellibranchiata.

Cardinia Ag. (*Thalassites* Quenst.) (Fig. 638). Oval oder verlängert, dick, vorne kurz, abgerundet. Schlofszähne sehr schwach oder fehlend. Vordere Seitenzähne kurz, hintere dick, leistenartig. Im unteren Lias häufig.

Fig. 638.
Cardinia hybrida Sow. Unt. Lias. Ohrsleben bei Halberstadt.

3. Familie. **Nayadidae.** Lam.
(*Unionidae* auct.)

Schale ungemein vielgestaltig, meist oval oder verlängert, geschlossen, mit dicker dunkelgrüner oder schwärzlichbrauner Epidermis bedeckt, darunter eine dünne Prismenschicht, und unter dieser die innere Perlmutterschicht. Ränder glatt. Wirbel weit nach vorne gerückt, meist korrodiert. Band äufserlich. Schlofszähne, wenn vorhanden, dick, etwas unregelmäfsig radial oder quer gestreift; hintere Seitenzähne lang, leistenförmig oder fehlend. Hinter dem vorderen Muskeleindruck zwei, und vor dem hinteren Muskeleindruck ein kleiner Fufsmuskeleindruck.

Sämtliche Nayadiden leben im Süfswasser und sind in nahezu 1000 Arten fast über die ganze Erde, am zahlreichsten in Nordamerika und Südchina verbreitet. Die Tiere besitzen einen grofsen beilförmigen Fufs, vier Kiemenblätter und meist getrennte Mantellappen. Nur bei *Mutela, Castalia, Spatha* etc. verwachsen die Mantellappen hinten und bilden zwei kurze Siphonen. Fossile Formen erscheinen zuerst im Perm, gewinnen aber erst in der jüngeren Kreide und im Tertiär gröfsere Häufigkeit.

Über die Entstehung der Nayadiden herrschen verschiedene Ansichten. Neumayr[1]) glaubte sie von den Trigonien, Pohlig von triasischen Vorläufern (*Anoplophora*), v. Wöhrmann[2]) von *Trigonodus* und Verwandten ableiten zu können. Eine ältere, wahrscheinlichere, schon von King und M'Coy, neuerdings von Amalitzky und Whiteaves vertreten Hypothese sieht in den karbonischen Anthracosien die Ahnen unserer heutigen weit verbreiteten Süfswassermuscheln.

Unio Philippson (Fig. 639). Schale vielgestaltig, glatt, seltener mit Höckern oder Falten verziert, meist dick. Schlofs variabel, in der Regel rechte Schale mit einem plumpen oder blattartigen, radial gestreiften, und einem schwachen, vorderen Schlofszahn, sowie einem sehr langen, leistenartigen, dem Schlofsrand parallelen, hinteren Seitenzahn, der sich zwischen zwei entsprechende Leistenzähne der linken Klappe einfügt; letztere besitzt aufserdem unter den Wirbeln zwei gestreifte divergierende Schlofszähne. Vorderer Muskeleindruck hoch gelegen.

Die Gattung *Unio* ist von den Conchyliologen in eine grofse Menge von Subgenera zerlegt worden, die sich jedoch auf die fossilen Formen kaum

1) Neumayr M. Über die Herkunft der Unioniden. Sitzungsber. Wien. Ak. 1889. Bd. 98.
2) Wöhrmann S. v., Über die systematische Stellung der Trigoniden und die Abstammung der Nayaden. Jahrb. geol. Reichsanst. 1893. Bd. 43.

Figure 10 Entry of the family Cardiniidae Zittel in Zittel's Grundzüge. From (Zittel, 1895c, p. 301)

Behind this representative method, or rather, behind this epistemic practice, Zittel wants to offer a notion of the fossil record quite apart from the quantitative and historical concept developed by Bronn. Although Zittel was a student of Heinrich Bronn at University of Heidelberg, he handled the fossil records without any numerical analysis. The key question[48] is, therefore: why did Zittel choose such a position?

It is difficult to give a definitive answer because that answer holds the nature of paleontology and the meaning of the fossil record at stake. As it emerges from biographical reports, it seems that Zittel was interested in mathematics and even had a "*mathemathischer Kopf*". So we can attempt to arrive at an answer through considering his education. As Fleck suggests, this provides useful insight. It is of importance that Zittel did not attend any cameral lectures in Heidelberg; he was however very well trained in collecting and classifying minerals, rocks, and fossils from his studies in Heidelberg and his time in Vienna. As I have shown in the first chapter, and with reference to paleontological data, cameral studies are essential to the development of a mathematical, historical approach. They require pre-comprehension of statistical tools. At the same time, they force the scholar to draw historical relations between data to arrive at etiological explanations.

Zittel also studied medicine in Heidelberg. In that period the Heidelberger faculty of medicine was a proponent of Friedrich Gustav Jakob Henle's ideas (1809-1885). Henle published an important article on medical science and empire in the *Zeitschrift für rationelle Medicin* in 1844. The paper aimed to delineate the structures of rational medicine by rescuing it from a probable and problematic knowledge based upon numerical techniques. Henle strenuously criticized the application of numerical methods to non-experimental sciences - as practiced by his rival Luis using "*numerische oder statistische Methode*" - and situated his rational medicine at the halfway point between theoretical and empirical methods[49]. Rational medicine does not derive its practices from an upper Principle, it focuses rather on particulars and tries through experience to acquire a valuable degree of knowledge[50].

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[48] I thank David Sepkoski for pointing this out to me.

[49] Henle's paper is fundamental because he also stressed the importance of the microscope for medical research. He asserts that, "*Die wichtigsten Thatsachen verdankt daher die Pathologie dem Gebrauche des mikorskops*" (Henle, 1844, p. 24). I will return to this paper in a few pages, because Henry Alleyne Nicholson studied zoology in Göttingen under Wilhelm Moritz Keferstein (1833-1870). He, in turn, studied medicine at Georg-August-Universität under Jakob Henle. I don't dismiss that Nicholson himself could have possibly attended some of Henle's lectures in Göttingen, because Henle was the director of the institute for anatomy until his death and his fame was worldwide. Thirty three years later, Nicholson celebrates the "immense benefit to palaeontology from the introduction of the microscope an absolutely indispensable instrument of paleontological research" (Nicholson, 1878, p. 5)

[50] Curiously to strengthen his argument, Henle provides an example of what should be done with the fossil record to obtain reliable information: "Wie wenig wüsste man von einem Fossil, wenn man sich mit dem Betrachten seiner Form und Farbe und mit dem Betasten seiner Oberfläche begnügte! Um mehr zu erfahren, ritzt man es mit

I can thus infer that Zittel's education was a potential factor in rejecting a quantitative approach to the fossil record. The question, nevertheless, remains: why did Zittel not use mathematics, i.e. pure relational connections among data, to study the fossil record?

Moving on from his education, an answer may lie in Zittel's concept of scientific truth. This chapter opens with the words Zittel used to characterize this: scientific truth is a relative and dynamical concept and it is extremely important to avoid metaphysical assumptions in order to deal with it. Between the end of the 19th and the beginning of the 20th century, this opinion was extremely widespread among scientists and philosophers: "Man war der kosmologisch-metaphysischen Spekulationen müde und setzte in die exakte Forschung die Hoffnung ad Natur". Consequently the scientific enterprise should be carried out "auf dem festen Boden der exakten Forschung", bearing in mind that "eine Erklärung der letzten Ursachen der Dinge […] entzieht sich der menschlichen Erkenntnis" (Heigel, 1904, p. 7).

This point is particularly interesting because statistics lies at the core of the exact sciences and a refusal of its method is indeed surprising. Nevertheless, it is necessary to bear in mind that Bronn had used statistics to discover patterns and laws in the temporal and spatial distribution of the fossil record. Due to their unstable and probable nature, Zittel considered them merely speculation and hence as something no longer acceptable. They were indeed perceived as similar to mythical theogonies as Schafhäutl asserted in his lecture in Munich. No matter if Bronn might be considered a forerunner—as Quenstedt asserted—of the theory of evolution in paleontological sciences and if the entry paleontology in *English Cyclopaedia* (1870) is entirely dedicated to Bronn's statistics; his method leads to dangerous conjectures and as such must be rejected. Bronn dealt with declarative statements—what happened in the past, and how—and these, on principle, are related to a changing notion of truth. in order to avoid metaphysical speculation, Zittel was forced to bracket off the paleontological static as well. In fact, Zittel knew perfectly well that the paleontological static is the first required step in order to declare what happened and thus to speculate on the causes of the temporal, spatial distribution of the fossil record on the earth's surface. Furthermore, he knew that the patterns derived from these mathematical treatments were only probable and therefore that subjectivity remained a feature [51]. The main consequence of such an un-metaphysical view is to

härteren Stoffen, zerstört es im Feuer, zersetzt es durch chemische Agentin. Etwas ähnliches ist nötig beim dem Studium der lebenden Natur." (Henle, 1844, p. 19)

[51] It is worth recalling again what Bronn wrote about this point: "wenn wir auch die Resultate dieser Vergleichungen mir mathematisch scharfen Ausdrücken hinstellen, Diess dennoch nur annähernde ungefähre Werthe nach dem jetzigen augenblicklichen Stande unsrer Kenntnisse sind […], dass das Bild, welches wir geben, sich auf die Summen der bisherigen Betrachtungen gründet, und dass neue Beobachtungen im Laufe der Jahre es sehr bedeutend

retain the security of a descriptive approach and to describe the structures of what can be seen in the petrified records[52]. As a result, paleontology aims to fix the referential burden. These descriptions could be written on various supports: handbooks, manuals, research paper, journals and even catalogues were reliable tools for spreading this idea of science through the paleontological community.

This approach is mirrored in Zittel's notion of paleontological data. As I have said, Zittel began his career reading Darwin's *Origin* and immediately understood the importance of paleontology for the theory of evolution. Paleontology could contribute to Darwin's theory if the paleontologist is able to both avoid conjectures and to create a notion of paleontological datum free from the speculation of historical geology. In fact, Zittel avoids the paleontological static because he sees it as a geological and speculative instrument only able to arrive at probable narrations of events. As such, he never taught it in his paleontological courses. In *Aus der Urzeit* (1871) Zittel is even more explicit. He asserts that "leider steht jedoch gerade die Geologie, jene Wissenschaft, welche sich vorzugsweise mit der Entstehung und Entwicklung der Erde beschäftigt, ziemlich hülflos da, wenn es sich um Ermittlung der ersten Zustande unseres Weltkörpers handelt." (Zittel, 1871, p. 1) If paleontology tries to narrate the first states of the nature, it is helpless. Therefore, it should not be meant as a theogony.

On the contrary, paleontology contributes to the theory of evolution by relying not on geology, but rather on systematics and phylogeny. By doing so, it is able to present an ordered set of facts upon which the theory of evolution can work. This is the crucial point in the coming into being of the notion of pure paleontological data. Such data are not conceived as possible narrations, but as stable facts pertaining to the theory of evolution. They are stable starting points for morphological and phylogenetic investigations. Zittel was very well trained in mineralogy and knew perfectly that the Linnean taxonomy could not be fruitfully applied to the inorganic kingdom. The application of taxonomical and phylogenetical methods to the fossil record implies a deep

umgestalten können, wenn auch viele Ergebnisse darin als für immer feststehend bereits betrachtet werden dürfen." (Bronn, 1849a, p. 137)

[52] Concrning this point, Christoph Beringer observes that "Das fossile Material lieferte also keine Stütze für das formale Abstammungsschema der herrschenden Theorien. Je mehr diese Erkenntnis durchdrang, desto zurückhaltender wurden die führenden Forscher. Typisch ist hierfür das Behalten von Karl Alfred von Zittel, der zwar die Deszendenztheorie als Grundlage aller biologischen Forschung anerkannte, aber statt mehr oder weiniger spekulativer Stammbaumkonstruktionen es vorzog, die fossilien Tiergruppen in Spezialarbeiten zu beschreiben und in seinem 'Handbuch der Paläontologie' zusammenfassend darzustellen" (Beringer, 1954, p. 125). This in turn entails an extreme caution in asserting which mechanisms guide the theory of evolution. See Reif with regard to this: "Zittel accepted the theory of descent but did not state whether evolution proceeded gradually or discontinuously. He spoke about selection theory and Lamarckian mechanisms but did not favour either side." (Reif, 1986, p. 93)

conviction of their biological nature[53]. By following this procedure, any sort of incommunicability derived from subjective practices in the representation of the fossil record can be avoided. It is therefore extremely important to only represent what is perceived in the rocks and to eschew arbitrary acts of interpretation. The contents of this perceptual activity are the perceptual morphological features of the fossil record. These are the of metaphysical essences which guarantee that paleontological data can survive the course of time; the stable form of this representation is in the end not so important, where the definition of the specimen, for instance, can always be modified. It is essential however to rule out the possible incommunicability among the paleontological community by preserving the connection between the represented fossil and its material record. In a letter, dated 03.01.1867, Zittel stressed this exact point to the Swiss paleontologist Charles David Mayer-Eymar: "for my part, I do not care much about names. If everything is correctly presented, it is does not really matter which symbol one chooses to come to an understanding with others"[54].

Zittel needed a medium whereby he might systematically order, represent, and spread the created version of paleontological things. He came up with the *Handbuch* and the *Grundzüge*, because textbooks and manuals can systematically create and easily spread such data among he scientific community. Both textbooks endeavor

> "to provide a general survey of palaeontological subject-matter in harmony with the modern standpoint of zoology […] throughout the entire work the primary object has been to point out the close relationships between paleontology and the other branches of biological science (zoology, comparative anatomy, botany, embryology) and to make application to paleontology of the data acquired by those sciences." (Zittel, 1901, p. 380)

A first conclusion can be drawn: Zittel conceived of paleontology as a systematic discipline that did not require quantitative tools to collect facts; he taught this approach to his students with his *Grundzüge der Paläontologie*. Consequently, he made a sharp distinction between historical geology—namely the history of the earth—and paleontology. The result is the *creation* of pure paleontological data. This data is then identified with sets of facts. By treating the fossils as descriptive data, Zittel decided to present a notion of the fossil record based upon an immediate

[53] On the relation between mineralogy, geology and historical geology see (Laudan, 1987).

[54] "Ich für meiner Theil lege sehr wenig Gewicht auf den Namen, wenn die Sache nur richtig gestellt ist, so kommt es am Ende sehr wenig darauf an, welche den Zeichnung man wählt, um sich mit anderen zu verständigen." (Zittel, 03.01.1867) This point entails two main consequences. On the one hand, it underlines the nature of objectivity sought by Zittel: it is important to correctly represent what one sees and to create an intersubjective agreement among the scientists. On the other, Zittel's sentence implies that the linguistic expression of the data is a pure conventional matter.

visual recognition of the specimen and not upon its historical dimension: paradoxically, he puts aside deep time, its narrativity, by focusing only on synchronic time. Zittel prefers to stress the importance of recognition and classification of extinct specimens, i.e. the importance of fixing a reference in the past, rather than controversial and geological techniques for quantifying this data. He thus follows Bronn only in collecting and cataloguing data, but not in using that data as events for a possible narration of the history of the nature. He avoided any attempt to declare what happened in the past.

In fact, in the preface to the first edition of the *Grundzüge*[55], Zittel asserts that the fossil record should primarily be understood as fossilized organisms; fossils should be treated only secondary as historical documents. This is a key statement, since it focuses on the biological weight of the fossils rather than on their geological meaning: the paleontologist uses the fossils primarily to identify, describe and catalogue ancient species. Only secondarily may he or she use them to reconstruct the geological history of the earth. Their meaning therefore lies not in their geological status, but in their biological, namely morphological, structure.

To sum up, Zittel was able to separate material objects, i.e. material fossils, from the event they might symbolize. This reacts against his former teacher; it also rejects the probable and incomplete conclusions about the history of life generated by a (con)fusion of object with event. Zittel transformed objects into data by representing them as ordered entries in his textbook. Subsequently, he identified data with a-temporal facts, thus establishing a secure foundation for paleontological science. Finally, he reinforced the connection between printed data and the material fossil: facts are based upon the perceptual morphological features of the objects found in the sedimentary rocks and exhibited in a museum. They share the same morphological structure.

Epistemological and ontological Consequences of this Coming into Being

The consequences of this coming into being are numerous: from both ontological and epistemological perspectives. From an epistemological point of view, Zittel suggests a paleontological map of knowledge, in which the fossil record is seen as a biological entity rather than in its geological-temporal context: the paleontologist may either explain the physiological features of the organisms or consider them as time markers. He may not treat the fossil record as both geological and biological entities at the same time. In other words, geological data is different from paleontological data and a sharp line must be drawn to separate the two. In both the *Handbuch* and the *Grundzüge*, Zittel underlines this in stressing the analogy as the most important epistemic

[55] "Die Versteinerungen sind in diesem Werke vorzugsweise als fossile Organismen behandelt, während ihre Bedeutung als historische Dokumente zur Altersbestimmung der Erdschichten nur in zweiter Linie Berücksichtigung finden konnte." (Zittel, 1895c)

tool. If paleontology is to provide biological insights into the classification of the ancient species, it can accomplish this only by an analogical process. The paleontologist has to compare the characteristics of fossils with those of living organisms to correctly describe and classify extinct life on earth. Only through analogies with living organisms, are paleontologists able to draw inferences about the nature of the extinct fauna.

The second epistemological consequence concerns epistemic access and the degree of knowledge related to the posing of such *explananda*. If the subject of the paleontological investigation is diachronically inserted in the flow of deep time (à la Bronn), even a minimal degree of certain knowledge is difficult to obtain. In other words, if paleontology uses an epistemic thing that is inseparable from the function it plays in the history of earth, the degree of knowledge it obtains is vey low because, as the paleontologist Henry Alleyne Nicholson put it:

> "the few thousand years of which we have historical evidence sink into absolute insignificance beside the unnumbered aeons which unroll themselves one by one as we penetrate the dim recesses of the past. […] Even speculation droops her wings in the attenuated atmosphere of a past so remote, and the light of imagination is quenched in the darkness of a history so ancient" (Nicholson, 1877, p. 9)

According to this extract, if even the light of imagination looses its power, we have very little hope of obtaining any satisfactory degree of knowledge. Yet by ruling out the diachronic factor we are able to use our imaginative powers to think analogically, and to infer the morphological structure of extinct fauna and flora – thus presenting facts for the theory of evolution. The passage from material object to data and successively to facts is based upon a deconstruction of the temporality: and thus data is rescued.

From a wider ontological point of view, Zittel is endeavoring the construction of the paleontological epistemic thing, or rather, he is bringing into being something that "had never existed anywhere in the universe" until 1870s, "at least not in a pure form" (Hacking, 2002, p. 14). He is breaking the distinction between stratigraphy and zoology (namely between invertebrate and vertebrate paleontology) to obtain an epistemic thing that is neither zoological nor stratigraphic. It is a fact, a pure relational and synchronic object.

Secondly, this construction implies a refusal of the time-dimension embodied in the fossil record and especially of the narrations possible from them. Pure paleontological data are no longer incomplete letters within the book of nature, and ours is no longer a reading project. On the contrary, we describe the relations between those words to re-establish facts for evolutionary theory. It is interesting to notice that the comparison between the fossil record and the incomplete letters of the book of nature is presented in the most part in historical geological studies [56] and not in the growing paleontological manuals of that period. The explanation for this change is simple: a text can be misleading and misinterpreted, whereas on the contrary, objects cannot lie. The paleontologist can erroneously perceive a feature of an object and he can be mistaken. But this is special case. It is a deviation from the normal perception: an erroneous perception presupposes the possibility of a correct perception. Even the tricky figures of Gestalt psychology stress the fact that objects cannot lie. For instance Rubin's famous vase can be perceived as a picture of two faces or as a vase. It cannot be perceived—for instance—as a rabbit. That means that even the tricky figures cannot lie: only the contents, which are presented *de facto* in these objects, can be perceived. The observer, in fact, has only two choices: the figure represents either a vase or two faces. Hence, the fossil record as proposed by Zittel is material rather than misleading fact.

Figure 11 Rubin's vase.

Data, Facts, and Events: epistemic Things and epistemic Virtues

Data are not facts and facts are not data. Their etymon and meaning is different. However, between the 1840s and the early 20th century paleontological data have been more and more closely associated with facts. The result was the coming into being of pure paleontological data. These can be intersubjectively communicated if they are established as facts written in manuals, textbooks, catalogues, and research papers. The paleontological epistemic thing is therefore the result of a layered process that transforms data into facts by removing vertical temporality. Before analyzing the extent to which the coming into being of the pure paleontological data has been established, it is important to shed light on the notion of data, facts and events in paleontology between the mid 19th and early 20th century. I will compare it with a particular kind of epistemic virtue, namely

[56] Zittel himself used this comparison in his *Aus der Urzeit*. He asserts that "die Buchstaben, aus denen ihre Geschischte zusammenstellt, warden undeutlchen und raethfelhafter"

objectivity. It is undeniable that one of the scientist's *telos* is objectivity. Therefore, this section concentrates on the relation between objectivity and the posing of paleontological facts. It is essential to understand how this epistemic virtue drove paleontologists "to rewrite and re-image the guides that divide nature into its fundamental objects" and to what extent these fundamental objects contributed to the creation and diffusion of this virtue among, at least, paleontology (L. Daston & Galison, 2007, p. 16).

I have argued above that Zittel may be considered the metaphysical founder of the coming into being of pure paleontological data, or rather paleontological facts. He was able to transform data into facts to support the theory of evolution and to open new insight into it.

The arguments so far provided allow me to bill paleontological data as pure, since this is now the source of identity for the establishment of paleontology as an autonomous discipline. The data provides a minimal identity for a discipline so far without any identity to speak of. The establishment of paleontological chairs in Germany and Europe was indeed a social manifestation of Zittel's creation. The purity of the paleontological data is, on the one hand, related to the mechanic objectivity that scientists and paleontologists had been seeking since the second half of the 19th century. On the other, it is connected with an attempt to obtain structural objectivity. This, in turn, was meant as the metaphysical *telos* able to overcome the subjective layers hidden in mechanical objectivity.

I will begin this section by engaging with what Daston and Galison meant by 'mechanical and structural objectivity' and proceed to connect these epistemic virtues with paleontological facts and data. "By *mechanical objectivity* we mean the insistent drive to repress the willful invention of the artist-author, and to put in its stead a set of procedures that would, as it were, move nature to the page through a strict protocol, if not automatically. (Ibid.) This epistemic virtue represents the natural meaning of the word 'objectivity', i.e. an aspiration "to knowledge that bears no trace of the knower – knowledge unmarked by prejudice or skill, fantasy or judgment, wishing or striving" (Ibid.). This epistemic *Streben* towards objectivity burst onto the epistemic scene at the end of 1830s - as represented in a different degree in both Bronn's investigations and in the collective empiricisms of Zittel.

Throughout his career, Bronn looked for strict protocols, or rather, pure mimetic means of representing nature. He even wrote manuals on how to gather, prepare and present animals, minerals and plants for museums (Bronn, 1838). His first concern was to collect facts or rather—as he learnt from his teachers—to discover those facts 'out there', in nature. He was not interested in drawing out a mythological *archetypus* from the visible, albeit incomplete, fossil record[57]. Instead, he aimed to reproduce the individuality of these specimens. Such reproduction is made possible only by constructing, i.e. synthesizing, the data itself: a paleontologist should borrow from the knowledge of other disciplines to discover, collect, and recognize his data. The observational data are then put to work within mathematical frames. As I have identified, this data is useful in two ways. On the one hand, it is essential to generate patterns that can bring to light natural laws; on the other, these patterns strengthen the observational inputs in order to obtain a higher accessibility to the fossil record and *a fortiori* a degree of objectivity. In this second sense, a mathematical treatment of the data participates in the creation of what has been called modern facts. Modern facts are "systematic-chronologic-diagnostic tables" (Schumacher, 1975, p. 77). They are based upon numerical representations and these, as Poovey has argued,

> "came to epitomize the peculiarity written into the modern facts […] as signs of (what looks like or passes as) counting, numbers seems to be simple description of phenomenal particulars and because the mathematical manipulation of numbers is governed by a set of invariable rules, numbers seem to resist the biases that many people associate with conjecture or theory" (Poovey, 1998, p. 5)

Facts in Bronn's systems are therefore stratigraphic tables. Their function is to count and to systematize the given materials. However, embracing *in toto* Poovey's conclusion on the absence of biased theories by posing modern facts is problematic. Although facts constitute the starting materials for Bronn's system and are obtained by mathematical treatments, conjectures and theories are not absent from these materials at all. Thus, the notion of *Tatsache*[58] in Bronn's system is at the same time modern and ancient. It underpins research for mechanical objectivity, but at the same time the mathematical framework does not preserve it from subjective and metaphysical conjectures. Metaphysical conjectures are not understood as an infinite search for mythological *archetypes*, rather as subjective and speculative conclusions about the history of life.

In Bronn's investigations, data are thus particular epistemic things. They are events that occurred in the deep past. They are based upon a material object (the material and recognizable fossil record) plus an occurrence in deep time. Following Peter Hacker's analysis, objects—as fossils—have at least three characteristics: they are located in a certain space, can be moved into another space, and are said to exist (Hacker, 1982). These perceptual features are fused with what is allegedly thought to be an event: an event simply occurs in a certain timespan. As a result, data are

[57] As Gliboff remarks "both [Darwin and Bronn] reasoned that the causes of organic change were ultimately to be sought in the changing external environment, rather than any internal law of development or the realm of transcendental archetypes of unfolding plans of nature" (Glidoff, 2008, p. 3).

[58] To avoid possible confusion, I translate Bronn's notion of *Tatsache* as *data*.

events that occur and exist at the same time. They are located in space, but at the same time indicate or take place in time[59]. Bronn's starting points are essentially events obtained through a rigorous statistical process of investigation. He can therefore use these as secure starting points for further analyses, given their non-subjective nature. Bronn supports a mechanical objectivity only in his point of departure. As soon as he tries a) to rely on data based upon material objects, and b) to obtain theoretical conclusions from these data, the sought objectivity becomes a subjective and speculative knowledge of nature.

A mechanical objectivity guides Zittel in his point of departure as well. He stresses in all his books and lectures that the meaning of the fossil records rests not in its diachronic referential power, but in its synchronical presentation. As Daston and Galison assert, "put conversely: Seductive as it might be to 'see as' this or that ideal, the premium for objective sight was 'seeing that,' full stop" (L. Daston & Galison, 2007, p. 122). The scientist, who is at the same time an artist who redraws what he sees, has to represent only what he directly perceives in the rocks. This entails excluding a subjective and thus uncertain temporal reference in his observational reports. He should not *see* the fossil record *as* an event. On the contrary, he has to describe what he perceives. This approach is reflected also in Zittel's autobiography: "Mechanical objectivity required a certain kind of scientist – long on diligence and self-restraint, scant on genial interpretation" (Ibid.) and Zittel, as Osborn reports, was not a genius, but a laborious and meticulous scientist (Henry Fairfield Osborn, 1904).

Zittel nevertheless understood that the power of mechanical objectivity is not enough given the incomplete and misleading material the paleontologist deals with. In fact, if the paleontologist relies only on a mechanical objectivity, space for subjectivism and metaphysical speculation is still left open (as Bronn showed). It was therefore important to follow the other sciences in pursuing a more radical version of objectivity "grounded in the structures rather than images as the only way to break out of the private mental world of subjectivity." (L. Daston & Galison, 2007, p. 254)

Mechanical objectivity is not radical enough: conjecture and unfounded theorizing still reside in the gaps of the material fossil record. The risk is a communications breakdown within the paleontological community - thus excluding this discipline from all epistemic discourse. The natural consequence was to accept a structural objectivity. This is able to contain any proliferation of the subjective and the metaphysical, limit incommunicability, within the paleontological community. This epistemic virtue is at first glance difficult to see. Indeed, structural objectivity refuses all kind of images and representations: "objectivity depended on structure alone; everything that pertained

[59] I will delve into the characteristics of the fossil record as an event in the fourth chapter.

‘not to structure, but to material, everything that is referred to concretely, is in the final analysis subjective’ – and hence unfit for science.” (Ibid.)

How is thus possible to seek this kind of objectivity in a science that is strongly founded upon images (both as visual things and as living-descriptive experiences)? I have already traced this answer historically in the sections above: it is made possible through pursuit of paleontological facts. Arriving at these facts, the paleontologist generates starting points epistemically and ontologically different from the data used, for instance, by Bronn or those that Gould would use some decades later. This is because, “facts are a mode of sifting and ordering what counts as experience” (See, L. Daston, 2005) and Zittel had another kind of experience which bracketed off every subjectivism.

The question is therefore: what constitutes a paleontological fact between the end of the 19th and early 20th century? To answer this question, I will focus on what kind of relation there is between objects, data (i.e. what counts as experience) and facts for Zittel’s *Denkstil*. Let us take Moritz Schlick’s (1882-1936) starting point – from his lectures at University of London, 1932:

> “I see a few black marks on white paper, and I know immediately that a good friend of mine has gone ashore in a far away country and has been thinking of me: these are two entirely distinct and different facts, there is apparently no similarity between them, and yet knowledge of the one conveys to me knowledge of the other. How is this possible? What peculiar relation is there between the two?” (Schlick, 2013, p. 172)

Mutatis mutandis, I see black marks on a page of Zittel’s textbook and I immediately see that this description is about a particular ammonite, which has certain morphological and ecological characteristics. How is this possible? How is it possible to connect material objects, data, and the facts presented in a catalogue? For Schlick, the relation between material objects, between what counts as experience (in the form of data) and the mode of sifting and ordering , comes down to an act of expression. That act of expression is able to share the structures of these distinct levels: “We say that one fact (the arrangement of little black marks) *expresses* the other (the landing of my distant friend)” (Ibid.). The characterization of this relation as an expression is useful in explaining the relation between epistemic virtue and epistemic unity in Zittel’s collective thought.

The starting point is the material object, i.e. the fossil record. It does not—ontologically—disappear in the flow of the deep time, since it has not been previously transformed into an event. The paleontologist can accordingly start constructing it as a stable and communicable fact. The move is made possible by strengthening what characterizes the mechanical objectivity. To avoid subjectivisms and incommunicability within the paleontological sciences, paleontologists need[60] to consider data as isomorphic - similar to facts because of a shared structure. As Ludwig Wittgenstein (1889-1951) asserts,

> "The gramophone record, the musical thought, the score, the waves of sound, all stand to one another in that pictorial internal relation, which holds exists between language and the world. the logical structure is common to them all. In the fact that there is a general rule by which the musician is able to read the symphony from the score, and that there is a rule by which one could reconstruct the symphony from the line on a gramophone record and from this again—by means of the first rule—construct the score, herein lies the internal similarity between these things which at first sight seem to be entirely different. And the rule is the law of projection which projects the symphony into the language of the musical score. It is the rule of translation of this language into the language of the gramophone record." (Wittgenstein, 2001)

There is a structural relation between what counts as experience and our mode of its representing it, because both share a general rule and behave identically with respect to it. Facts, objects, and data share a rule of vision based upon morphological and recognizable features. You can see that this material object is a trilobite, since there is a particular morphological relation between its parts. Conversely you can acquire a communicable picture of that material object (in the form of data), because you write it down in a catalogue (fact). The result is the that "whatever we may express, and in whatever way we may do it: nothing but structure can enter into our discourse, nothing else can be communicated" (Schlick, 2013). Schlick claims that you share the form of the fossil record with a community and not the content of your private perception of it. Zittel's step is thus addressed to the making of paleontological facts by starting from the morphological structures of what counts as experience, i.e. from what can be seen in the material objects. The product of this process is the coming into being of pure paleontological data, identifiable *in toto* with facts. Therefore, according again to Schlick, "wherever it is impossible or inconvenient to operate with the objects themselves, we replace them with signs which can be manipulated more easily and as desired" (Schlick, 1974, p. 59). These replaced signs are facts.

So far I have shown how Zittel was able to propose a way of overcoming the subjectivisms hidden in the identification of a material object with an event. By pursuing a structural objectivity, Zittel was able to see that the fossils can be used as data for epistemic investigations if they are structurally ordered. Facts are a mode of sifting and ordering what counts as experience and "it makes no sense to apply the term 'certain' and 'uncertain' to fact, a fact simply *is*." (Schlick, 1974, p. 121) Facts are thus neither certain nor uncertain. Moreover, they are neither true nor false, since a

[60] It worth emphasising again that this is a pragmatic attempt to institute paleontology as an objective and communicable science.

proposition can be true or false, but not the fact that underlies that proposition. Facts are therefore neither related to our beliefs nor to any truth value. Moving away from the Wittgenstein-Schlick approach so far used, I may claim that facts, as Zittel conceived them, are classifications based upon a convention and as such they are just convenient or inconvenient[61] . The paleontologists choose a particular aspect from among the different relations presented in the material fossil record and seek to generate a fact from it and about it. Consequently, facts are not found out there, on the contrary they are small theories made and set as conventions. Further, they are useful only so long as they are convenient[62]. Max Scheler makes the same point in his *Lehre von den drei Tatsachen*. He asserts that scientific facts are "*an erster Stelle 'Sachverhalte'*" (Scheler, 1933, p. 455), and that they are not given, but constructed and indirectly conceived.

The genesis and the making of paleontological facts are based upon an isomorphic relation, -expressed in the form of replaced signs presented in the taxonomic catalogue, and the material fossil record. The paleontologist chooses to privilege a particular kind of relation between the parts: morphological similarities, experiential qualities, and recognizable traits are preferred relational categories. The facts' function as time markers in the history of nature is rejected, since we are no longer talking about events. This generates an epistemic stability and enables the establishment of pure paleontological facts. Facts are free from the abyss of deep time and as such they are free from speculation, because they are based upon structures. The choice not to identify the material object with an event, has the advantage that this object can then be used without being considered a possible narration. What are givens, namely what counts as experience in the form of data, are thus the intersubjective and atemporal facts in catalogues and textbooks. Although they are not found out there—they are small theories—they need the morphological characteristics of the material fossil record as a metaphysical essence. This provides the last tangible foundation for paleontological investigation.

Conclusion

[61] See (Poincaré, 1913). This point is clearly visible in the notion of paleontological species derived from pure data. Nicholson asserts that "Many palaeontologists, therefore, prefer, as we think rightly, to follow the general practice of giving distinct names to 'varieties' and 'sub-genera' thus practically raising them to the rank of 'species' and 'genera'; and this practice can hardly be injurious if accompanied with the well-understood reservation that this is done *as a matter of convenience* [italics mine] only, and that a somewhat wider and looser signification is to be given to the terms 'species' and 'genus' in palaeontology than would be admissible in zoology."(Nicholson & Lydekker, 1889)

[62] As a consequence, paleontologists are able to define and redefine the fossils into catalogues. Definitions are only conventions: they are useful as long as they are convenient.

The conclusion of this chapter is twofold. First, by narrating the coming into being of pure paleontological data, I have shown how epistemic virtues are able to re-shape and re-write both *explananda* and data. However, data exceeds the epistemic virtue sought. Both Bronn and Zittel are, to different degrees, significant examples. To achieve a degree of objectivity, both had to reformulate, reshape, and redefine their data. Data itself, however, exceeds this hopeful aim. In Bronn's investigations, data is insufficiently redefined and reconstructed. Consequently he is led toward a sloppy metaphysical domain. For Zittel, the data's material characteristics forced a change of epistemic view: he rejects misleading images and unstable mathematical methods for applicable and conventional structures in the form of stable facts. Nevertheless, the fabrication of paleontological facts was not radical enough. Strictly speaking it was not a fabrication (à la Nelson Goodman) at all. Zittel standardizes the making of facts in textbooks, manuals, and lectures, but he relies again on material, imperfect data. These are merely observational expressions of patchy, incomplete, and material objects. What counts as experience for Zittel is shared by those scientists who work in the field: there is an absolute identity between the propriety of the material object and that of the epistemic data. Zittel was not able to create new ontological starting points; he relied completely on the materials offered by observation. This provides the required essence to connect the material records with the textbook entries. Therefore, an obsession would capture scientists' self: if data and facts share the same material structure, they are incomplete and imperfect exactly as the material fossil record. This question would become central to the paleobiological movement and force scientists to come up with epistemic tools to ontologically construct new epistemic entities.

The second conclusion concerns the relation between data and facts. Although facts are not identifiable *in toto* with data, as Dan Rosenberg has recently argued (Gitelman, 2013), there is a continuity between the notion of data and of facts. Zittel stressed this continuity even going so far as to identify paleontological data with facts. Both data and facts are processes and as such are subject to a lifecycle: they come into being, they have a developmental phase, in which they are able to furnish epistemic/ontological functions, and inevitably they pass away. This cycle is influenced by many factors (for instance pedagogical, social, economical, practical, philosophical, ethical and so forth). In fact, I have argued so far that the coming into being of pure paleontological data and facts occurs to the detriment of the temporal narrativity of the fossil record, from at least three perspectives: pedagogical, social and philosophical.

Having here clarified the relation between data, facts, and objectivity in the crucial span of time between the mid 19th and the beginning of the 20th century, I can now investigate how and to what extent this coming into being was established.

Chapter III. A Strenuous Effort of Thought: Zittel's Legacy

Introduction

I have shown so far that Zittel assimilated paleontological data with facts—to the detriment of the temporality of fossils. This enabled Zittel to identify paleontological data with paleontological epistemic things. In terms of their materiality however, those epistemic things remained imperfect and incomplete. By bracketing off deep time, paleontologists removed the fossil record from its vertical dimension, but it nevertheless remained an incomplete and imperfect material object. Although it could now be treated as a datum, i.e. as a starting point in an epistemic process, its material and recognizable features persisted. This point is particularly interesting. Paleontological data could thus function as starting points for further epistemic investigations where they are identified with facts gathered, written, and discussed in textbooks, catalogues, lectures or research papers. Through this process the vertical dimension of time is bracketed off in order to secure paleontology from metaphysical speculations. At the same time, however, paleontological data becomes the paleontological *explananda*. Hence, there is an exchange between data and explananda: paleontological data are both starting points and the material to be explained.

The concept of pure paleontological data was developed initially in German-speaking countries and subsequently spread through the international scientific community. The petrified object is lifted from a temporal, i.e historical context – preserving, nevertheless, its historicity. This object is the metaphysical essence of the paleontological data[63], since the representational work of the paleontologist is based *in toto* upon what he can see and recognize in the morphological structure. Data would subsequently be identified with facts to protect them from metaphysical conjecture. As a consequence, the characteristics and biases present in the material objects ontologically influence the paleontological data and what can be done with them.

In the previous chapter, I have shown how the establishment of the paleontological epistemic thing, metaphysically embodied by Zittel, was able to open a space for representation in which the union of vertebrate with invertebrate paleontology gained validity. By identifying the fossil record as an epistemic object that represents only a point of time and not an entire segment, paleontologists developed catalogues (not meant however as stratigraphic charts) to indicate the conditions of the ancient species. The value of this classification, however, is not limited to a mere practice of description, but, as Nicholson has put it, leads to a collection of facts that can be used to accomplish "certain general deductions." (Nicholson, 1877, p. 367) The paleontological epistemic

[63] For the justification of this claim, see chapter 7

thing is thus a set of facts based upon the material features of the fossil record. As a result, it supports broader biological reasoning.

However, the deductive practice, or rather, the theoretical approach would be taken into account only sixty years later with the complete destruction of the materiality of the fossil record. Paleontological facts are nonetheless material objects, since they are based upon data directly derived from observations and as such are imperfect and incomplete. This materiality does not enable certain general deductions because the material fossil record is always imperfect and incomplete. The first half of the 20th century was characterized by a strenuous effort to overcome these aspects, made possible only by an ontological construction of the paleontological data – opening up the required space for a theoretical treatment of the fossil record. In this chapter, I will show the effects of the coming into being of the paleontological thing as read through Zittel's paleontologist contemporaries and the paleontological community of the early 20th century (pre-1940s): I will investigate how and to what extent this coming into being was established. I will commence with analyzing three case studies: Nicholson's works (1872; 1877; 1889), Neumayr's *Die Stämme des Thierreiches* (1889), and Stromer's *Lehrbuch der Paläozoologie* (1907). Zittel influenced all directly and they contributed in turn to shaping the features of paleontological data. I will proceed to illustrate the acceptance of Zittel's notion of the fossil record by American paleontologists during the first half of the 20th century. I will argue that the identification of fossils with atemporal fact was one of the causes of the paleontological "crisis of identity" (D. Sepkoski, 2012, p. 52). By equating invertebrate with vertebrate fossils, Zittel unified *de facto* them leading to a crisis in those disciplines' respective aims and functions.

This chapter provides a picture of paleontology until the years immediately preceding the 1970s paleobiological revolution. It does so by tracing the notion of paleontological data over this period. I will argue that paleontology was a science that was able to fix the reference of extinct biological entities by studying and classifying both vertebrate and invertebrate fossils. This activity ensures paleontology an epistemic status, but equally implies an admission of guilt: paleontology as ill-equipped to discuss the mechanisms of evolution. It is only able to collect data and facts concerning deep time.

Zittel's Paleontological Data at the End of 19th Century

My claims should not be misunderstood. Zittel was only the *metaphysical* founder of pure paleontological data – in the way Galilei or Newton were for their disciplines[64]. That means that he set the criteria for reading, establishing and producing these data. A wider collective enterprise was instituted in the construction of paleontological data between the end of the 19th and the beginning of the 20th century. Among others, Henry Alleyne Nicholson (1844-1899) played an active role in this. I have briefly mentioned him above, but will return here in more depth.

Nicholson is the typical international scholar of the second half of the 19th century. He studied in Göttingen and Edinburgh. He became professor of natural history at the University of Toronto and afterward professor of biology at Durham College of Science and at the University of St. Andrews. As mentioned, he studied under Keferstein in Göttingen, who was deeply influenced by Henle during that period. In the first edition of his *A Manual of Palaeontology* (1872), Nicholson tells us that he is going to "restrict himself entirely to those facts which are absolutely necessary to any one who would study Palaeontology as a department of science, sufficiently distinct to stand alone" (Nicholson, 1872, p. v) and in the second edition (1889) he is even more explicit by claiming that "there is, perhaps, no branch of Biology which in recent years has advanced so rapidly, and, on the whole, so surely and in so many directions, as has Palaeontology." (Nicholson & Lydekker, 1889, p. v) Nicholson sums up the aims of this book claiming that the "Author has endeavored to furnish a summary of the more *important facts* of Palaeontology regarded in its *strictly scientific* aspect [emphasis added]" (Nicholson, 1877, p. V) In both the first and second edition, Nicholson differentiates the paleontological record from the geological one. He thus poses a room for studying the former: paleontological data constitute the facts of evolutionary theory. Paleontology as a rigorous and independent discipline is able to gather and deal with these facts. It is worth noting that he does not use the metaphor of the fossil record as a book of nature - thus stressing the different features of the new data.

However, the most explicit evidence to suggest that pure paleontological data were *de facto* used and sought, can be found in Nicholson's *The ancient Life* (1877). The subtitle of the book is significant: the book provides "a comprehensive outline of the principles and *leading facts* [my italics] of the palaeontological science". Nicholson asserts that the study of paleontology "may be pursued by two parallel but essentially distinct paths" (Nicholson, 1877, p. v). These respectively

[64] As Alexandre Koyré claims "Modern science did not spring perfect and complete, as Athena from the head of Zeus, from the minds of Galileo and Descartes. On the contrary, the Galilean and Cartesian revolution – which remains nevertheless a revolution – had been prepared by a strenuous effort of thought".

represent historical geology—or as Nicholson puts it, historical paleontology—and paleontology. He then goes further, stressing the main difference between the two distinct approaches:

> "by the one method of inquiry, we may study the anatomical characters and structure of the innumerable extinct forms? of life which lie buried in the rocks simply as so many organisms. with but a slight and secondary reference to the *time* at which they lived. By the other method, fossil animals are regarded principally as so many landmarks in the ancient records of the worlds, and are studied *historically* and as regards their relations to the chronological succession of the strata in which they are entombed" (Nicholson, 1877, p. v)

The difference between paleontological data and historical data consists in the role played by time[65]. Paleontological data is no longer affected by deep time, or rather, deep time only partially composes the ontology of this epistemic thing. In fact, the data is presented synchronically and not diachronically. The entire collective thought centered on Zittel shares and strengthens this conclusion. Neumayr's invertebrate paleontology also supports my claim.

Melchior Neumayr (1845-1890) offers another outstanding case study highlighting how the paleontological epistemic thing was established. Neumayr was born in Munich and started studying law in the same city in 1863. After a few semesters, he changed faculty to natural sciences, studying under Albert Oppel and Wilhelm von Gümbel (1823-1898)[66]. He studied afterwards at Heidelberg, where he took his Ph.D and *venia legendi*. He moved then to Vienna and—after working at the Australian *Reichsanstalt*—took the professorship of Paleontology (the first chair in Austria, as above) at the University of Vienna. Neumayr is an interesting case study, because his is a layered notion of the fossil record. In his *Erdgeschichte* (1885), he treats the fossil record as source of evidence for evolutionary narrations. This notion of data is deeply influenced by Oppel and I will deal with it in the fifth chapter. He realized that the fossil record should be defined and treated as a valuable set of facts for evolutionary theory. As Zittel wrote in Neumayr's obituary, after his *Erdgeschichte* Neumayr began to collect facts and observations for his lifelong task. The result of this collection is the publication of *Die Stämme des Thierreiches* (1889), in which he deals with

[65] Also in the second edition of *A Manual of Paleontology*, Nicholson and Lydekker asserted that "the methods of palaeontological study are precisely the same as those of Zoology and Botany. It is true that the earlier palaeontologists attached a certain importance to the age of a fossil, as bearing upon the determination of its affinities, and that it was sometimes assumed that fossil deposits of different geological ages were necessarily referable to different specific types. At the present day, however, it is recognised that the systematic position and relationships of an extinct organism must be settled by an appeal to its morphological characters, altogether or to a great extent irrespective of the age of the deposit in which it occurs." (Nicholson & Lydekker, 1889, p. 82)

[66] I will extensively return to Oppel and Gümbel in the next chapter.

invertebrate fossils[67]. These are allegedly considered the source of information for stratigraphic and geological studies. However, in accordance with Zittel, he explicitly asserts that

> "Die Paläontologie befasst sich mit der Untersuchung der Hier- und Pflanzenwelt, welche vor der Jetztzeit auf der Erde gelebt hat. Bei der Untersuchung der Thierreste, [...] geht dieselbe nach den gleichen Grundsätzen vor, welche in der Zoologie nur Anwendung kommen, und steht mit dieser Wissenschaft in innigstem Zusammen hange, so dass eine scharfe Trennung beider Gebiete kaum möglich ist. [...] Die Scheidung zwischen der Jetztzeit und den früheren Abschnitten der Erdgeschichte ist in vieler Beziehung eine ziemlich willkürliche [...] Wo liegt hier die Grenze, bei der man sagen kann, die Thierreste der älteren Ablagerung gehören noch dem Paläontologen zu, die der jüngeren dem Zoologen? Hier verschwimmen die verschiedenen Gebiete ineinander und dieser Umstand lässt uns deutlicher als irgend ein anderer die innige Verbindung der Paläontologie mit Zoologie und Botanik erkennen." (Melchior Neumayr, 1889, p. 2)

According to Neumayr, it is impossible to draw a clear division between paleontology and zoology (and it is worth recalling that in this book he is working with invertebrate paleontology) because any distinction between the two temporal dimensions (deep past and present) is quite arbitrary[68]. This entails the removal of fossils from the abyss of deep time and seeing them in relation to modern fauna. In other words, Neumayr accepts both the loss of the narrativity of deep time and an atemporal treatment of fossils as Zittel proposed. The epistemic thing in invertebrate paleontology is exactly the same as in vertebrate paleontology: an a-temporal set of facts.

Neumayr goes further asserting that zoology and paleontology "bedingen bei aller Verwandtschaft des Gegenstandes doch eine tiefgreifende Verschiedenheit zwischen den Untersuchungsmethoden der Palaeotologie und denjenigen der Zoologie" (Ibid.). Paleontological and geological objects are thus related to each other as a result of the exclusion of the deep time narration within the paleontological field. Nevertheless, the zoologist deals with complete, perfect data, whereas paleontological data[69] is always incomplete and "mit Ausnahme überaus seltener,

[67] Wolf-Ernst Reif describes "The book's 150-page introduction [as] probably one of the best treatises on Darwinism to be found anywhere in the literature of the nineteenth century" (Reif, 1986, p. 89), and Zittel asserts that "Neumayrs Studienergebnisse auf diesem Gebiete zu den solidesten Stützen der Descendenztheorie gehoeren" (Toula, 1890, p. 316) I will return to this marvelous book and Neumayr's theory of evolution in the following chapters.

[68]. It is interesting to note that this remark is proposed in a manual of invertebrate paleontology. Willam Twenhofel and Robert Shrock in their *Principles of Invertebrate Paleontology* (1933) flag the same point.

[69] Nicholson and Lydekker emphasise the same point: "in some respects, however the zoologist has a great advantage over the palaeontologist. The student of living beings can investigate the entire organism, the soft parts as well as the hard; and he can also study the 'development' of the organism, and by tracing it through its early stages can discover how it came to assume its adult characters. The student of fossil organisms, on the other hand, is restricted, with the rarest exceptions, to an investigation of the hard parts only" (Nicholson & Lydekker, 1889, p. 83)

vollständig vereinzelter Falle gehen alle Weichteilen verloren, nur die Hartgebilde können sich erhalten." (Ibid.)

Neumayr's invertebrate paleontology therefore constitutes another aspect of Zittel's collective thought. Neumayr shares with Zittel the conviction that there is no separation between vertebrate and invertebrate paleontology, if fossils are no longer time-markers. In the making of new paleontological epistemic things, deep time has been put aside. This entails a closer relation between paleontology and zoology. This relation—and this is worth reiterating—is not the same as that posed by Bronn. The historical dimension is abandoned in Neumayr's investigation. In other words, history has a pivotal role, but it has to be correctly framed.

To introduce the last case study I will begin by narrating the success and diffusion of a particular series as featured by B. G. Teubners's publisher: famous and very well-known and specializing in mathematics and natural sciences. In 1908 a new series appeared in its catalogue: '*Naturwissenschaft und Technik in Lehre und Forschung*', edited in chief by Doflein, professor of Zoology at Munich, and Fischer, professor of Physics also at Munich. The aim of this series was to support the scientific spirit of that year. The editors' aim was to fight what they saw as a vulgar popularizing of the natural sciences[70] through developing a series of handbooks and textbooks providing a pure objective clarification of the problems and achievements of the discipline. This series is divided into two main subject groups: the first, Physics and Chemistry, edited by K. T. Fisher. The second, directed by Franz Doflein (1873-1924), brings together biology and the history of the earth. The description of this second group is very significant, because it shows that paleontological facts forced the publisher to re-think their series and textbook contents. The textbooks of this second group aimed to cover what has been previously named "*beschreibenden Naturwissenschaften"*. Their aim was to elucidate the required evidences of the laws that control the variety of forms of living beings. To achieve this aim, the textbooks "sollen dem Leser Tatsachen bieten, nicht ein künstliches Weltbild, welches nur durch Hypothesen zusammengehalten wird. Das ist gerade auf dem Gebiete der Biologie besonders notwendig". Biological and geological sciences should research and gather facts, instead of producing artificial and spurious worldviews. The editor should publish those books conforming to this epistemic virtue. This point is reflected in the structure of the textbooks edited by Doflein: "deswegen ist es erforderlich, dass in der Darstellung eine strenge Scheidung von Tatsachenmaterial und Theorien durchgeführt wird" The

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[70] "Die Sammlung von Lehr- und Handbüchern will gegenüber einer verflachenden Popularisierung der Naturwissenschaften und einer Überschätzung der Resultate einzelner Zweige derselben eine gediegene sachliche Klarlegung ihrer Probleme geben und die wirklichen Errungenschaften der exakten Wissenschaften aufdecken." (Teubner, 1908, p. XXXV)

first textbook of this series was *Einleitung in die experimentelle Morphologie der Pflanzen* (1908) by K. Goehel. The second one was *Lehrbuch der Paläozoologie* (1909) by E. Stromer. Karl Heinrich Ernst Freiherr Stromer von Reichenbach (1871-1952) offers the last case study of this section.

Ernst Stomer studied natural sciences in Munich and Berlin. Under Zittel's suggestion and supervision, he wrote his Ph.D. on the critical geological exposition of the German protectorate in Africa. Stomer obtained his *venia legendi* in 1908 and a professorship for systematic paleontology in the same year. I will briefly focus on his *Lehrbuch der Paläozoologie*, as temporally related to Zittel's positing of pure paleontological data. This provides a valid source of information. In fact, as I am arguing in this section, Zittel's enterprise remained fundamental during the first decades of the 20th century: in the first part of the textbook, Stomer refers to Zittell's *Handbuch* as "welches das ganze paläozoologische Wissen des letzten Drittels des 19. Jahrhunderts in übersichtlicher, auf modernen zoologischen Anschauungen beruhender Weise zusammenfaßt." (Stromer, 1909, p. 3)

The textbook deals with both invertebrate and vertebrate fossils[71] and begins by claiming that it will offer an introduction to pure paleozoology. There is indeed a pure paleozoology, i.e. a discipline that has its own data and structures, and this discipline needs a dedicated introduction that can rule out metaphysical and artificial speculation. To achieve this, it is essential to choose the correct starting point - as Neumayr and Nicholson have done:

> "[Ich] bin in der Regel von den lebenden Formen zu den geologisch älteren vorgegangen, weil ich für richtig hielt, vom gut Erforschten zum weniger Gesicherten zu führen, da die älteren bekannte Fauna doch keineswegs eine ursprüngliche ist, und die stammesgeschichtliche Betrachtung noch zu wenig gesicherte Resultate ergibt, um in einem Lehrbuche anders als im Anhang und mit größter Vorsicht geübt werden zu können." (Ibid.)

Since the phylogenetic treatment of the ancient forms is still unsecure and it can consequently lead to dangerous speculation, the required starting point is given by what can actually be observed in the living forms. This point should not be misunderstood. In fact, the difficulties are not related to Darwin's theory *per se*, but rather to the analogical reasoning that provides too weak foundation for paleozoological science. Deep time has a destructive power and it is possible that "noch weitere wesentliche Bedingungen erheblich anders waren als in der Gegenwart. Deshalb verlieren Analogieschlüsse immer mehr an Sicherheit und Geltung, je weiter man sich von ihr entfernt" (Ibid.) The vertical dimension of time is destructive and causes our analogical reasoning to lose its certainty. Consequently "kann der Paläozoolge keine direkten unzweifelhaften Beweise für die

[71] The section on the vertebrate fossil record would be published only in 1912.

Richtigkeit der Entwicklungstheorie liefern, sondern höchstens Wahrscheinlichkeitsbeweise." (Ibid.) In the deep past, paleontology can achieve only probable conclusions.
To overcome this stalemate, the paleontologist should not deal with the vertical dimension of time, but should consider the fossil record in its horizontal dimension, thus as facts:

> "Die größte Bedeutung hat aber die Paläozoologie für die Stammesgeschichte (Phylogenie), denn sie allein ist imstande, direkte Beweise für die einstige Existenz der Ahnen der jetzigen Tiere beizubringen und uns über deren Bau und Lebensweise, räumliche und zeitliche Verbreitung aufzuklären." (Ibid.)

As Zittel suggested, paleontology deals with the existence of our ancestors by drawing out their vertical dimension, namely their temporal and spatial dimension. Textbooks, lectures, *Leitfäden*, and catalogues are not the only way to promote the posed notion of paleontological data. Journals are another important form of transmission. Both Bronn and Zittel became editors of two important journals. Bronn directed the *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde* between 1833 and 1863; whereas Zittel edited *Paleontolographica* between 1867 and 1904. This entails a wider control of the publications and leading research in the paleontological area. In the next section I will briefly analyze these two journals and discuss their contributions for the establishment of paleontological science.

Palaeontographica and Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde

Zittel's inheritance can be further analyzed by studying the contents and structure of two of the most important paleontological journals of the 19th and 20th centuries: *Palaeontographica* and *Neues Jahrbuch*. Both published papers and contributions by pre-eminent paleontologists and naturalists and share a common origin. The 19th century was witness to a specialization of the sciences, generating a need for print coverage. Karl von Leonhard responded to this in 1806, founding the *Taschenbuch für due gesamte Mineralogie, mit hinsicht auf die neuesten Entdeckungen*. Georg zu Münster, a fossil collector in Bayreuth, then founded the *Beiträge zu Petrefactenkunde* in 1838. These journals provide foundation for the subsequent publications *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde* (1833), and *Palaeontographica* (1846). They supplied a gap in the literature, in a period where the collection of data steadily increased.

Both journals share another feature: both were, and still are, published [72] by *Schweizerbart'shce Verlagsbuchhandlung*, Stuttgart. This publisher focuses on natural sciences,

[72] Schweizerbart starts publishing Palaeontographica in 1885; whereas Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde has been part of the Schweizerbart's catalogue since 1833.

particularly paleontology and geology[73], and could offer the wide distribution required by the journals.

Neues Jahrbuch für Mineralogie was the most important 19th century geological journal in the German language. Almost every geological-oriented naturalist contributed to it. As the title suggests it accepted contributions in paleontology, geology, and mineralogy. This fits perfectly with Bronn's idea of science. As I have shown, his investigation is characterized by a synthetic approach and the opportunity to edit an all-embracing geological journal gave him the required material to construct his system. For Bronn science is a complex unity and should be pursued only by bringing different perspectives to bear on the explananda. This outlook continued after Bronn and Leonhard's death, with the tenure of three editors with paleontology, mineralogy and geology specialisms. Under their direction, these disciplines feature more strongly. We can see that studies dedicated to paleontology were not so numerous. I have calculated that between 1833 and 1863 only 18% of the papers published dealt with paleontological topics[74]. In addition to the limited space dedicated to the description and the study of the fossil record, the other important particularity is that the journal offers only limited possibility for illustration of the fossils..

This last feature is essential to understanding the further development of paleontological science. *Palaeontographica* was a reaction to the absence of illustrations and descriptions in palaeo-geological journals[75]. As the name suggests, it aims to "depict and describe new or only marginally known fossils" (Hass, 1997, p. 4), indicating that among paleontologists there was great need to share their sightings with maximum precision. This may be seen as a consequence of the structural objectivity they were seeking. Paleontological perceptions had to be codified and the journal

[73] I would like to mention that the publisher's first publication was indeed a geological book: *Versteinerungen Wüttembergrs* (1829-1833) edited by C. H. von Zieten.

[74] Overall, 725 papers were published in the section *Mitteilungen* between 1833 and 1862. Among them, only 129 dealt with vertebrate, invertebrate or plant fossils.

[75] Wolfhart Langer stresses the uniqueness of the Journal. He asserts that Palaeontographica was not only the sole journal able to offer reliable illustrations of the fossil record, but it also had international (rathr than national) pretensions. A natural consequence of this policy was the relatively expensive price of the journal and thus a difficulty selling its subscription. The price was fixed after strenuous negotiations at 45 Reichsmark (see. (Hass, 1997)). Under Zittel's direction *Palaeontographica* not only dealt with fossils from the entire world, but impressed its public so much that the Italian paleontologist Mario Canavari decided to found an Italian version of the journal in 1895. Canavari's *Palaeontographica*, however, had the same financial troubles as the original German version. In a letter to Charles Mayer, Canavari underlines the difficulties of selling its subscriptions to European libraries. Canavari askes Mayer to subscribe to *Palaeontographica Italica*, since only the University of Bologna had so far undertaken to do so (for 50 French gold coins) (Canavari, 06.03.1896). As I have also stressed how, in previous sections, financial support is key to the growing and shaping of the paleontological discipline.

offered the best medium for diffusing and standardizing this data. It has exactly the same function as Zittel's textbook: it spreads paleontological facts via various forms and images.

Zittel's Heredity and the Attempt to unify Vertebrate with Invertebrate Data during the first Half of 20th Century.

Zittel's criteria for accepting and making paleontological data generated a vigorous geological and paleontologiacal debate. It was one cause of the paleontological "crisis of identity." (D. Sepkoski, 2012, p. 52) This crisis of identity was a reaction against the coming into being of a paleontological epistemic thing that places invertebrate and vertebrate paleontology on the same ontological and epistemological level. Zittel stressed the similarities between invertebrate and vertebrate paleontology in his constitution of paleontological data. Paleontology can use facts equally composed by invertebrate and vertebrate fossils to accomplish "certain general deductions" (Nicholson, 1877, p. 367). This coming into being generated a crisis of identity where, if the majority of American geologists were inclined to accept the biological power of vertebrate fossils, they were not yet ready to abandon their physical time markers, i.e. invertebrate fossils. Geologists were accustomed to using invertebrate fossils to mark rock formations, and so to construct the geological scale. Allegedly, they conceive "the fossils [as] no longer the remains of organisms that once were active, living things, but rather [as] convenient markers having certain diagnostic characters, placed in the rocks to tell how old these rocks may be."

In his famous presidential address gave in 1947, James Brookes Knight pointed out the differences between paleontologists and geologists in the light of Zittel's notion of data: he even urged the creation of a separate department for paleontological studies. Directly quoting Zittel's *History of Geology* on the necessity of separating paleontology from the geological departments, he noticed that "vertebrate paleontology has made great advances, but invertebrate paleontology has remained largely on the same plane and for the reason that "in the universities it has been relegated to the care of geological specialist" as Zittel put it 50 years ago. (Knight, 1947, p. 284) Therefore, it seems that Zittel's notion of data was positively received only by vertebrate paleontologists, whereas invertebrate paleontologists remained confined to a geological approach treating the fossil record as a mere time marker. This is in part correct. As I have noted, the crisis of identity was characterized by the reaction against the biological weight given to invertebrate fossils. Edwin Harris Colbert stresses this point exactly in his address as retiring president of the society of vertebrate paleontology:

> "it is the fate of the vertebrate paleontologist that he very frequently feels rather out of place when he is gathered together with some of his close scientific colleagues. With a group of geologists he is too much of a biologist. With a group of biologists he is too much of a geologist [...] The invertebrate paleontologist is not

> quite the same sort of an intermediate fellow that the vertebrate paleontologist is, for during the years the invertebrate paleontologist has tended to draw further and further away from the biological side of his subject, until he has to a considerable degree become less a student of life than a student of the stratigraphic sequence of little objects that happen to be fossils." (Edwin Harris Colbert, 1947, p. 287)

Colbert suggests that this "bad situation should be corrected" by applying the required "evolutionary concept" within geological communities and institutions.

From a sociological point of view, Colbert was completely right. The establishment of social and pedagogical instruments was essential to the formation of paleontological and paleobiological disciplines. The constitution of separate institutes or departments is essential for establishing identity, as the establishment of chairs was for the coming into being of pure paleontological data. This section does not examine these important factors, but deals with Zittel's legacy by analyzing the extent to which his creation was *de facto* established in invertebrate and vertebrate paleontology during the first half of the 19th century. As case studies, I will examine two extremely influential 20th century textbooks as well the Newell and Simpson's projected, but unrealized, textbook. Specifically, this section analyses Romer's *Vertebrate Paleontology* (1933), Willam Twenhofel and Robert Shrock's *Principles of Invertebrate Paleontology* (1933), and some pages from the draft of Newell and Simpson's *Principles of Paleontology*

Romer's *Vertebrate Paleontology* was used as a textbook in many universities and constitutes the most important vertebrate textbook not only in the period between 1933 and 1953 (first and second edition), but also in the 60s in a third edition. In a review of the third edition in *The Quarterly Review of Biology*, for example, the reviewer claims that "like its predecessors, it is a fine, authoritative, moderately comprehensive account of the fossil vertebrates, their morphology, taxonomy and geological distribution." (Olson, 1967, p. 297)

Alfred Romer (1894-1973) was the founder of the *Society of Vertebrate Paleontology* and a "gifted teacher who trained several generations of paleontologists and anatomists" (Edwin H. Colbert, 1982, p. 265). He taught at the University of Chicago and at Harvard, and "it should be emphasized that during his years at Harvard, Professor Romer trained an outstanding cadre of vertebrate paleontologists, anatomists and vertebrate zoologists" (Edwin H. Colbert, 1982, p. 275). Romer decided to write *Vertebrate Paleontology* to fill "the lack of any modern work in English dealing with the subject as a whole." (Romer, 1933, p. 5) Indeed, the main textbook dedicated to the study and classification of vertebrates and invertebrates was Zittel's *Grundzüge*.

The presentation of the contents of the manual is very classical, in line with Romer's notion of the fossil record: the fossil as a petrified organism that can be understood only by means of description. Romer meticulously describes the features presented in the fossils narrating thus an evolutionary scenario: the reader is carefully guided through the main groups of vertebrates which existed on the earth surface. Both the method of exposition and classification, albeit updated, and the meaning of the fossil record are entirely ascribable to Zittel's collective thought. Indeed, Romer asserts that "vertebrate paleontology is a biological science" and the fossils are reliable biological data:

> "to the paleontologist the animals of the present constitute but a brief cross-section of the vertebrate story. To him a separation of fossils from the modern forms which have descended from extinct types and are destined to become the fossils of the future would seem extremely artificial." (Ibid.)

This quotation is extremely significant and covers all the key theoretical points: i) the fossil record is conceived as a pure paleontological datum, i.e. a morphological complex unity; ii) paleontological knowledge is quantitatively wider than a biological one, thus if we want to understand something from a biological point of view, we should study paleontological facts; iii) pure paleontological data are atemporal, or rather, they lie in the same temporal level as modern fauna. They are no longer historical records, but rather synchronic points. As a result, Romer trains new generations of paleontologists to perceive no gaps between biological and paleontological fields: atemporal fossils are pure biological facts. The characteristic of this new epistemic phenomenon is that it is not subject to the deconstruction of time. Indeed, the temporal dimension had been entirely suspended following Zittel's investigations - with the result that paleontologists were able to arrive at important facts concerning evolutionary theory. The conclusion of this first case study is that vertebrate paleontology is, for the most, part of the 'paradigm' inaugurated by Zittel. It investigates the morphological and physiological structures of extinct animals.

Let us now examine invertebrate paleontology. As I have mentioned above, in his *Die Staemme des Thierreiches,* Neumayr stressed the characteristics of the invertebrate paleontological epistemic thing in agreement with Zittel's data. From a sociological point of view however, invertebrate paleontology was confined to geological reflections. The coming into being of the paleontological epistemic thing generates a shift in the nature of invertebrate paleontology itself. This shift, emphasized by a crisis of identity, concerns the role of invertebrate paleontology: it should be separated from stratigraphy so that can feature in the core of paleontology. This shift can be clearly seen in the treatment of the fossil record proposed in Willam Twenhofel and Robert Shrock's *Principles of Invertebrate Paleontology*.

In the preface to first edition (1933) the authors assert that the fossils

> "are no longer mere lifeless stones but become entities of a? onetime living world; they represent adaptations to and products of the environments in which they and their ancestor lived; they appear as living organisms in harmony with, but also in competition with, their plant and animal associates; and finally they interwoven

> fabric of organic development and become at the same time beacons along the road of geologic time, marking off successive stages in earth history" (Shrock & Twenhofel, 1953, p. xi)

This key quotation shows that the invertebrate fossil record constitutes onetime living organisms and not mere lifeless stones. The fossil record can be treated as such because the abyss of deep time does not constitute the ontological statute of the fossil record. The authors confirm this turning point through a phenomenology of the 'fossil record': under which conditions can something be dubbed a fossil record? The answer is worth quoting in entirety:

> "the skeletons of many kinds of animals trapped long ago in the tar pits of California are regarded as fossils, yet one would hesitate to apply the term fossil to the bones of Cro-Magnon man found buried in the caves of Europe, [and]? not think of applying the same term to the skeleton of John Smith buried a few years ago in the Crown Point cemetery. It becomes obvious, therefore, that *a fossil must have age*, but this particular requirement is so intangible and indeterminable that it cannot be defined. In the majority of cases the organisms represented by fossils live prior to the present time unit. They need not be extinct, however." (Shrock & Twenhofel, 1953, p. 15)

The temporality carried by the fossil record has only synchronic dimension: a fossil must have an age[76], but it does not represent an entire age, or as Nicholson has put it, the "reference to the *time*" at which the organisms lived is "slight and secondary". This point would prove decisive during the 1950s. During those years, George Gaylord Simpson and Norman Dennis Newell attempted to write a manual of paleontology, entitled *Principles of Paleontology*[77]. The second chapter—under Newell's direction—concerned the material of paleontology. The chapter begins with the question: *what are fossils?* Addressing this, Newell employed a slippery analogy using the role of temporality:

> "In the 1870s when the pioneer archaeologist, Heinrich Schlleman was excavating what he thought was ancient Troy, he was able to identify successive layers containing the remains of nine cities that had been built one above another and repeatedly destroyed over a period of several thousand years. From his studies he deduced much about the history and life of these ancient cities. The key to this archaeological puzzle lay in a method that was already well established in paleontology, the study and interpretation of objects peculiar to each successive time level. […] The basic material of paleontology consists similarly of fossils and the rock strata which contain them. […] Antiquity is usually impelled in the use of them, because most fossils are very old, belonging to species long since extinct, but the geological record of recent organisms is also a very important part of the history of life and therefore occupies the attention of paleontologists."

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[76] By asserting this, the invertebrate paleontologist is also able to use the fossil record in bio-chronological correlation. See the fourth chapter.

[77] I thank David Sepkoski for the idea and materials

Simpson was completely unsatisfied with this crucial chapter and particularly with its starting point. He resent the chapter draft to Newell asserting that he would have rewritten the entire chapter. Simpson's version begins with the same question: What is a fossil? The answer, however, is completely different: "A fossil is now defined as any indication of ancient life. The definition is a bit blurred because there is a no exact moment when something becomes ancient"[78]. Simpson recognizes that the paleontologist must be careful in relating the fossil record ontologically to vertical deep time. Only by reducing the role of time in the definition of the fossil record, is the skeptical drift avoided. Hence, following Zittel's legacy, Simpson urges a synchronic treatment of the fossil.

This point is connected to a second. Where temporality is no longer a fundamental factor: invertebrate paleontology acknowledges its debt to Zittel's paradigm. However, there is an element that differentiates Shrock's textbook from this paradigm, proving key to the development of paleobiological data. We can read that "a fossil must be *some evidence of the existence of an animal or plant that once lived*" (Ibid.). Fossils are treated as evidence of the ancient world as well. This approach was common in historical geology and it was applied in the treatment of the invertebrate fossil record. This would be a determining characteristic in the birth of paleobiological data. Despite this further development, the identification of paleontological data with facts was positively received and recognized in both invertebrate and vertebrate paleontology by the first half of the 20th century. Paleontology appeared as a discipline able to indicate the required condition to refer to entities in the past. It lucidly sets this burden by representing the fossils as set of facts.

Conclusion

In the chapter, I have examined Zittel's legacy between the end of the 19th and the beginning of the 20th century: data is identifiable *in toto* with sets of facts represented and spread in, for instance, textbooks, catalogues, and journals. I have tracked the fundamental intellectual steps required for establishing and diffusing this data. Particularly, I have shown its growth from a philosophical,

[78] It is extremely interesting to notice that Simpson quasi-quotes Neumayr's words: "Die Scheidung zwischen der Jetztzeit und den früheren Abschnitten der Erdgeschichte ist in vieler Beziehung eine ziemlich willkürliche [...] Wo liegt hier die Grenze, bei der man sagen kann, die Thierreste der älteren Ablagerung gehören noch dem Paläontologen zu, die der jüngeren dem Zoologen? Hier verschwimmen die verschiedenen Gebiete ineinander und dieser Umstand lässt uns deutlicher als irgend ein anderer die innige Verbindung der Paläontologie mit Zoologie und Botanik erkennen." (Nueumayr, 1889) This corroborates my arguments that the coming into being of paleobiological data is deeply influenced by the making of the fossil record as a set of facts - to the detriment of vertical deep time. This move, albeit necessary, is not sufficient. I will deal with the reasons for this in this chapter's conclusion; I will investigate in which sense historical geology gives another necessary condition for the construction of paleobiological data in the fifth chapter

pedagogica,l and social point of view. Pure paleontological data was established in Germany and subsequently spread through English-speaking countries. In Germany, the socio-economic conditions facilitated the creation of chairs and professorships of paleontology constituting and hence diffusing a *Denkkollektiv*. The first and most important chair was in Munich. Karl von Zittel, the chairman between 1866 and 1904, was able to attract numerous students from Germany and abroad. He taught future generations how to identify paleontological data with stable, atemporal—not metaphysical—facts.

By setting the criteria for the identification of paleontological data, Zittel aimed to differentiate himself from 'old', subjective, and metaphysically oriented paleontologists (embodied in Bronn, Zittel's teacher in Heidelberg). The clear separation between paleontology and stratigraphy was the required step to avoid metaphysical and speculative conclusions concerning the history of the earth. In fact, the stratigraphic approach—meant in a very broad sense—conceived fossils as narrative unities, which needed to be read. By seeing the fossil record as a mark of an event in the earth's history, it became possible to make statements about what happened in the deep past. The context for these statements was a changing concept of truth unable to support and emancipate paleontological analysis. As a result, the historical and narrative investigation of the fossil record opened a dangerous zone of uncertainty and speculation. The paleontological static, and with it the mathematical treatment of the paleontological data, was abandoned.

To overcome this danger of uncertainty, Zittel did not identify his starting points with events. He understood that if deep time ontologically determines paleontological data, it has a destructive power: no stable knowledge can be pursued in the abyss of time. As a consequence, he established paleontological data as synchronic unities, namely as pure facts. By using such epistemic unities, Zittel was able to provide a great number of morphological structures for the theory of evolution: metaphysical speculations can be put aside *in toto*, as Neumayr wrote, "Die Richtigkeit der thatsächlichen Beobachtungen ist in der großen Mehrzahl der Fälle nie in Zweifel gezogen, ja von verschiedenen Gegner der Abstammungslehre rückhaltlos anerkannt worden" (Melchior Neumayr, 1889, p. 58)

This enterprise was taken up in Germany and abroad. Bavaria provided financial stimulus seeing a good opportunity to represent its intellectual power and freedom worldwide. Many paleontologists developed Zittel's idea and between the end of the 19th and the beginning of the 20th centuries a collective enterprise worked to redefine and set the conditions for the data. For example, Nicholson, Neumayr, and Stromer worked to spread the features of the paleontological epistemic thing through the scientific community. Zittel's legacy was positively adopted by many paleontologists in the first half of the 20th century: both invertebrate and vertebrate paleontologists accepted and promoted the identification of data with facts.

However, the making of paleontological facts did not generate a theoretical-deductive practice to understand, corroborate, and develop the theory of evolution. Although the declared aim of many paleontologists—who favorably embraced Zittel's conception of data (see among others Nicholson or Neumayr)—was to use the paleontological data to understand evolution, they were unable to pursue this goal. The main reason being that Zittel and his contemporaries did not explicitly determine how, and how far, these facts should be read in order to come up with biological processes and patterns. They were so worried about opening a space for subjective statements that they delimited every possible misunderstanding. Zittel's first move was to crop the vertical dimension of time because no possible knowledge could be obtained within it. By dealing rather with a horizontal dimension of time, the paleontologist obtains a secure space for classifying and describing facts without accepting controversial and metaphysical practices. He only sets the referential burden and does not deal with declarative statements. This implies a double process of identification: data are identified with facts and afterwards recognized as *explananda*. The paleontological investigations can achieve a degree of knowledge, since they do not move away from their starting points. Indeed, data are at the same time starting points and the final aims of paleontological research. A constructive practice guides the initial stages of the paleontological investigations: paleontological data and *explananda* are both—in a diverse degree—constructed.

Nevertheless, Zittel's *Denkstil* established at the same time a consolidated practice of reading the fossil record. The 'old' historical geology was able at least to furnish a method for reading its data. As Neumayr put it "*dagegen hat man den Versucht gemacht, den Thatsachen eine andere Deutung zu geben.*" (Melchior Neumayr, 1889, p. 58) Zittel, on the contrary, was not able to identify valuable alternatives, explanations or instructions to elaborate his *explananda*: he was not able to furnish any practice by which to read, interpret or explain the diversity of the fossil record. The refusal of the paleontological static contributed in part to this stalemate. To sum up, Zittel's collective enterprise was not able to open the theoretical process sought by the same scholars: "they failed to provide one coherent theory." (Reif, 1986, p. 121)

This point is reflected in Zittel's textbook. It was a powerful *medium* for attracting, promoting, and teaching the qualities of pure paleontological data; however, it retained all the ambiguity of this notion as well. Zittel's thought-styles did not teach how this data could properly be used as data, i.e. as starting points for further investigations. Watson in *Nature* notices this:

> "the title adopted for the English edition 'Text-Book of Paleontology' neither correctly translates the German title nor expresses the character of the book.

> Consisting as it does of a mass of facts with no indication either of methods of work or of the general theory of the subject, it is by itself by little use for the beginner, and requires to be supplemented in some way, either by a teacher or by some, as yet unwritten, introduction." (Watson, 1946, p. 584)

The same can be said for the allegedly English updated 'versions' of Zittel's *Grundzüge*: Romer's *Vertebrate Paleontology*. In this manual, the students find different useful taxonomical choices, but Romer's textbook shares with Zittel the same biases. Romer does not engage with and/or identify a) how far the data may be read, b) what are its structural features, and c) whether the paleontologist may take a step forward and seek the reasons behind the diversity of the gathered data.

This impasse would be overcome by enlarging the concept of paleontological data and its role in evolutionary processes. Historical geology and stratigraphy play a pivotal role in shaping this notion - giving paleontologists the required training to use this data in depicting evolutionary mechanisms. Such training is based upon a vertical dimension of time and proposes seeing the fossil record as evidence for the theory of evolution. The use of representative tools such as graphs and tables would be essential. No longer to obtain speculative and metaphysical conclusions, but as "methods of expressing the morphological features of several types concisely" and by using these tools "the evolutionary significance may be easily grasped" (Swinnerton, 1922, p. 357) In the following chapters, I will investigate the genesis of this training to indicate how the evolutionary significance can be easily grasped if it can appear in a graphical space. I argue that stratigraphy and historical geology play major role in pushing paleontology toward biological conclusions. The key figure of the next chapter is Carl Albert Oppel (1831-1865). The German paleontologist was able to create and diffuse bio-stratigraphic zones by using the fossil record as a local source of evidence. He taught perception of time in space, thus answering Bronn's need. The zones he created would be used as reliable starting points for a mathematical treatment of the fossil record.

Chapter IV. How to observe?

Introduction

In the previous chapters I have argued that although Zittel accepted Darwin's theory, he did not attempt to exploration of evolutionary mechanisms, i.e. he developed important classificatory and phylogenetic tolls, but avoided discussion of the causes and mechanisms of evolution. Thus, if a paleontologist follows Zittel's method strictly, he is unable to define biological events. To be more precise, he can discover a variety of forms, but is unable to connect up this data. Paradoxically however, this approach successfully emancipated paleontology from geology – pushing paleontology toward biology. According to Zittel, paleontology provides numerous facts concerning the theory of evolution, but does not attempt to elaborate or read them. It does not make any statements about the past, but rather fixes the referential burden.

On the contrary, historical geology has provided key contribution to knowledge of biological mechanisms and processes in the deep past during the 19th century. Bronn was indubitably one of its main exponents. He conceived the fossil record as a synthetic construction that can give valuable insight to the history of the earth and especially to natural history. The fossil record is a material object that—by means of synthetic operations—can reveal a particular path within the history of life. It is *seen as* an event that requires narration. Hence, the paleontologist is able to pronounce on what happened on the earth's surface, and how. Nonetheless, the narration is imprecise and it may lead to dangerous results: it might open a metaphysical space, which, according to Zittel, would undermine the epistemological status of paleontology. The more data is inserted into deep time, the more problematic is becomes to manage without losing or altering its meaning. Moreover, the truth that emerges from declarative statements about the past is unstable and changing. As a consequence, Zittel excluded this narration. He decided instead to focus on the morphological elements of the narration in order to stress its features. This field is more secure and, at the same time, protects the ultimate biological vocation of paleontology. By describing the morphological features of the fossil record, the paleontologist sets the referential burden of the extinct past species. He provides a rich collection of facts, which can be used to support the theory of evolution.

As I have shown in the previous chapters, Zittel's approach formed a proper collective enterprise. Many paleontologists tried to gather and set facts for evolution. They stopped making statements about the past in order to preserve paleontology from speculation. The problem with this approach is—as the paleontologist Derek Ager puts it—that "paleontology [is constructed] by the telephone book". Ager uses this expression in reviewing Ulrich Lehmann's *Fossils Invertebrate* (1983). Ager argues that this textbook is a manifestation of Zittel's tradition:

> "in fact it out-Zittels, Zittel, though at much shorter length: […] apart from a brief section on the origin of life, there is very little on evolution, or paleoecology, or functional morphology, or geographical distribution or any of the dozen other subjects that many of us find so fascinating. No doubt that makes it the more scientific in a purely descriptive sense; it also—regrettably— makes it extremely dull." (Ager, 1983, p. 470)

Zittel's approach to the fossil record encounters the same problem: it is scientific, but it seems not to have utility for comprehending the mechanisms of evolution. Hence, the question is how to use the fossil record for investigating the theory of evolution without, on the one hand, making metaphysical pitfalls and, on the other, ending up with a useless collection of facts? This is the key question, which signals the development of paleontology and the birth of paleobiology. Due to the complex nature of this question, it is worth dividing it into two distinct parts. In this chapter, I will analyze how it is possible to see the fossil record as an event, without succumbing to metaphysical pitfalls. As I have argued in the second chapter, Bronn saw fossils as events in deep time. This approach is based upon a metaphysical instance and an empirical difficulty. Since the fossil record is incomplete and imperfect, it can be used only when all the different information about it are put together. Natural history is a synthetic discipline and its data is the product of a synthesis between various branches of knowledge. Successively, data is treated statically to reveal patterns in the history of earth. The main difficulty is that deep time has a destructive role: the narrations derived by a statistical treatment of data are always instable. Only a low and unstable degree of knowledge can be achieved.

To overcome this impasse without embracing *in toto* Zittel's notion of the fossil record, some paleontologists began to refine the temporal dimension. In fact, the vertical dimension of time is not a zoological feature: its origin is geological. Stratigraphical analysis constitutes it. By studying the features of deep time, stratigraphy would be transformed from a strongly geological-oriented discipline into an ecological-oriented investigation during the second half of 19th century. This change began in the German universities, within a group of geologists already quoted in the previous chapters. Bronn, Oppel, Neumayr and Waagen can equally be called founders. This development was, however, only made possible by Carl Albert Oppel's work on the *Jurassic formation in England, France and south Germany* (1856-57). Oppel taught the observation of the strata of the earth in order to identify its zones. These zones are meant as a faunal assemblages and the paleontologist puts their data together to draw an ideal profile of a particular formation. The ideal profile is an ordered disposition of zones and has a temporal and spatial meaning.

Furthermore, it can be biologically interpreted: it provides a vertically ordered succession of events in time.

This chapter shows that answering the question 'how to observe' leads to a specific concept of the fossil record and to the development of different epistemic practices. In fact, if the fossil record is seen as an event, the paleontologist necessarily needs to come up with a practice for reading and tracing it. Bronn indelibly characterized this practice, but his reading was extremely inexact. His temporal dimension was too vague and imprecise and this influenced further mathematical treatment. After having recapitulated on the inaccuracies related to Bronn's method, I will analyze Oppel's answer to the same question. Oppel decided to re-observe the rock strata in order to develop a reading of its contents. The main result of Oppel's enterprise is that the fossil record has a meaning only if it is *seen as an entire fauna*. Oppel treated the fossil record in bulk to draw an ideal profile that could facilitate both the temporal and spatial detection of patterns. Nevertheless, he did not discuss and define this notion: he simply used it. He did however establish and transmit an epistemic practice. In lieu of this practice, Oppel's scholars will argue extensively about the features and potentialities of this notion of data. They will analyze how Oppel's ideal profile can be seen and used fruitfully in light of the theory of evolution.

How to observe? Facts, Events, and The geological Law of Development of Molluscs

Heinrich Bronn is the founder of two different concepts of the fossil record, emphasizing different characteristics: the fossil record can either be seen as an event or as a stable set of facts. Bronn gave the correct impetus for discovering temporal patterns among data and thus for narrating an evolutionary history; however, research of patterns of development within deep time, leading to only probable conclusions, had been perceived by Zittel as problematic. Paleontology would be able not merely to acquire probable conclusions, if fossils are not considered as events requiring narration. This discipline deals rather with something communicable and stable: paleontology researches facts of import to evolutionary theory. First and foremost, it explores the form and, at a later stage, the phylogenetic disposition of the fossil record. To put it concisely, paleontology does not attempt to make truth statements about the past, but to fix the referential burden.

Both these directions have a common origin. During the 19^{th} century, the leading question in geological sciences was 'how to observe?' Bronn and Zittel answered this question in two different and diametrically opposite ways: Bronn's observational practice was characterized by 'seeing as'; Zittel's practice by 'seeing that'[79]. Bronn sees the fossils as events that need to be read. Zittel sees them only for what they were: complex figures that could be depicted. He was continually looking

[79] See the second chapter.

for codified practices to bring out the relationships among the parts of the fossils. This difference is important in shaping the features of paleontological data. This section pushes this distinction a little further. I will focus on Bronn's practice of observing and reading the fossil record to recapitulate the characteristics of the fossil record as event. At the same time, this investigation will open possibility of marking the starting point for a less evolutionary oriented, but more empirically grounded, historical geology: Oppel's stratigraphical investigation.

The question of how an epistemic observation should be led is fundamental to every discipline. It is *a fortiori* important in those sciences tied with observational protocols, descriptions, and travellers' reports. The English geologist and paleontologist Henry Thomas De la Beche (1796-1855) published a small and extremely important book on this topic in 1835. Its title is emblematic. It is simply entitled *How to observe*; the book's aim "teach how to observe." It is meant as a complete guide for students and scientific travellers who wanted to carry out geological observations. The book spoke to a perceptible requirement of these years. Geologists had to learn how to discern what is important from what is merely accidental. Too many factors contribute to shaping the current crust surface. The good scientist chooses what he needs to perceive, isolating this from other disturbing factors. He lays aside factors which have not shaped a landscape essentially and by doing so can approach the core features of a geological process.

In the preface of the German translation of De la Beche's book (1836), the Berliner geologist Ernst Heinrich von Dechen (1800-1889) stressed this point exactly. He asserts[80] "eine solche Anweisung [the book *How to observe*] scheint gerade in Bezug auf Geognosie nothwendiger, als für manchen anderen Zweig der Naturwissenschaften, weil die Schwierigkeiten, mit denen der Anfänger, der Ungeübte beim Beobachten zu kämpfen hat, eigenthümlicher Art sind." (De La Beche, 1836b, p. iv). Beginners or unpracticed students have to deal with many perceptual difficulties and are not always able to overcome them. Perceptual difficulties can also undermine the judgment of the most trained geologist. Therefore it is necessary to define the limits and the nature of paleontological perception. This is important, because geological sciences were less involved in the separation between "active experiment and passive observation" (L. L. Daston, Elizabeth, 2011) and therefore an observation has to be both passive and active: it both provides "raw data" and simultaneously cooks that data (the active experiment.)

To understand the importance of perception in the geological sciences and its relation to the notion of fossil as event, I will briefly deal with two situations that a geologist might encounter.

[80] Dechen points out also that Leonhard's *Agenda geognostica* (1838) has equally offered a "vollständige Anweisung" on the nature of the geological observation. This remark highilts the importance of Leonhard for the development of the geological sciences. See the first chapter.

These examples will particularly show the degree of abstraction related to this activity and the consequent necessity for teaching paleontologists how, and under which conditions, to perceive. Let us consider two examples to better emphasize this point. A disposition of three elements characterizes a slope as follows:

Sand
Cobble
Clay
Sand
Cobble
Clay

Figure 12 The profile of a possible geological slope. Freely taken from (Hölder, 1996)

Clay, Cobble, and Sand are the three constitutive elements of a slope and the paleontologist wants to identify the changes related to it. Firstly, he needs to scan the plausibility of this perception. The German paleontologist Hölder describes the possible thought process of the geologist as follows: "Die Horizonte Textur und die Verschiedenheit der Gesteinsausbildung in den einzelnen Lagen können ursprünglich, sie können aber vielleicht auch erst nachträglich durch Gliederung und Differenzierung eines anfangs einheitlichen Körpers entstanden sein" (Hölder, 1996, p. 5). The first doubt concerns the nature of the particular formation: is this original to the region or a later product? This doubt disappears as soon as the geologist better observes the formation:

> "Um von diesem Entstehung etwas zu erfahren, muß man genauer hinsehen. Man erkennt dann eine doppelte Folge von Geröll-Sand-Ton - Geröll-Sand-Ton und fragt als Geologe nach dem Ursprung dieses doppelten Zyklus. Es könnte sich um zwei Hochwasser handeln, bei welchen die Geröllagen im Unterlauf eines Flusses und im Abstand von vielleicht nur wenigen Tagen angeschüttet wurden. Wenn sich das Wasser verlief, breitete es über der Schotterlage zunächst noch Sand und zum Schluß den feinen Ton aus, auf dem dann der nächste Hochwasserstoß die nächste Schotterlage hiterließ." (Ibid.)

The geologist should thus carefully learn how to observe the place under examination: this is the only possible way to perceive the sequence of materials within the formation. These materials constitute the data for his investigation and the more carefully he perceives the more reliable these are. In the next step, the geologist has to come up with a possible historical explanation in accordance with the gathered materials. As William Conybeare and William Phillips put it, "the intelligent enquirer, when he has once generalized these observations, can scarcely fail to conclude that such coincidences cannot be casual" (Conybeare, 1822, p. 2). The intelligent enquirer can thus find a possible historical scenario to explain the data once he has accurately perceived and gathered it. However, the perceptual scenarios are never so simple in reality. In my example, the geologist cannot conclude that water was the true cause because he does not have enough data. However, by training his perceptual skills, he can exclude many improbable situations. As a consequence, he can use what he has gathered as evidence for his historical scenario.

Let us consider another example to better illustrate this point. In *How to observe*, the author sets out this possible scenario.

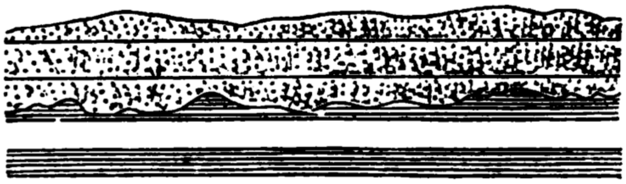


Figure 13 A possible situation where we have no evidence to show that the flora and fauna of a exists before b

Here we have two fossiliferous rocks that rest conformably on each other. The geologist has to learn how to observe in order to guide his behavior and his inferences, as below:

> "The beds of the two rocks […] may, as masses, rest conformably on each other […] If we find, that the upper surface of a fossiliferous rock, *a,* has been water-worn before another fossiferous rock, b, was deposited upon it, we have no evidence to show that the animals and plants existing when *a* was formed were succeeded by those whose remains are detected in *b*". (De La Beche, 1836, p. 27)

The geologist must refine his skills to avoid mistakes and learn which elements he lay to one side. In fact, as the two examples clearly show, the paleontological perception is always related: with both a degree of abstraction and a theoretical frame. This point is extremely important because as the German philosopher Ernst Cassirer[81] wrote "it is not clocks and physical measuring-rods but principles and postulates that are the real instruments of measurement. (Cassirer, 1923, p. 365) The same practice is active in proper paleontological perceptions. The question is accordingly, how—or rather, under which conditions and principles—can paleontological data be perceived?

The perceptual problem was of pivotal importance to paleontological science during the first half of the 19th century. Bronn wrote a book about the mechanisms that scientific travellers should adopt to mimetically represent nature (Bronn, 1838). The issue however exceeds the practice of a mere traveller and assumes a slightly different value in Bronn's historical geology[82]. In historical geology the difficulties involve not only recognition of the correct starting points, but also their further historical narration: raw data requires a previous treatment in order to be used. The essential

[81] See chapter 7 concerning the philosophical implications of this statement

[82] I have dealt with the relation between perception and paleontological data, meant as pure taxonomical discipline, in the first chapter.

role of perception is central to an important paper that Bronn published in the *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde* in 1856. The paper concerns the geological laws of molluscs development; in order to describe these laws a preliminary investigation of the perceptual contents is required:

> "Die Wahrnehmung, 103as seine grosse Anzahl paläolithischer Muscheln von dem einen Autor unter die Ganzmäntel versetzt wird, während der andere Beobachter sie zu den Buchtmänteln gestellt, hat uns veranlasst näher zu prüfen, von wie vielen und welchen derselben die buchtige Beschaffenheit des Mantel-Randes tatsächlich bekannt sey." (Bronn, 1856, p. 640)

The first problem that Bronn has to face is a taxonomical one, since data have to be correctly named before they are used. The taxonomical problem is a common issue in paleontology – shared both by paleontologists more inclined toward a historical treatment of data and by morphologists. Bronn notices that many authors have classified the same specimen under different taxonomical entries and this misidentification can generate a flawed starting point for further analyses. This is not an insignificant issue, particularly if the morphological data are inserted into a temporal and spatial frame: a small difference in the temporal position of the fossils or an error in naming them can change the entire structure of the paleontological research. In fact, Bronn's investigations are entirely based upon lists of fossils in their spatial and temporal appearance; if a number of shells is listed erroneously in a chart or row, the whole procedure of patterns-identification will bring erroneous results. The teaching of observation and classification is consequently essential for successfully coming up with patterns and processes.

The correct identification of the morphological features of fossils is essential. Although this complex process is subject to possible perceptual errors, these can be more or less easily overcome. For example, Bronn in *Italiens Tertiär-Gebilde und deren organische Einschlüsse* (1831) asserted explicitly that his purpose "geht darin, viele neue Arten zu beschreiben, die Synonymie mit Bezug auf die von mir untersuchte BROCCHI'sche Sammlung zu berichtigen, die Fundorte nach den Gebirgsschichten genauer anzugeben" (Bronn, 1831, p. 2). Perception should be trained in order to perceive the fossils and recognize that despite diverse names the two allegedly different exemplars belong to the same species. To solve the confusion between the several classifications made by different authors, it is necessary to find out *how many* specimens *de facto* are known ["vielen und welchen derselben tatsächlich bekannt sey"][83]. Once having re-collected these materials, the

[83] Bronn used this method since his first European trip to Swiss, south France, and Italy. Concerning the *Ichthyolithenkalk des Bolca*, he affirms that the first step towards solving this problem is count the number of petrified specimens. (Bronn, 1826) Bronn learnt this method during his cameral studies in Heidelberg. See the first chapter.

taxonomical description can begin. This will reveal the numerical relations between data. In fact, Bronn notices that after having analyzed 221 mollusks species, the result is:

> "28 Arten sind jetzt unwidersprochen mit einfachem Mantel-Rand verstehen. — 185 Arten sind in dieser Hinsicht unbekannt, und die Annahme, dass ihr Mantel eine Bucht habe, beruht nur auf einer äusseren Formen-Ähnlichkeit der fossilen Muschel (oder ihres Abdrucks) mit irgend einer unserer jetzigen mantelbuchtigen Sippen. — Sichere Sinupallia sind höchstens 8-10 vorhanden." (Bronn, 1856, p. 650)

The ability to conduct a precise and thorough observation is thus the starting point for identifying patterns, processes, laws of dispersion and development of the fossil record. Based upon our perceptual ability, we are able to draw up lists of fossils and thus we can point out the general changes of the organisms. As Bronn explicitly claims in his *Einleitung in die Naturgeschichte*, perception gives us the first source of knowledge and therefore the scientist has to train it. Perception has a triple role: i) it provides the required data, ii) it tests the validity of the data gathered by other paleontologists, iii) it cooks the data as an active experiment. In this sense, paleontology is based upon a sophisticated empiricism.

Nevertheless, Bronn's data does not constitute mere lists of data, but bio-chronological tables. In the *Handbuch einer Geschichte der Natur*, he describes the required data by emphasizing the essential steps for a proper paleontological investigation. The first step that a paleontologist should undertake is examination of the crust surface, layer by layer. As we have seen, this operation conduces the paleontologist to establish the number and the kind of species presented in the various epochs. Second, the *Bildungszeit* of the found records needs to be determined. They can appear in different periods or formations and the paleontologist needs to be able to recognize them. Third, these temporal points should be compared in order to point out developmental laws. Returning to the Palaeolithic molluscs, Bronn affirms:

> "während der ganzen paläolithischen Zeit herrschen die Brachiopoden oder Pallibranchiaten über die Lamellibranchiaten vor, mehr an Arten- als an Sippen-Zahl; sie treten gegen diese letzten immer mehr zurück, je jünger die Fauna, […] bis sie in der heutigen Schöpfung zu einer ganz unbedeutenden Quote den übrigen Schaalen-Acephalen gegenüber herabsinken."(Ibid.)

The paleontologist has to learn how to observe because the developmental laws depend *in toto* upon the observational data. Nevertheless, many possible errors are hidden in the folds of this process. The perceptual problem appears thus fundamental: perceptual illusion could lead to erroneous report, in turn, invalidating paleontological investigations. Zittel addressed this by spreading a stable and verifiable notion of data through his textbook. However, in another respect, differences in author perceptions and classifications generate in themselves erroneous representations of the development of the fossil record. The morphological data needed to assume a temporal validity for use in statistical analyses: the time dimension is therefore fundamental. Even a little imprecision can undermine the entire inference.

Even if the paleontologist is able to overcome all the difficulties related to the description and recognition of the data by setting reliable bio-stratigraphic charts, this still remains only raw data for historical geology. Successively, they the charts are statistically treated. The paleontological static is connected in turn with other kinds of problems. The main problem is that a general comparison of the numbers of the individuals taken from the different earth's strata is, in principle, impossible. Bronn asserts that it is impossible to determinate, "in wie ferne sich die den einzelne Schichten, Formationen, Perioden entsprechenden Zeitabschnitte unter sich gleich verhalten, oder ob nicht der eine derselben 2-3-4 mal länger als der andere in gleiche Kategorie gestellte Abschnitt ist." (Bronn, 1849f, p. 783)

Hence, Bronn admits that it is extremely difficult to understand and delimit the vertical dimension of time. Even if we reject die "wunderlichen Vorstellungen von verwirrten Generalalluvionen" (Bronn, 1826, p. 568) accepting thus the uniformitarianism *in toto*, we do not know the rate of sedimentation and therefore we cannot be sure whether one period is 2-3-4 times longer than another. This is, indeed, the crucial point: we can learn how to perceive the fossil record in order to correctly classify it, *but it is extremely difficult, indeed impossible, to learn how to perceive the vertical dimension of time*. This problem has a direct consequence on Bronn's work. Bronn develops an epistemic practice based upon an exhaustive use of bio-chronological charts in order to overcome the abyss of time. These, as he reminds us in 1856, are not monographic studies[84]. They are neither descriptive reports on the species found nor the data presented in Zittel's textbook. On the contrary, they are lists of fossils that reveal points in vertical time and space. Bronn's lists do not deal with the morphological and phylogenetic relations among data, but with their temporal and geographical appearance.

However, even the mathematical treatment of the fossil record cannot overcome the destructive role of deep time: "eine genaue Vergleichung der Zahlen der zu verschiedenen Zeiten lebenden Thier- und Pflanzen-Formen ist nicht möglich" (Bronn, 1849f, p. 783) Therefore Bronn needed to figure out how to deal with time to fruitfully come up with biological results. This is again a perceptual problem because time is only given in the form of space. Bronn, in fact,

[84] In 1849, Bronn tries again to clarify the aims of his *Enumerator* and *Index palaeontologicus*: "Wir haben im Enumerator palaeontologicus, der den zweiten Theil des Insex palaeontologicus bildet, die Sippen und Arten der fossilen Körper nach den Gebirgs-Perioden und –Formationen, worin sie vorkommen, in 5 grösseren oder weiteren und in 24 Rubriken aufgezählt" (Bronn, 1849a, p. 129)

characterized the temporal dimension by localities in which the fossil record was found. He disposed them chronologically according to their lithological characteristics. Nonetheless, this method was unable to univocally determine the temporal dimension. Bronn clearly affirms that the letters h, s, ü, v do not yet have a secure place within the temporal dimension. Again, the problem concerns first and foremost our ability to perceive space and to ascribe to it temporal meaning.

Benennungen.	Weltgegend.	KohlenP.	SalzP.	OolithP.	Kreide P.	MolasseP.	Neu
	E1,2 Europa. S1,2,3 Asien. F2,3,4 Afrika. M1,2,3,4 Amerika U3,4 Australien. E S F M U kein Zeichen: bedeutet E2.	U.-Silurische F. O.-Silurische F. Devonische F. Bergkalk. Kohlen-Gebirge Todtliegendes. Zechst.-Kupfer.	St. Cassian. Bunt-Sandstein Muschelkalk. Keuper.	Lias. Unter-Jura. Ober-Jura. Wealden.	Neocomien. Grünsand. Kreide.	Nummuliten-Gest. Untere Mittle (Molasse.) Obere Diluvial.	Alluvial. Lebend.
		a b c d e f g	h i k l	m n o p	q r f	s t u v w x	y z

Figure 14 Values used by Bronn to characterize his tables.

Oppel will address this problem through reformulating it. Perception is a fundamental skill and the sort of answer given to the question of the modality of the paleontological observation determinates what can be done with the fossil record. By this point, Bronn has already paved the way. It was necessary to perceive time in the form of space.

How to re-observe Time in the Form of Space?

"Setting aside all lithological features, Oppel deduced from his observations a series of palaeontological horizons which he termed *Zones*" (Zittel, 1901, p. 509). In this way, Zittel introduces Carl Albert Oppel's importance (1831–1865) for the growth of paleontology and geology. The sole use of the fossil record to order and explain the disposition of the elements of the Jurassic characterizes Oppel's analysis. This practice is based in turn upon a precise use of perceptual skills. Oppel was indeed "a young man, gifted with more than ordinary powers of observation, generalization and exposition" (Arkell, 1970, p. 15).

Oppel's scholarship began at the polytechnic school in Stuttgart. However, he soon abandoned the school to study mineralogy, paleontology and geology at the University of Tubingen in 1851. Oppel thus belongs among those scientists that did not begin their academic career under Darwin's influence. Even after the publication of Darwin's masterpiece, his *Origin of the species*, Oppel was not immediately impressed[85]. In fact, "Oppel verfocht ja keinesweg das überholte Dogma von der Unveränderlichkeit der Art, sondern versucht die Arten lediglich als relative Größen zu definieren". (Martin, 1965a, p. 188) August Quenstedt[86] (1809-1889) lead the University of Tubingen in that period. Of Quenstedt, Zittel said that he was one of the "most versatile and original German geologists and a born teacher" (Zittel, 1901). Oppel immediately became one Quenstedt's most talented students, not only in paleontology, but also in mineralogy and particularly in crystallography (Hochstetter, 1866, p. 59). In 1854, he began his travels through Europe. He visited all the collections of the most important paleontologists of the period in order to perceive the paleontological data directly. He spent seven months in France, where be became friends with Gilles Dewalque (1826-1905), Eugène Dumortier (1801-1876), Jules Marcou (1824-1898), and Alcide d'Orbigny. Afterwards he spent four months in England. During that time he met John Phillip (1800-1874) and James De Carle Sowerby (1781-1871). He came then back to Stuttgart where he would meet with the most important geologists and paleontologists of the area in a tavern every Monday. He published his masterpiece, *Die Jurasformation Englands, Frankreichs und des südwestlichen Deutschlands*, in the journal of the just founded *Verein für vaterländische Naturkunde in Wüttemberg* in 1856-58.

The professor of paleontology in Munich, Andreas Wagner (1797-1861), was so impressed by Oppel's work that he offered him a position at the same university. Without hesitation, Oppel accepted Wagner's offer, under pressure from Quenstedt to do so. (Quenstedt and Oppel's relationship was troubled[87] - characterized as Quendstedt's lack of appreciation for Oppel's work.) In particular, Quendstedt had numerous objections to the use of data derived from d'Orbigny's investigations. In pressuring Oppel to accept Wagner's offer, Quenstedt was in fact working to impede Oppel's career in Tübingen. Oppel obtained his *venia legendi* at the Münchner University with a cumulative habitation and started teaching, for the most, courses on the paleontology of invertebrate fossils and techniques for collecting and describing them. After Wagner's death (1861),

[85] He changed his opinion a few years before his death. This change is confirmed in a letter between Oppel and Rolle. Also Hochstetter reports a dialogue between Oppel and himself a few months before Oppel's death: Oppel was "fest überzeugt, dass die eine Art aus der anderen durch langsame Veränderung hervorgegangen ist, und ich [Oppel] hoffe es noch einmal beweisen zu können; aber ich bedarf dazu einer viel grösseren Anzahl von Exemplaren, um durch viele Vergleiche den ganzen Uebergang zu constatieren" (Hochstetter, 1866, p. 66)

[86] Quenstedt was an important paleontologist and mineralogists. He studied in Berlin where he obtained both his Ph.D and *venia legendi*. In 1842 he took the position of Professor of Geology in Tübingen. His masterpieces are *Handbuch der Petrefaktenkunde* (1852) *and Der Jura* (1858).

[87] As I have pointed out in the first chapter, the teacher-student relationship is fundamental for explaining the historical and philosophical development of the paleontology in German speaking countries.

Oppel took the full professorship and the directorship of the paleontological collection. He would die prematurely just four years later.

From Local to Global History

Through the accurate reading of rock layers, stratigraphy perceives the historical development of the earth. During the 19th century, some stratigraphic studies were published. They were mainly investigations of the structures of a geological formation in a specific country[88]. A global stratigraphic monograph was, however, absent: it was Oppel who would rise to this challenge. His *Jurasformation* was a comparative investigation of the common structures behind the various local systems in France, Germany, and England. Oppel's investigation marked a turning point both as regards the notion of fossil record as event and the method of perceiving and using deep time[89]. In fact, "the man who was to place the whole science of stratigraphical geology on a new footing and to breathe new life into it was Albert Oppel" (Arkell, 1970, p. 15). He placed stratigraphical geology on a secure and non-speculative footing.

As he set out to accomplish his investigation, Oppel first faced a methodological problem. How was it possible to carry out a comparative study between apparently different systems so that the flow of time could be globally perceived? Although Smith, Phillips and Conybaere had established a detailed system of names and layers for the Jurassic period in England, their time units and scale were vague. They could not be used globally. Bronn's solution, i.e. to list the localities in which the fossils were found, must be rejected. The important question is therefore whether, and to

[88] William Smith (1769-1839) mapped England in 1815. He asserts that "each stratum is also possessed of proprieties peculiar to itself, has the same exterior characters and chemical qualities, and the same extraneous or organized fossils throughout its course" (W. Smith, 1815, p. 2) William Conybeare (1787-1857) and William Phillips (1775-1828) followed this work. In *Outlines of the Geology of England and Wales* (1822) they tried to catalogue the rocks by the means of the by fossil record. Nevertheless, in their attempt they did not use only the fossil record to identify the formation. As J. M. Hancock asserts "the idea of being able to subdivide a broadly homogeneous formation on fossils alone did not exist in Conybeare and Philipps's general study"[88] (Kauffman, 1977, p. 9). Only after the works of Deshayes (1830), Bronn (1831), and Lyell (1833) was the recognition and division of a formation centred on the fossil record and not on lithological features.

[89] Andreas Wagner (1797-1861) asserts "Eine der allerwichtigsten und erfolgreichsten Arbeiten, die in neuerer Zeit auf dem geognostichen und palaeontologischen Gebiete erschienen sind, den zum Erstenmale wird hier die Große Confusion, die in der Bestimmung der Schichten und der Petrefacten bei den einzelnen Autoren herrschte, auf Grund eigner Anschauungen und Vergleiche gründlich gelöst. Das ungeheure Verdienst, welches sich OPPEL mit dieser Arbeit um die Kenntniß der Juraformation erworben, ist auch alsobald allenthalben anerkannt worden und sein Buch ist jetzt der Ausgangpunkt für alle weiteren Untersuchungen über diese wichtige Formation geworden" (Martin, 1965a, p. 186). Not only did academics appreciate Oppel's work, but it was also recognised by the kings of Württemberg – who appointed Oppel with the gold medal for art and science.

what extent, it is possible to export the acquired results of a local formation into other similar formations recognized in diverse countries? Roughly speaking, the problem involves the use of materials gathered locally and stocked in a catalogue or an index for acquiring a global degree of knowledge. Can paleontologists use data collected and developed in one place to explain a global phenomenon[90]?

Let us consider again the two examples presented in Fig 1., and Fig. 2. The geological profile drawn in the Fig.1 might have a different genesis to that as given here, and thus we need to look to different causes. It might not be the product of the sea, but the result of telluric movements. To overcome this impasse, the geologist's only option is to find other places where this phenomenon occurred and verify whether the same local conditions are present. If he comes across other dispositions of rocks with the same names and environment, he obtains a global explanation. He exports the data gathered locally to another system – an attempt to explain and understand a global phenomenon by means of the local. However, using the same practice for paleontological investigations is extremely dangerous. About this point Oppel was very clear. In exporting names and contents from one system to one other, many difficulties arise: "die Resultate waren nicht günstig und die Fehler gross". If we try to subsume the data gathered in a place into the lithological features emerging in another place, we encounter many errors.

Accordingly, another path was taken. Instead of trying to transfer the English system to other countries, an attempt was made to divide, for example, the Jura in "grössere Gruppen". This separation had the effect of obtaining a local dissection of the system. D'Orbigny divided the French Jura in 10 "Etagen". The main problem was, however, that "in diesem ersten Gruppen wird die Jura-formation meist bloss in grössere Gruppen, nicht in ihre einzelen Elemente zerlegt". (Oppel, 1856, p. 122) The second attempt was, further, not able to provide a valuable practice for acquiring a global degree of knowledge. The division into stages is too approximate to show precisely what happened in those formations[91]. We cannot acquire a global knowledge, because we cannot unify and compare two containers that represent two different unities of time and space. We are not even quite sure about what happened within a stage, since it is extremely difficult to order its elements and thus the degree of approximation is even higher. If we consider the *Etagen* as our starting point, we can only have an imprecise knowledge. We may list the organisms of these periods, but we are not able to order these elements.

[90] This is *mutatis mutandis* Bronn's problem. Bronn's starting points in, for instance, *Italiens Tertiär-Gebilde*, are data collected in Italy. By the means of this data [nach Maasgabe ihrer fossilen Reste], he tries to come up with a global degree of knowledge.

[91] This is precisely the problem that Bronn points out.

As a consequence, the only possible means of accessing deep time was through re-scanning all the defined *Etagen* to annotate their constitutive elements and differences. In fact, even a tiny vertical section of rock can represent a huge span of time and speak for different environments. At the same time though, it is important to go beyond a local certainty in seeking a global degree of knowledge. By means of a local investigation "kann eine genaue Vergleichung ganzer Systeme gesichert werden." In other words, one can access all the formations and so acquire a wide range of knowledge. Oppel's starting point is therefore threefold. First, it is about the problem of identification of local layers that are useful in identifying the finer unity of time and space. Second, it is about the possibility of correlating the different layers found in disparate places. These places are not only different parts of the Swabian Alps, but of the entire of Europe. This point entails the necessity of overcoming national boundaries. From now on paleontology and geology should globally investigate the formations and genesis of space-time[92]. Third, Oppel is concerned with the possibility of a comparison between locally acquired results. A precise comparison is, in fact, what allows the birth of a new kind of data and of global knowledge.

Oppel's starting point is a description of all fossils present in a certain area. The problem is now how to correlate and how to determine the fundamental characteristics of the different rock layers. In response to this, Oppel came up with a method of correlating the rock layers of one place with those of another, working with the nature and the number of the fossils. He suggested that, the same kind of species collected in a zone can be found in another one. This implies that the paleontologist draws a vertical temporal profile by putting together the species found in different places[93]. As a result, "man erhält dadurch ein ideales Profil, dessen Glieder gleichen Alters in den verschiedenen Gegenden immer wieder durch dieselben Arten charakterisiert werden." (ibid.) A global knowledge is generated which goes beyond the local source of its data.

Oppel suggests that the paleontologist can compare the elements of various beds by using the same number and kind of fossils. This epistemic practice, in turn, requires two preliminary

[92] It is not a case that in the next twenty years both geologists and paleontologist will develop a geological map for the entire of Europe.

[93] It is worth noticing that Oppel probably took this idea form his teacher Quenstedt. In concluding his *Der Jura* (1858), he asserts "Aber ermüden wir nur nicht im Durchforschen unserer Schichten, suche Jeder in seinem Nachbarlichen Gebiete mit genauer Aufzeichnung der Fundstellen so viel als möglich zu sammeln und das Gesammelte Andern mitzutheilen, dann dürfte wenigstens das **erste Ziel** aller geologischen Forschungen uns nicht mehr ferne liegen: *eine treue Darstellung der Schichtenfolge*." (Friedrich August Quenstedt, 1858, p. 823) I would like here to notice Arkell's translation error, since it may create confusion. Arkell translates the last sentence, "*eine treue Darstellung der Schichtenfolge*" in "*a true table of succession of strata*" (Arkell, 1970, p. 14). However, Quenstedt did not mean to give a true table of succession, but only a faithful, i.e. reliable, presentation. In other words, the point is not about the truthfulness of the presentation, but about its use as a reliable tool.

conditions. First, the paleontologist needs a good amount of data: "die Schwierigkeit dabei hängt hauptsächlich an der ungenügenden Zahl gut beschreibender Arten". The first condition thus concerns the quantity of the fossil record. The quantity of the data is key element in the accessing of a global degree of knowledge. The quality of the fossil record also plays an essential role. From a chaotic bunch of data, an ideal profile cannot appear. It is essential to sharply differentiate between that data. To accomplish this aim, perception must be trained. The second condition is that the paleontologist must necessarily improve his observational skills. He must learn how to observe because he has to distinguish what is essential from what is not. The fundamental data that he must gather are in turn divided into two groups. On the one hand, the paleontologist should collect only species that characterize the particular bed in which they are found. On the other, these should be qualitatively good enough for comparison with exemplars taken from other localities. Therefore, "Je schärfer die Species getrennt ist, desto genauer können auch die Schichten eingetheilt werden."

To summarize, Oppel identifies the fossil record with events that occur in time. But unlike Bronn, he zooms in on points of vertical time to study how they are connected. He found out that in reality these points are zones in which a good amount of data can be found. However, not all information contained in these zones can be used: the paleontologist should learn how to 1) perceive qualitatively good data, 2) mange a large amount of data and 3) elaborate this in order to narrate the history of the earth.

Oppel's Zone

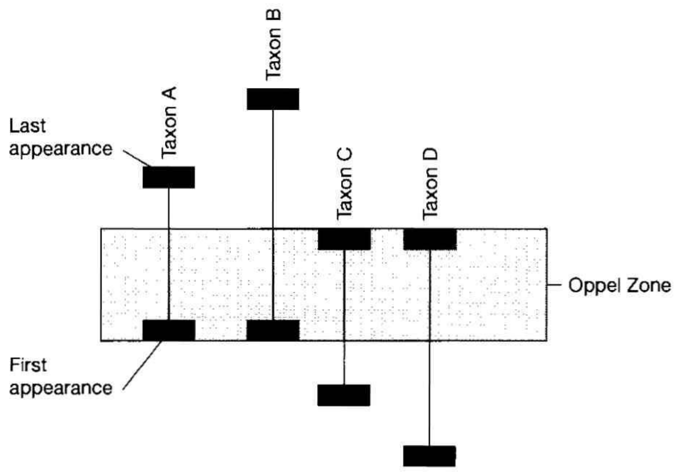
Oppel's most significant result entailed how to distinguish and correctly classify paleontological data. In fact, Oppel's concept of zone differs from that one theorized by d'Orbigny or from Smith's idea of stages. This difference marks its utility and value for the evolutionary investigations of the next generation of paleontologists. Consequently, it is worth comparing d'Orbigny's stage with Oppel's zone.

In the famous paragraph 116 of the second volume of the *Cours élémentaires de paléontologie et de géologie stratigraphiques* (1852), d'Orbigny revealed what he meant by *étage* in relation to the species:

> "Un étage, pour nous, est une époque en tout identique à l'époque actuelle. C'est un état de repos de la nature passée, pendant lequel il existait, commedans la nature actuelle, des continents et des mers, des plantes et des animaux terrestres, des plantes et des animaux marins; et, dans les mers, des animaux pélagiens et des animaux côtiers à toutes les zones de profondeur." (D'Orbigny, 1852, p. 256)

D'Orbigny's notion of stage is identifiable with the notion of epoch (à la Buffon). Stages are vast spans of time in which flora and fauna existed as they can be found today. They are analogically similar to the current state of the earth system. Étages are meant to be a vast states of nature in which the temporal and the spatial direction (i.e. geographical dispersion) are inextricably woven. On the contrary, zones are for d'Orbigny pure intervals of time. As such, they provide stable time unity for the vast stages. As Claude Monty pointed out, "Zones were the indices of time which gave chronological significance to the stages." (Monty, 1968, p. 689) D'Orbigny's notions of zone and stage are thus characterized by temporal and spatial proprieties. Space and time are two elements melded into an organic unity.

Oppel refused this confusion of temporal and spatial dimension. Although he did not define what a zone is, we can infer a definition through his use of the term. The zone is the smallest unit by which the layers of the rocks can be divided - indicating a spatial disposition. It is characterized by paleontological elements, i.e. by great number of fossils (see figure 4). Oppel lists the most typical species for every *Étage* or zone and their geographical diffusion. The identification of the most typical species is, however, only the first step. Successively, these layers should be reconnected to



deal with the general relations among the formations. As a result, Oppel draw an ideal profile of the Jura.

Figure 15 Illustration of Oppel's notion of zone. From (Boggs, 2006)

Let us take as example the Lias formation in the low Jura to better analyze Oppel's idea. The formation can be divided into three *Etagen* – termed respectively, by country: Unterer Lias, Mittelere Lias, Oberer Lias (Germany); Sinémurien, Liasien, and Toarcien (France); Lower Lias, Marlastone and Upper Lias (England). Oppel divided the Lias into eight zones based only on the fact that “immer diejenigen Arten beigeschrieben, welche sie besonders charakterisieren und noch in keiner anderen Schichte gefunden wurde.”

1 Germany	2 France	3 England	4 Italy
a, b, c, d, l	a, b, f, g, h	a, b, c, d, f	b, g, f, h

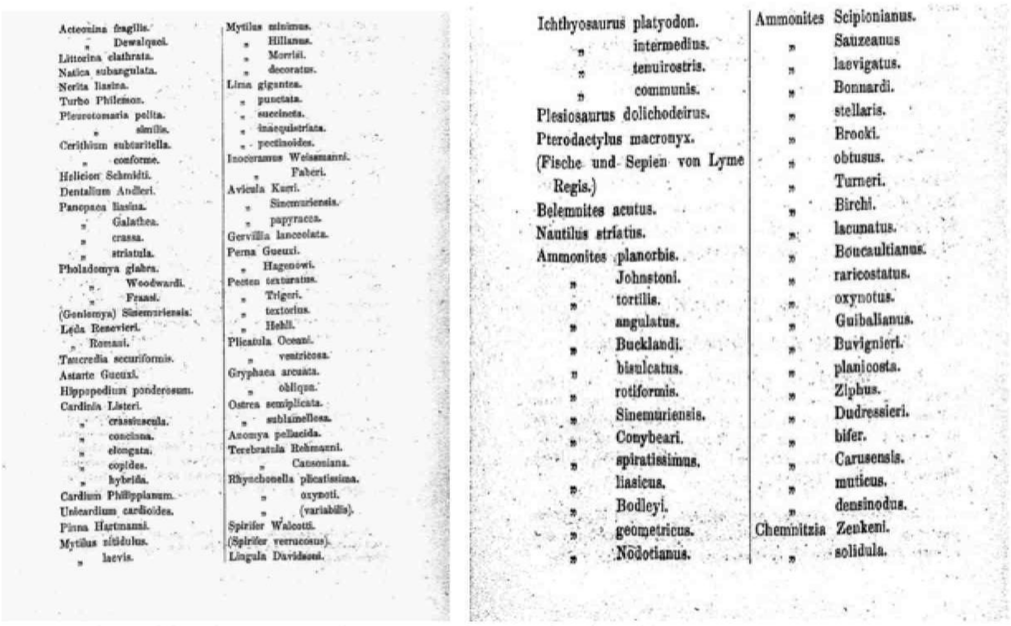
Figure 16 Four different stages from diverse localities in Germany, France, England, and Italy.

For instance, assume that we have four different stages of the same étage from diverse places (1-4 above). The paleontologist aims to order these stages in order to narrate a history. They contain in turn various species *(a-h)*. By sharply observing and differentiating these fossils, he obtains an initial correlation between the strata. He recognizes the constitutive elements of each layer by differentiating it from the others. For example, the species *a, d, c, d, l* characterize the first formation. At the same time, they differentiate the first stage from the others. Secondly, the paleontologist has to face the problem of their order. He observes that the species *a* is the most present in the first stage, the species *b* in the second, and *c* in the third. He accordingly names the first stage as *zone A*, the second as *zone B* and the third as *zone C*. The process of identification of zones, however, is not based upon the occurrence of one single species, namely what Leopold von Buch (1774-1853) called *Leitfossil*. A single species is neither enough to determinate zones nor to order them. Zones are determinable only by using and comparing the complete fauna[94], “beziehungsweise nach den vertikal am wenigsten, dagegen horizontal möglichst weit verbreiteten Elementen” (Diener, 1925, p. 218). Coming back to the four possible zones above (Fig.5), it is only possible to determinate their order and development after having compared the entire fauna of the forth selected regions. It turns out that the third zone precedes the second because it shares greater quantity of fossils. The essential characteristic of the zones and *a fortiori* of the *Etagen* is thus that they represent not only the most common fossils, but also the entire fauna of the period. Oppel’s zones are complex and complete windows into the diversity and richness of species of the past.

At first glance, it might seem that the paleontological judgment is a mere expression of what he observes: he perceives that the species *a* occurs mostly in the first stage and he names it accordingly *zone A*. However, this process is not the manifestation of a mere collection of data. It is

[94] It is surprising to notice that many Oppel’s contemporaries did not realise this important point. Among others, I will recall Woodward’s statement that “zones are assemblages of organic remains of which one abundant and characteristic form is chosen as index”

based upon numerous theoretical assumptions. As I mentioned before, principles and postulates are the real instruments of measurement and perception. In fact, Oppel aimed not only to reconstruct a zone, but to come up with a procedure for obtaining a precise temporal and spatial profile of a determinate geological period. To accomplish this aim, he focused on the local correlation between diverse zones. For example, he listed which kind of species can be found in the *unterer Lias*.


Actaeonina fragilis.
" Dewalquei.
Littorina clathrata.
Natica subangulata.
Nerita liasina.
Turbo Philemon.
Pleurotomaria polita.
" similis.
Cerithium subturritella.
" conforme.
Helicion Schmidti.
Dentalium Andleri.
Panopaea liasina.
" Galathea.
" crassa.
" striatula.
Pholadomya glabra.
" Woodwardi.
" Fraasi.
(Goniomya) Sinemuriensis.
Leda Renevieri.
" Romani.
Tancredia securiformis.
Astarte Gueuxi.
Hippopodium ponderosum.
Cardinia Listeri.
" crassiuscula.
" concinna.
" elongata.
" copides.
" hybrida.
Cardium Philippianum.
Unicardium cardioides.
Pinna Hartmanni.
Mytilus nitidulus.
" laevis.

Mytilus minimus.
" Hillanus.
" Morrisi.
" decoratus.
Lima gigantea.
" punctata.
" succincta.
" inaequistriata.
" pectinoides.
Inoceramus Weissmanni.
" Faberi.
Avicula Kurri.
" Sinemuriensis.
" papyracea.
Gervillia lanceolata.
Perna Gueuxi.
" Hagenowi.
Pecten texturatus.
" Trigeri.
" textorius.
" Hehli.
Plicatula Oceani.
" ventricosa.
Gryphaea arcuata.
" obliqua.
Ostrea semiplicata.
" sublamellosa.
Anomya pellucida.
Terebratula Rehmanni.
" Causoniana.
Rhynchonella plicatissima.
" oxynoti.
" (variabilis).
Spirifer Walcotti.
(Spirifer verrucosus).
Lingula Davidsoni.

Ichthyosaurus platyodon.
" intermedius.
" tenuirostris.
" communis.
Plesiosaurus dolichodeirus.
Pterodactylus macronyx.
(Fische und Sepien von Lyme Regis.)
Belemnites acutus.
Nautilus striatus.
Ammonites planorbis.
" Johnstoni.
" tortilis.
" angulatus.
" Bucklandi.
" bisulcatus.
" rotiformis.
" Sinemuriensis.
" Conybeari.
" spiratissimus.
" liasicus.
" Bodleyi.
" geometricus.
" Nodotianus.

Ammonites Scipionianus.
" Sauzeanus
" laevigatus.
" Bonnardi.
" stellaris.
" Brooki.
" obtusus.
" Turneri.
" Birchi.
" lacunatus.
" Boucaultianus.
" raricostatus.
" oxynotus.
" Guibalianus.
" Buvignieri.
" planicosta.
" Ziphus.
" Dudressieri.
" bifer.
" Carusensis.
" muticus.
" densinodus.
Chemnitzia Zenkeni.
" solidula.

Figure 17 Species presented one zone of Lias named *Ammonite planorbis*

First, he collected and described all the species present in the Unterer Lias. Second, in order to facilitate the further treatment of this set of fossils, Oppel assigned the name of the most strongly present fossil record to the entire zone. This operation is based upon particular kinds of fossil singled out by morphological peculiarities. As Fig. 6 shows, one zone of the *unterer Lias* is named *Ammonite planorbis*. This is due to the relative abundance of the species Ammonite planorbis in this particular spatial and temporal dimension. However, it is important to stress again that it is not the presence of a *Leitfossil* which characterizes a zone, but the entire fauna[95]. The *Ammonite planorbis* is only a useful support for the easy handling of a specific fauna. Third, Oppel concentrates on the description of the geographical dispersion of these faunas by listing the places in Germany, France and England where these fossils have been found. This procedure is particularly interesting: it shows the possible patterns of geographical dispersion of the species in

[95] Karl Diener (1862-1928) significantly stresses this point ‚asserting that „Die Tatsache, daß die Oppelsche Zone durch die Fauna, nicht durch die Art definiert werden muß, kann nicht scharf genug betont werden.“ (Diener, 1925)

Europa. In fact, one can trace the dispersion of the different species of ammonite from their first appearance in a particular zone to their last one. It turns out, for instance, that

> "Viele Punkte wären in Württemberg zu erwähnen, an denen Amm. Planorbis eine reiche Lange bildet, dagegen finden wir auch Stellen, an welchen er sparsamer auftritt [...] In Frankreich finden sich die Schichten des Amm. Planorbis am mehreren Punkten Burgunds; [...] In England ist die Zone des Amm. Planorbis mächtig entwickelt."(Oppel, 1856, p. 146)

That means that some of the species contained in this zone also lived in undetermined time in France, Germany and England. If we were able to collect them, we could precisely narrate their temporal and spatial growth. This method has an heuristic value. It guides the paleontological perception step by step, so that the paleontologist can unearth new data by having previous knowledge of their possible spatial location. As a result, we obtain a first pattern of dispersion and development of the species collected. By simply narrating the spatial and temporal modality of the succession of the species through the Triassic period we acquire biologically precise trends. Oppel did not, however, push this conclusion further. He started working on it only the last years of his life. His students took up this field of research and published important papers in the following years[96].

As above, Oppel's work aimed to unify what was previously discrete in order to generate a global knowledge of the Jura system and fauna. Therefore, his final goal was to unify the results of the descriptive local work: for each of the three *Etagen* of the Unterer Lias, Oppel provided orderly listing of the fossils presented.

[96] It is clear that the two possible directions of investigation are respectively the construction of evolutionary and temporally orientated trends (they will be named *Formenreihen*) and the recognition of spatial patterns. Paleogeography will take up this former investigation. However, these two branches are only apparently separate. In fact, their data and methods are tightly linked. Concerning the possible patterns traceable from Oppel's data and their nature, another question can be raised. For instance, we can attempt to answer old questions such as: "Do the various fossil bearing layers represent: (a) successive spontaneous generations; (b) successive creations of supernatural origin; (c) or the transformation of species? Did case (c) imply a theory of evolution? Do the fossil faunas and floras found in various layers of a geological formation give any evidence to the primordial climates of the periods in which the respective layers were formed? How long is the time-span of Earth history?" (Schweizer, 2008, p. 261) Oppel, however, did not answer any of these questions. But his practice was able to shape the required data to answer those questions. I will return to this point in the next pages.

Eintheilung des unteren Lias nach seinen paläontologischen Characteren.

Nro. 1.

Raricostatusbett.	Zone des *Amm. raricostatus.*	Amm. densinodus. Amm. muticus. Amm. Carusensis. Pentacrinus scalaris.
Oxynotusbett.	Zone des *Amm. oxynotus.* Amm. bifer. Amm. lacunatus.	Acteonina Dewalquei. Mytilus minimus. Leda Romani. Plicatula ventricosa. Rhynch. oxynoti. Lingula Davidsoni.
Obtususbett.	Zone des *Amm. obtusus.*	Panopaea crassa. Pholadomya Fraasi. Cardinia hybrida. Terebratula Causoniana. Amm. Brooki, stellaris. Amm. planicosta, ziphus, Dudressieri.
Tuberculatusbett.	*Saurierbett.* Ichthyos. platyodon. „ intermedius. „ communis. „ tenuirostris. Plesiosaurus.	Amm. Birchi, Bonnardi, Turneri. Gervillia lanceolata, Inoceramus Faberi. Gryphaea obliqua beginnt hier. Acrosalenia minuta.
	Bank des *Pentacrinus tuberculatus.*	
Bucklandibett.	Zone des *Amm. geometricus.*	Bel. acutus erscheint hier zum ersten Male. Amm. Sauzeanus „ Scipionianus „ laevigatus.
	Zone des *Amm. Bucklandi.*	Amm. Bucklandi, „ bisulcatus, „ Sinemuriensis, „ Kridion, Amm. Conybeari. „ rotiformis. „ liasicus. „ spiratissimus.
Angulatusbett.	Zone des *Amm. angulatus,* Schl. (Moreanus d'Orb.)	Chemnitzia Zenkeni. „ solidula. Acteonina fragilis. Litterina clathrata. Natica subangulata. Nerita liasina. Cerithium subturritella. Panopaea Galathea. Tancredia securiformis. Cardinia elongata. „ concinna. Mytilus nitidulus. „ Hillanus. Perna Gueuxi. Asterias lumbricalis. Cidaris arietis.
Bett des Amm. planorbis.	Zone des *Amm. planorbis* u. Amm. Johnstoni.	Avicula Kurri. Pecten Trigeri.
Bonebed. Knochenbett	Microlestes, Nothosaurus, Termatosaurus, Gyrolepis, Saurichthys, Sphaerodus, Ceratodus, Acrodus, Thectodus, Hybodus.	Eine Anzahl unbestimmter Muscheln: Avicula, Gervillia, Pecten u. s. w.

Keuper = New Red = Marnes irisées.

Figure 18 The ideal profile of the *unter Lias* based entirely on the fossil record presented in it

Fig. 6 shows the sequence of the zones contained in the Etage *unter Lias*. At the same time, it lists the organisms which lived in Germany, France and England during this determinate span of time. Oppel applied the same method to the other *Etagen*, so producing so an ideal profile of the Jurassic:

Formationsabtheilungen.	Etagen oder Zonengruppen.	Zonen (Lager oder Stufen, d. h. paläontol. bestimmbare Schichtencomplexe).	Conybeare & Phillips. 1822. England.	Dufrénoy & Élie de Beaumont. 1848. Frankreich.
Oberer Jura oder Malm.	*Kimmeridge-gruppe.*	Zone der Trigonia gibbosa.	Upper Division of Oolites.	Ét. supér. du système oolithique.
		Zone der Pterocera Oceani.		
		Zone d. Astarte supracorallina.		Étage moyen du système oolithique.
	?	Zone der Diceras arietina.	?	
	Oxford-gruppe.	Zone des Cidaris florigemma.	Middle Division of Oolites.	
		Low. calc. grit & Scyphienkalke.		
		Zone des Amm. biarmatus.		
	Kelloway-gruppe.	Zone des Amm. athleta.		
		Zone des Amm. anceps.		
		Zone des Amm. macrocephalus.		
Mittlerer Jura oder Dogger.	*Bathgruppe.*	Zone der Terebr. lagenalis.	Lower Division of Oolites.	Étage inférieur du système oolithique.
		Zone der Terebr. digona.		
	Bayeux-gruppe.	Zone des Amm. Parkinsoni.		
		Zone d. Amm. Humphriesianus.		
		Zone des Amm. Sauzei.		
		Zone des Amm. Murchisonae.		
		Zone der Trigonia navis.		
		Zone des Amm. torulosus.		
Unterer Jura oder Lias.	*Thouars-gruppe.*	Zone des Amm. jurensis.	Lias.	
		Zone der Posidon. Bronni.		
	Pliensbach-gruppe. (Liasien d'Orb.)	Zone des Amm. spinatus.		
		Obere Z. d. A. margaritatus.		
		Untere Z. d. A. margaritatus.		
		Zone des Amm. Davöi.		
		Zone des Amm. ibex.		
		Zone des Amm. Jamesoni.		
	Semur-gruppe.	Zone des Amm. raricostatus.		Calcaire à Gryphées arquées ou Lias.
		Zone des Amm. oxynotus.		
		Zone des Amm. obtusus.		
		Zone des Pentacr. tuberculatus.		
		Zone des Amm. Bucklandi.		
		Zone des Amm. angulatus.		
		Zone des Amm. planorbis.		

Nr. 63.

Vte. d'Archiac. 1856. Frankreich & England.	J. Marcou. 1848 u. 1857. Franche-Comté.	D'Orbigny. 1852. Nach ihrer ganzen Verbreitung.	Quenstedt. 1843. Schwäbische Alp.	Leop. v. Buch. 1837. Deutschland.
1e Groupe. Oolithique supérieur.	Upper Oolite.	*Étage portlandien.*		Oberer Jura.
		Étage kimméridg.	Weisser Jura. Weisser Jura ζ.	
2e Groupe. Oolithique moyen.		*Étage corallien.*	Weisser Jura ε. Weisser Jura δ.	
		Étage oxfordien.	Weisser Jura γ. Weisser Jura β. Weisser Jura α.	
	Oxfordian.	*Étage callovien.*	Brauner Jura ζ.	Mittlerer Jura.
3e Groupe. Oolithique inférieur.	Lower Oolite.	*Étage bathonien.*	Brauner Jura. Brauner Jura ε.	
		Étage bajocien.	Brauner Jura δ. Brauner Jura γ.	
		Z. Thl. mit dem Bajocien z. Thl. mit dem Toarcien vereinigt.	Brauner Jura β. Brauner Jura α.	
4e Groupe. Lias.	Lias.	*Étage toarcien.*	Schwarzer Jura oder Lias. Lias ζ. Lias ε.	Unterer Jura oder Lias.
		Étage liasien.	Lias δ. Lias γ.	
		Étage sinémurien.	Lias β. Lias α.	

Württemb. naturw. Jahreshefte. 1858. 3s Heft. 17

Figure 19 Ideal profile of the Jura as it results from the division in zones.

The final result of Oppel's investigation is thus an ideal profile that can be used to show patterns of temporal and spatial diversity through a particular span of time.

Hence, it is without any surprise that this ideal profile can be interpreted in two different ways. It can represent an accurate span of time or a geographical dispersion. According to G. H. Scott, the first interpretation is putative: "the putative view is that, because its method arranges zones in depositional order, it is a temporal classification — a zone identifies bodies of rock that were deposited in the same interval of past time and whose boundaries are isochronous" (Scott, 2013, p. 266). The second interpretation is empirical; it is about "an ordered classification of strata from observations on the distributions of fossils" (Ibid.). Although Oppel's concept of zone is purely spatial[97], he interpreted his ideal profile in both a spatial and temporal way: this fact generated two diverse approaches to the notion of zone and fossil record. The defenders of the empirical approach used Oppel's teaching to arrive at the biological meaning of the notion of zone and fauna. As I will show in the next chapters, this approach found two different expressions. On the one hand, many paleontologists concentrated on the quality of the fossils. They attempted to unify the well-preserved exemplars of a species through vertical temporal zones. On the other, a few paleontologists stressed the notion of quantity. By using statistical tools, they aimed to narrate a global evolutionary history.

Conclusion

Oppel's concept of zone was the essential condition for obtaining a precise temporal dimension. He taught how to perceive rock layers in order to give them a temporal meaning. His concept of the fossil record was entirely in line with that proposed in historical geology. Oppel conceived the fossil record as an event that can be used to narrate a history. It has a temporal or spatial development. The kind of interpretation about the development of these objects gives the impetus for four different developments. First it gives impetus for developing a method, which can be used to classify and recognize the species. Species, in fact, are the raw materials for bio-stratigraphical reconstructions. Hence, it is important not only to see the species as diverse, but also to find names that correspond to their characteristics[98]. These names in turn have to be universally accepted and

[97] Diener asserts that "Die *Zone* im Sinne *Oppels* ist also ein Terminus für einen räumlichen stratigraphischen Begriff." (Diener, 1925, p. 218)

[98] It is worth noticing that this method produces an incentive towards the realization of epistemic tools to contain and save the data. For example, Neumayr proposed to draw up an all-embracing *Nomenclator palaeontologicus* and the Russian paleontologist Hermann von Trautschold (1817-1902) attempted the *Nomenclator palaeontologicus der jurassischen Formation in Russland* (1863).

used. This line of investigation lies at the bottom of Zittel's study. Second, the putative interpretation will provide the ordered temporal scale sought by Bronn. Bronn complained about the lack of precise temporal strata since his first studies. By following Oppel's methods a more precise local determination of time can be given. The gaps presented in Bronn's time scale could be finally filled, implying that the mathematical treatments of paleontological data could be finally carried out even on smaller unities[99]. In fact, many paleontologists would carry out a statistical treatment of the fossil record in later years. Third, since all the members of the various zones are carefully listed, the majority of paleontologists decided to follow the development of some of the well-preserved fossils in the course of the time. They traced this development to achieve biological conclusions. Fourth, if the paleontologists stress the empirical interpretation, a geographical dispersion of the species can be accomplished.

Oppel did not radically change the meaning of the fossil record as proposed by Bronn's quantitative treatment of data. Nevertheless, he marked an indubitable turning point in paleontological investigations, spreading an important method which would modify Bronn's notion of data during the subsequent years: this transformation would open a space for paleontological contributions to the theory of evolution.

[99] Interestingly, Oppel did not even try to use mathematical methods to depict the history of life, because—as his friend the geologist and paleontologist Ferdinand von Hochstetter (1829-1884) reports—he was not trained at all in mathematics. (Hochstetter, 1866, p. 60)

Chapter V. How an Epistemic Practice shapes its Data: Formenreihen and Evolution

Introduction. Zone: Range or Assemblage?

Oppel died prematurely in 1865 and it was not easy to find someone able to take over his professorship. Although he had trained many scholars[100], all were as yet lacking the expertise or formal qualification (*venia legendi*), required for a university post. Oppel's work had proved formative for all, their careers evidencing his thinking at different points, and to various degrees. This section deals with the putative interpretation of Oppel's ideal profile. It considers the disposition of the fossil record as a temporal succession. This temporal unity provides the schema required for narrating an evolutionary history. Due to the imperfect and incomplete nature of the fossil record, it has only a local validity and the paleontologist is unable to arrive at evolutionary processes, but can achieve accurate local patterns.

The starting point is Oppel's notion of zone. As I have shown, Oppel considered zone as a spatial content whereby it is possible to list the events that happened in a particular time. Emphasizing the spatial interpretation of Oppel's concept of zone, Diener describes its two directional development in the second half of the 19th century. He claims that "Obschon ursprünglich im Sinne eines räumlichen Begriffes aufgefaßt — entsprechend einer Schichte oder Shichtgruppe mit einer ihr eigentümlichen Einzelfauna — erlangt die Zone durch ihren faunistischen Inhalt einerseits einen zoologischen, anderseits einen chronologischen Wert" (Diener, 1925, p. 217).

It seems than that zone has been conceptualized in two different, even quite opposite, ways. It can have a chronological, i.e. stratigraphic meaning, or a zoological one. Despite Diener's analysis, this distinction was not apparent within the paleo-geological community that adopted Oppel's investigations. Indeed, pursuing it would have had adverse effect upon efforts to shape the paleontological data required for evolutionary explanation. The zone provides the epistemic thing for historical paleontology. The first point to clarify is the notion of zone and its weight in evolutionary thought.

The British geologist Ralph Tate (1840-191) provides us with fitting point of departure - towards understanding the notion of zone. In 1867, Tate published a paper on *the Lower Lias of the North-east of Ireland*, in which he carefully followed Oppel's methods of investigation. At the same time, though, he developed a zoologically oriented interpretation of the concept of zone. He was

[100] I would like to recall Th. Schrüfer, W. Waagen, G. Laube, G. Maack, G. Schlönbach, C. Schwager, M. Neumayer.

firmly convinced that a zone has a zoological meaning, since it represents a fauna. The zoological meaning consists in the richness of biological information held in this particular kind of assemblage. The paleontologist can obtain various information from it about, for instance, the biological, ecological, or geographical nature of the sample. A zone is not therefore "the range of [for example] an Ammonite" (Ralph, 1867, p. 301).

At first glance, there is a clear difference between considering a zone (namely an assemblage of fossils) as a range of a species than as a zoological element. This distinction is, at foremost, historical. By stressing the zoological meaning, the paleontologist immediately has in mind the names of d'Orbigny, Bronn, Agassiz; whereas he associates the notion of range of a fossil with a stratigraphic investigation (à la Smith, Conybeare, or Phillips). It must be said that the stratigraphic purpose is what Tate aimed at, but it can only be carried out without taking into account the zoological meaning of the fossil record. This entails a second point. Not only does the zoological meaning of the zone mean that the fossil record is seen in its morphological and phylogenetic development, but *also that it cannot be considered as isolated point*. A fossil alone has no meaning at all: it has a meaning only to a museum or private collection. The fossil record should be related to other fossils to obtain a full meaning. The fauna contained in a rock layer is thus an assemblage of fossils. That assemblage must be used in its entirety: a single specimen finds space for validity only in a morphological catalogue or in a museum, but has no utility in stratigraphic works.

This point is particularly interesting, since it clarifies the notion of fossil record proposed by Oppel and as successively used in historical geology: a single fossil record has no meaning. It assumes a meaning only once employed in relation to other elements. The assemblage of fossils holds meaning as a chronological list of events, marking "a determinate stage in the life-history of the formation." (Ibid.) This means that the paleontologist can narrate a history from that assemblage – although the history would assume, in turn, a new feature. i.e. no longer merely a chronological list of events, it also narrates the changes of fauna within deep time.

This point was, indeed, hidden in the folds of Oppel's investigation. Tate read Oppel's works carefully in order to draw their natural conclusions. Nevertheless, he missed one important point. Although Tate emphasized the epistemic importance of the quantity of the fossil record, he refused to reconsider the 'old' notion of fossil range. He was therefore not able to follow the development of the species of families within a particular span of time. Some of Oppel's students, on the contrary, did pursue this. Unlike Tate, they did not recognize the importance of treating the fossil record as a bulk of data, but they genetically expanded the notion of range of fossil.

Neumayr and Waagen were the main paleontologists to develop and expand the notion of the fossil record in this direction. They not only emphasized how fossils have to be connected, both vertically and horizontally, by scanning the rocks layer by layer, but they also set this particular notion of fossil as a fundamental concept for historical geology. Their analysis obtained a wide audience and both Simpson and Eldredge reviewed Neumayr and Waagen's methods positively.

This chapter will begin *ex abrupto* by exposing what the genetic relationship is, according to Waagen. Afterwards I will return to the wider historical framework of this method. I will then continue to investigate the relations between genetic relationships and the theory of evolution by focusing on the contribution of paleontology to the Darwinian theory of evolution. In the last section of the chapter, I will explore the role of statistics for paleontological sciences during the 19th century. Statistically oriented paleontologists developed the notion of fossil as range and assemblage by means of statistical analysis. However, the statistical method was purposely rejected because its results appeared openly against the Darwinian theory of evolution. I will thus analyze in-depth the paleontological reception of Darwin theory and the objections raised against statistics. Furthermore, I will spell which kind of notion of data owned statically oriented paleontologists. Fourth, I will sketch out how historical geology and paleogeography met. This last part will be useful in summarizing the life cycle of this particular notion of fossil – engaging with its reception during the paleobiological revolution.

Genetic Relationship

In my investigation I have so far provided some guidelines towards understanding what the particular material object named the fossil record is. By means of a historical epistemology, I have identified the various points of rupture and departure required before the fossil record can be perceived as a reliable source for paleontological investigations. Furthermore, I have attempted to single out the numerous layers of meaning that compose this object. A good way to catalogue these layers is to read them through the role played by perception. So far, I have emphasized the central role of observational processes in recognizing the function of the fossil record.

It is no wonder therefore if, in the first page of the preface of Waagen's *Formenreihe des Ammonites subradiatus* (1869), we find a lengthy celebration of perception. The paleontologist's desire is first and foremost to connect the "gemachten Beobachtungen in einer allgemeineren Arbeit" (Waagen, 1869, p. 181). Only by training his perceptual skills to perceive reliable local data, can the paleontologist begin his work. This training naturally progresses into globally-oriented investigation. The interesting question is how this more general work may be carried out. Under which conditions can perceptual materials be put together in order to ask questions that overcome the local validity of the data? Is there a method able to read the locally gathered paleontological data for a global degree of knowledge? And how do the characteristics of these objects influence the paleontologist's theoretical framework?

In 1869, Waagen proposed a global reading of local data able to generate global inferences: local data can be collected together to show their genetic relationships[101]. This particular reading of the fossil record depends on at least two conditions. Waagen had to specify the aims and essence of paleontology; he also needed to confront the existing approaches presented in the paleontological and geological sciences. This latter is the key criteria and impacts on the former. By taking a clear position on the methods and essence of paleontology, Waagen developed a technique for connecting local data to obtain a broader degree of knowledge. In this respect, Waagen more or less implicitly dealt with all the models that I have so far presented and adopted a clear position on them. Bronn's investigations provided the first model for reading the fossil record. His method of treating and reading the fossil record had profoundly impacted upon paleontological thought. He stressed a) the notion of chronology and its importance for coming up with patterns and processes of evolution; b) the use of statistics to generate patterns of development, and c) the continuity between the fossil record and its meaning as historical event. At the same time Bronn's method led—unsatisfactorily—to metaphysical and merely probable conclusions. Both Zittel and Oppel underlined the qualities and biases of Bronn's investigations; but in doing so established two different methods. Although they both argued that paleontology should avoid metaphysical conclusions and that it was essential to open a space for secure paleontological analysis, they addressed this differently. Oppel emphasized the local range of the fossil record and the certainty inscribed in it, whereas Zittel's investigations delimited the vertical dimension of time in order to focus on the morphological structures of the fossils.

In part, Waagen's analysis was a reaction against Bronn's attitude. In fact, although Waagen shared the fear of metaphysical conclusions, he did not reject the importance of chronology for paleontological investigations. He chose Oppel's approach to the fossil record and in doing so adhered to a particular interpretation. In interpreting the nature of the Oppelian zone, Tate, for instance, emphasized its zoological nature and not its stratigraphic meaning. At the same time, he underlined the incomplete nature of the segments represented by zones within the line of the history of the earth. Waagen took this further: if paleontology is a zoological discipline, it cannot be reduced *in toto* to zoology. It has an essential peculiarity: it is inevitably connected to chronology. In fact, it is not enough "die Form zu fixieren und durch eine genaue Beschreibung auch für Andere kenntlich zu machen" (Waagen, 1869, p. 182). The 'mere' description of forms (à la Zittel) has its validity in zoology, but it does not find its characterization in paleontology. Although Waagen

[101] Franz Martin Hilgendorf (1839 – 1904) was the first to introduce the term Formenreihe.

maintained that Zittel had given him the required impetus for his investigation, he seemed to refuse Zittel's radical methods and conclusions. Waagen understood the importance of Zittel's taxonomical and morphological analysis, but, following Bronn and the radical interpretation of Oppel's method, he indicated that the main paleontological aim should be research of temporal patterns of development. He claimed that the paleontological goal is "den historischen Zusammenhang der einzelnen Typen richtig aufzufassen, die organische Entwickelung einer Form aus der andern im Laufe der Zeiten nachzuweisen." (Ibid.)

Accordingly, temporal patterns of development would appear to constitute the essence of paleontology. This is a dangerous position. Bronn's analyses have shown too clearly the difficulty of coming up with such patterns. To address this, a different concept of the fossil record was required. This is deducible from the definition of paleontology Waagen gave:

> "Wenn man das Ziel, welches die Paläontologie im' Grunde genommen verfolgt, näher fixieren will, so kann nur die Absicht als solches bezeichnet werden, sämmtliche Organismen, welche je unsere Erde bewohnten, unserem Geiste, mithin unserem Erkenntniss- und zugänglich zu machen." [Italics mine] (Ibid.)

Paleontology aims to obtain *access* to *all the organisms* [sämmtliche Organismen] that once lived. At first glance, this definition seems not to be new at all. It seems to reflect, on the contrary, the classical definition of paleontology given by Cuvier or d'Orbigny. After a second reading though, we can clearly see its innovative power: it stresses the capacity of the paleontologist for knowledge of all the organisms that occupied the earth surface. Waagen admits explicitly that the paleontological epistemic object is the sämmtliche Organismen. This means the diversity of the forms that have appeared on the earth surface. He defines the global organism as the union of "eine Reihe sich successive folgender und gegenseitig sich verdrängender Faunen und Floren." (Ibid.) The paleontological epistemic thing is the union of all the plants and animals which have appeared; these elements are then inserted into a[102] possible line. This has a direction: fauna follow one another sequentially from the start to the end of the line. They are connected to each another each successive element shares something which the previous. At the same time, as they progress, they acquire new features and characteristics. Where the line is composed by an ordered succession of segments, it becomes possible to obtain the rate of this replacement.

Although the innovations of early 19th century paleontological investigations are clear, this is perhaps not the case with Bronn. This is in part correct. Both Bronn and Waagen share the vertical dimension of time as fundamental to the characterization of the fossil record. Waagen adds however an important feature to these objects. The time they represent is the result of stratigraphic investigations: it is the result of the interpretation of the concept of zone in the light of temporality. Time is not given, but patiently constructed.

[102] It is worth noticing the use of the indefinite article. In fact, Waagen is careful in his proceeding. As I will argue later, the fossil record is still ontologically imperfect and therefore the conclusions traceable from it are imperfect and probable only. The indefinite article warms the reader of this pitfall.

Waagen's starting points are Oppel's results. In fact, Waagen developed some of the points just drafted from Oppel. Due to his premature death, Oppel did not have the chance to expand his notion of zone, but was nevertheless able to spread his epistemic practice. Tate, among others, tried to use it by consequently modifying the notion of data. However, he firmly separated the zoological meaning from the stratigraphic one; Waagen aimed to reunite them.

The ideal line that represents the development of the organisms has to be applied to the spatial disposition of the rocks layers. The segments of the former line are seen now as the zones in rock layers. By vertically passing from one zone to another, the paleontologist draws a new line that marks the possible line of development of these forms. For instance, by carefully scanning diverse zones, it is possible to recognize that the ammonites have for "eine grosse Zahl von Schichten […] ein und desselben Bildungstypus" (Ibid.). This means that the different forms of ammonite are closely related to each other. By tracing the differences and similarity between the records found, Waagen thus draws "eine zusammenhängende Reihe, die man am besten mit dem technischen Ausdrucke „Formenreihe" belegen könnte" (Ibid.). Every point and segment of the Formenreihen are connected to each other by sharing a same structure: all the forms share the same *Bildungstypus*.

The relation between the elements of the series of forms is particular however:

> "Im Verhältnisse zu der früher vorhandenen Form des gleichen Bildungstypus mag die spätere vielleicht als Varietät erscheinen, doch ist dann das etwas ganz Verschiedenes von unseren heutigen, zoologischen oder botanischen Varietäten, welche in einer und der gleichen Zeitperiode neben einander auftreten: man muss daher streng unterscheiden zwischen *räumlichen* oder *zeitlichen* Varietäten." (Ibid.).

Variety is therefore a term related to a temporal succession, but it is essentially spatial. Contrary to zoological or botanical verities, paleontological diversity is purely the difference between specimens on the same horizon. This in turn is obtained through a spatial representation: "man muss daher streng unterscheiden zwischen räumlichen oder zeitlichen Varietäten". (Ibid.)

This conclusion is the natural consequence that derives from Oppel's notion of zone. The zones represent an assemblage of fossils and diversity can be easily detected by comparing their elements. We may determine another phenomenon from this practice. The species "in Rücksicht auf ihren Zusammenhang mit früheren oder späteren Formen aber als Mutation aufgefasst und betrachtet werden" (Ibid.). Mutation emerges from the temporally ordering of zone. If we go through the Oppelian ideal profile from the bottom to the top, we see that some species are tied together by a continuity of mutations. These occur gradually and "gewöhnlich die Unterschiede zwischen den einzelnen Mutationen um so minutiöser sind, je inniger verbunden die Schichten erscheinen, denen die Stucke entstamme" (Ibid.).

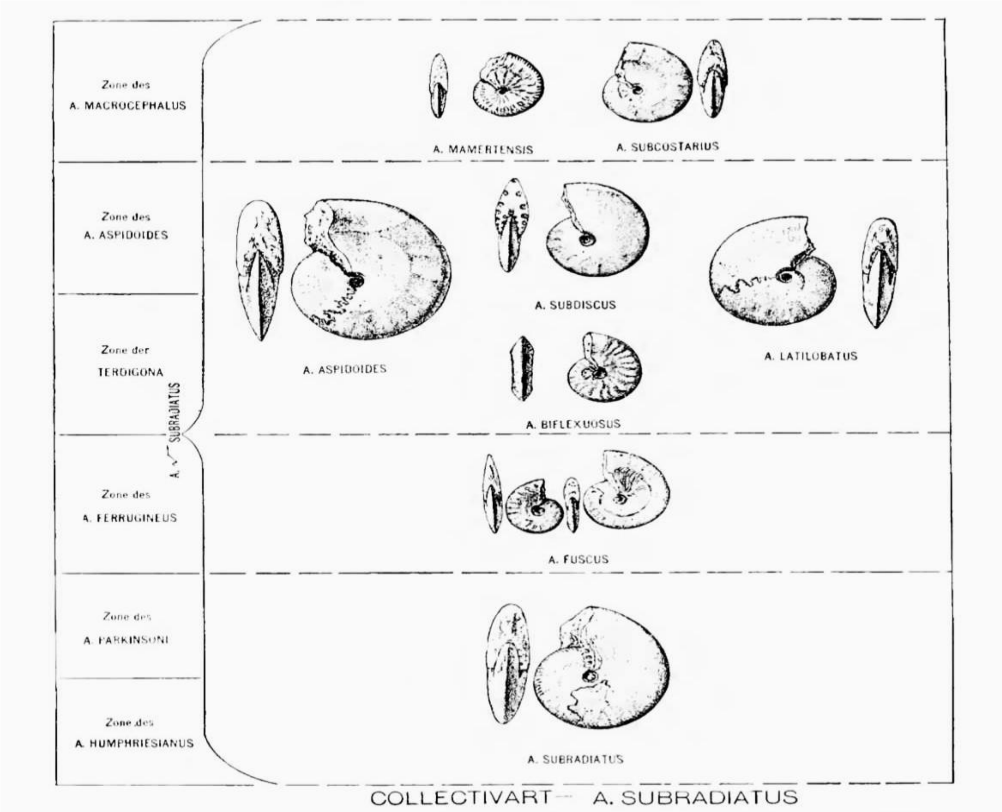


Figure 20 Osborn's graphical elaboration of the successive geologic mutations of *Ammonites subradiatus* based on Waagen's data. From (Henry Fairfield Osborn, 1917, p. 136)

This point is very important for the development of further paleontological investigations. The American paleontologist Henry Fairfield Osborn (1857-1935) called it "the greatest contribution which paleontology has made to evolution" (Henry Fairfield Osborn, 1907, p. 764). Although I deal in-depth with the repercussions of the *Formenreihen* for the theory of evolution in the next section, I will anticipate one important element here. What kind of utility does the *Formenreihen* have for evolutionary theory? Waagner's answer is:

> "Wenn wir nun von Abstammung überhaupt sprechen wollen, müssen wir jedenfalls einen genetischen Zusammenhang zwischen den einzelnen Mutationen einer und derselben Formenreihe annehmen, und es lässt sich auch wirklich der Gedanke nur schwer zurückweisen, dass so nah verwandte Formen nicht auseinander hervorgegangen sein sollten." (ibid.)

The genetic connections are pre-requisites for speaking about and thus for studying the process of origin and descent of species. They exhibit the proof that closely related forms do indeed stem from the same point. Waagen proposed that this be clearly signed through modification of the paleontological nomenclature:

> "Der Vorschlag, welchen ich nun in dieser Beziehung machen möchte, ist einfach der, dass man die Stammart durch das der Mathematik entlehnte Zeichen $\sqrt{\ }$

> hervorheben, und der Mutation beisetzen möchte; die Mutation selbst ist als Art zu behandeln und bei Wahl des Namens für dieselbe streng nach Prioritätsregeln zu verfahren." (Waagen, 1869, p. 187)

Waagen thus emphasized the necessity for a clear identifying mark to underline the relation of descendant between two members. This requires in turn a new kind of nomenclature. It is important here to avoid possible confusion in the phase of cataloguing the data. The fossil record is historical data and therefore it is on principle layered and open to many interpretations. The paleontologist needs to correctly define these layers in order to use them correctly. In fact, Waagen stressed the necessity that paleontology develops a more precise systematics to facilitate the treatment of this data:

> "Die Wissenschaft bedarf aber höchst conkreter und bestimmter Ausdrücke, um fortschreiten zu können, und je mehr Darwinianistische Doktrinen und Ideen sich in ihr festzusetzen beginnen, um so bestimmter und concreter muss sie sich auszudrücken im Stande sein, damit sie nicht Gefahr laufe, dass ihr die gesammte organische Welt in ein unentwirrbares Chaos in einander verschwimmender Formen zusammen fliesse" (Ibid.)

The development of more concrete and determinate expressions is pivotal both for spreading the Darwinian theory and providing a secure terrain for paleontological data. For example, the paleontologist can use the mathematical sign √ to underline that the *Ammonites subcostarius Sow*. is mutation of the *Ammonites subcostarius Opp*.: *Ammonites subcostarius Opp*. (√ *Ammonites subcostarius Sow*.).

Not only Waagen, but—in the same year—Zittel and the international geological congresses would declare the necessity for a new systematics able to express the potentiality of the fossil record.

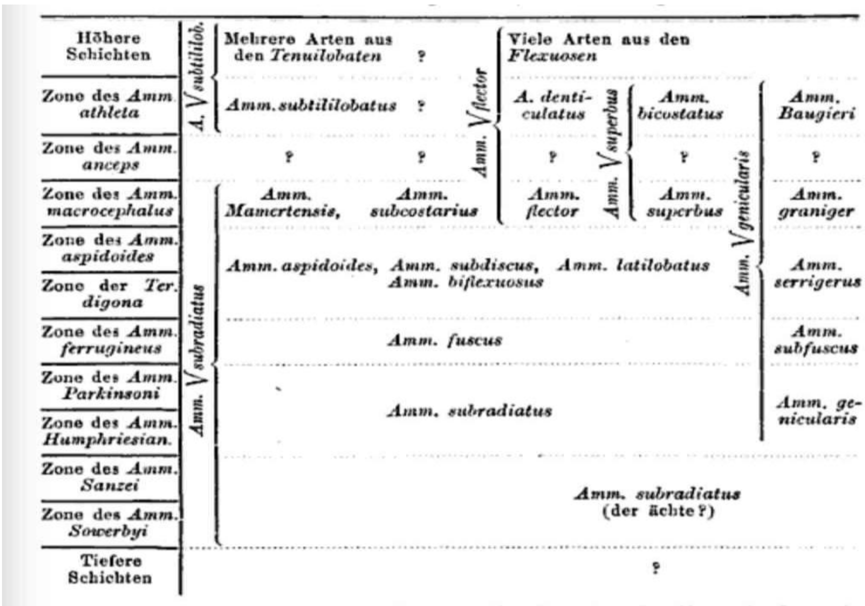


Figure 21 A formal representation of the Formenreihe of *Ammonites subradiatus*. Taken from (Waagen, 1869, p. 192)

To summarize, genetic relationships are epistemic things for paleontological investigations. They are a set of fossils connected through their morphological features. This constitution stems from a temporal interpretation of the Oppellian concept of zone. This is only possible if "die Grenze [are] enge gezogen und strenge geschieden." (Melchior Neumayr, 1873, p. 20) Waagen in fact emphasized the notion of fossil range without rejecting a higher zoological meaning. He worked namely on the possibility of narrating the development of the fossil record by connecting its morphological and temporal characteristics. It is worth underlining that mutations can be identified only if the paleontologist considers the zones as temporal intervals. Only within this perspective, can he observe a change in the *Bildungstypus* of the line under investigation. The result of this complex perceptual and theoretical process is the constitution of historical data.

Waagen's paper had an extraordinary diffusion. It was intensely discussed in every paleontological school both in America and Europa. Waagen was firmly convinced that the research of lines of forms was the main aim of paleontological research and would call his paper his "first pure paleontological analysis". In order to understand the importance of genetic relationships for the development of the theory of evolution, it is necessary to historically frame the concept of *Formenreihen*. I will show the importance of the *Formenreihen* for understanding the mechanisms of the evolution.

"The paleontologist as an observer is practically immortal": Genetic Relationships and Evolution

Oppel deeply influenced the development of the paleontological science during the 19th century: passing down to his students the notion of zone as key concept for both framing and understanding the paleontological epistemic object. Three names stand out in the list of his past students: Benecke, Waagen and Neumayr, all whom studied under Oppel in Munich. These names would profoundly mark the history of paleontology. They both improved on Oppel's main ideas and at the same time supported them through the Darwinian framework. The second layer of meaning of the paleontological data is, in fact, an extension of what I have pointed out so far. *Paleontological knowledge is able to prove the Darwinian theory of evolution by constructing Formenreihen: these are the paleontological epistemic things*. This conclusion was extensively discussed and accepted in the English-speaking word. The paleontological epistemic thing contributes to the Darwinian theory of evolution by inserting it into the flow of deep time,

> "Vertreter der Selektionslehre pflegen darauf hinzuweisen, daß vor unseren Augen sich wohl K[l]assen und Varietäten einer Art bilden, daß aber zur Trennung von zwei wirklichen Arten von allem Zeit notwendig sei, daß nur eine lange Dauer der die Formveränderung beeinflussenden Faktoren es bewirken könne, daß der Varietät eine Art wird." (Diener, 1910, p. 54)

As Carl Diener identifies, the theory of selection, i.e. Darwin's theory of evolution, calls attention to the fact that classes and species are growing out there, in front of our eyes. We can indeed see a great deal of variation, but in order to observe the splitting up of the species we need the temporal dimension. This is the key idea underpinning Osborn's claim that "the paleontologist as an observer is practically immortal" (Henry Fairfield Osborn, 1907, p. 745). He is able to trace the "history of individual characters […] from their origin through their various changes, through their entire history, in fact. In this sense he is immortal." (Ibid.) Such is the main aim of the *Formenreihen*.

In the previous section I have explained the notion of Formenreihe as it is presented in Waagen's work. I have pointed out in which sense the series of forms trace the history of the mutations of morphological characters in time. Waagen's paper was extremely well received by his contemporaries; it was also much appreciated during the historical revising of the synthetic evolution (see for example Eldredge (1979) and Mayr (1942)[103]). Nevertheless, Waagen did not take advantage of the epistemic potentialities hidden in the folds of this idea. Although he shared with other paleontologists the same notion of fossil record as historical entity, he did not attempt to characterize the features of evolution. This is due mainly to the influence of Zittel and his notion of data.

On the contrary, other paleontologists developed the notion of fossil record and its meaning to uncover the mechanism of evolution. Although they share a putative interpretation of Oppel's investigation—namely, a temporal interpretation of Oppel's *ideales Profil*—they cannot be placed within the same historical category due to their social, geographical, and temporal differences. To

[103] Eldredge supports Simpson in affirming that 'Waagen's mutations' were actually discrete taxa, an early example of the taxic approach to evolutionary studies in paleontology." (Eldredge, 1979, p. 10)

clarify the mechanisms of evolution, Neumayr and Benecke developed a particular notion of paleontological data based upon the series of form[104].

I will nevertheless proceed with order, since in these authors—especially in Neumayr—the notion of paleontological data is complex. In fact, Neumayr embraced at least two different conceptions of paleontological data. In the last years of his life, he treated the fossil record as a set of facts for evolutionary theory. At the same time, he conceived it as evidence for a possible narration and thus attempted to contribute to evolutionary theory. In this respect, fossils are events in time and space. If we are to understand this development, it is important to retrace his education and consider the significance of his academic education.

As I discuss in the first chapter, Neumayr started studying law in Munich but after a semester changed for paleontology and geology under Oppel and Gümbel. He then moved for one year to Heidelberg. In Heidelberg, Neumayr was fascinated by Benecke's lectures. Ernst Wilhelm Benecke (1838-1917) was Oppel's student in Munich. He wrote his first paleontological work under Oppel's supervision: *Über Trias und Jura in Südalpen* (1866). In Heidelberg he mainly taught paleontological practica. On his return to Munich he attended Waagen's lectures; then, after a period of teaching in Vienna and Heidelberg, he was named ordinary professor of paleontology at the University of Vienna in 1879.

As discussed, Neumayr's thought is complex and his concept of the fossil is layered. He employed at least two different meanings of the fossil record. On the one hand, fossils are facts for evolutionary theory; on the other hand, they are events. These double notions fuse in his masterpiece, *Die Stämme des Thierreiches* (1889). In this section, I will however focus only on the second meaning of fossil record[105]. It is this notion which provides the most important insights for the theory of evolution.

The key paleontologists of the second half of the 19th century influenced Neumayr's ideas and the best way to untangle his complex thought is to study his *Erdgeschichte* (1887). The work is in two volumes. The subject of volume one is dynamical geology; the second is dedicated to *Beschreibende Geologie*. The topic of this second part is historical geology. Hence, Neumayr identified historical geology with *Beschreibende Geologie*: the identification of historical trends is possible only through a description of the elements that compose them[106]. That means that historical

[104] Although these two paleontologists are equally important for the development and the establishment of these particular data, I will for the most focus on Neumayr. This is due mainly to a) his personal biography, b) the role he had in the European paleontology.

[105] See the first chapter for the other meaning of the fossil record.

[106] Neumayr puts as epigraph in a paper dedicated to the nature of the *fauna and formenreihen Aspidocearas acanthicum* (1873) a quotation taken from Friedrich August von Quenstedt's Jura (1858): "Wollen wir erfahren, ob die

geology follows the same method as stratigraphy and hence these approaches are completely identifiable. Neumayr backed up this point after a few sentences. He asserted that the aim of historical geology is to report on how events have occurred over the centuries and millennia. This is possible only if the paleontologists experience [kennenlernen] “die Abschnitte der Erdgeschichte”. To experience the periods of the history of the earth, paleontology’s only way is to uncover and step-by-step follow the long chain of events that characterizes it. Neumayr is clear: historical geology aims to narrate the chain of events that has shaped the various periods of history of the earth. By scanning what is current in the earth’s crust, the paleontologist can experience the required data for his narration.

From the very beginning of the book, it is clear that historical geology is a continuation of stratigraphic analysis. The principle that guides its investigation is the *Lagerung der Gesteinen*. There is nevertheless a problem. If we decide to follow the lithological sedimentation, we will obtain a “sehr unvollständig” knowledge of what happened. This point is a classical trope within the paleo-stratigraphical sciences: there is no place on the earth where the ratio of sedimentation has been perfectly constant, furthermore it might happen that there are gaps between two sediments due to environmental conditions. Hence, it is quite difficult, even impossible, to come up with a history of the past epochs entirely based on lithological data. This classical trope finds, however, new meaning in Neumayr. It is thus worth quoting Neumayr’s passage in entirety: if we relied only on the lithological disposition of the rocks, we would have:

> “eine Menge einzelner lokaler Schichtfolgen, die wir miteinander vergleichen und verbinden könnte; niemals wäre es möglich, aus solchen Elementen eine allgemeine Auffassung und einen Einblick in die Gesetzmäßigkeit der Aufeinanderfolge zu gewinnen, zumal da kein Punkt auf der Erde Bekannt ist, wo eine ununterbrochene und lückenlose Aufeinanderfolge von Ablagerung aus allen Abschnitten der Erdgeschichte vorhanden wäre.” (Melchior Neumayr, 1886, p. 4)

The point underlined in this passage is central for the development of the historical geology. It concerns the degree of knowledge that historical geology can acquire. At first glance, Neumayr is merely asserting that the paleontologist can obtain only a local degree of knowledge; any stratigrapher of the beginning of the 19th century could have written this statement. Smith, or Quenstedt would have surely subscribed to it. Oppel, Neumayr’s teacher at the beginning of his scholarship, would have found it difficult to support *in toto*. Nevertheless after a few reflections and

Fauna sich allmiilig verändert habe, so müssen wir selbst zu den minutiösesten Unterschieden greifen, sonst kommen wir nicht zur Klarheit”. This point underlines the importance of description for arriving at the mechanism of evolution. Bronn himself used a descriptive discipline (*Beschreibende Statistik*) to discern biological patterns.

concerns, he would have endorsed it. He would have accepted the point that geologists cannot obtain the laws behind the process of the sedimentation.

But if we look at the sentence closely, we notice an important turning point within the stratigraphic tradition. Smith, Quenstedt and—in part—Oppel would accept the fact that the geological knowledge is local and incomplete. Neumayr, on the contrary, is pushing the idea that what distinguishes historical geology is the search for the "allgemeine Auffassung" and "die Gesetzmäßigkeit der Aufeinanderfolge". What characterizes his investigations is an overcoming of a local and incomplete degree of knowledge and the geologist should do his utmost to describe the legality [*Gesetzmäßigkeit*] of the sedimentation. To put it succinctly, historical geology aims at a global degree of knowledge.

To overcome this stalemate, historical geology needs new practices and methods. The starting point is—again—Oppel. Although Oppel identified the correct methodology, he did not paradoxically put it to correct use. First and foremost, it is important to carry Oppel's approach to extremes. One needs to compare the local occurrences [*Vorkommnisse*] that are buried in the formations in order to unify the spatially separated sediments. In accomplishing this "Der Begriff der Formation erhielt dabei eine durchaus paläontologische Begründung; man verstand darunter einen Abschnitt, der durch ganz selbständige Fauna und Flora ausgezeichnet ist" (Ibid.). The comparison of formations was under proposal from the beginning of the 18th century. Cuvier, d'Orbigny, Bronn, to list a few, had struggled with the nature of the formations and with connecting and explaining them. Oppel marks, on the contrary, a point of departure within this research area. As I have shown, he avoided placing accent on the formation and proposed conversely the notion of zone[107].

Entirely following Oppel, Neumayr claims that "der Schwerpunkt der Untersuchung liegt heute nicht in der Verfolgung dieser großen Hauptgruppen, sondern ihrer kleineren und kleinsten Abteilungen und zwar sehr mit Recht."(Ibid.) This move enables him to cut out the old, and according to his later works, metaphysical debate. The *kleinere und kleinste Abteilungen* are the Oppelian zones. As a consequence, Neumayr recognizes the importance of Oppel for the development of paleontological science: the entire method of historical geology has undergone "eine wesentliche Umgestaltung […] durch die Arbeiten von Oppel" (Ibid.).

So far, Neumayr has been following his teacher step by step. His next move concerns the interpretation of these unities. He asks: to what extent, and how successfully may this method be

[107] Nevertheless, it is worth emphasizing that the lithological data play an essential, albeit hidden, role. If Oppel interprets his ideal profile spatially, the lithological data gives the rate of sedimentation and thus the required time.

pursued? And which kind of results can emerge from it? Neumayr is clear about this point. The zones do not indicate spatial unities; they are, on the contrary, temporal points. There are nevertheless many problems related to the building of a global temporal scale. Hence he recognizes that "eine leichte und einfache Methode der Altersbestimmung durch die Versteinerungen nicht immer möglich ist." (Ibid.)

Although this method cannot always be used, it provides an important theoretical framework. By grouping together the single points, the paleontologist is able to obtain a general, albeit imprecise, chronology. In line with the tradition opened by Bronn, a chronology is the first step required for coming up with evolutionary processes and explanations. The problem is, however, how it is possible to say something about the mechanisms of evolution if we have only local data and generations. This is again Oppel's starting point. I have explained that Oppel was struggling to figure out how it is possible to use local data to obtain a global knowledge (his ideal profile). Neumayr asks exactly the same question, even if the answer is pointed to cover two different phenomena. Neumayr aims to identify and depict "die einzelnen Entwicklungsphasen der Organismenwelt" (Ibid.): he intends to illustrate the evolutionary phases of the organic world.

To detect and thus to use the *Entwicklungsphasen*, the paleontologist has to provide the correct method for progressing from a local classification to a global one. This entails at the same time the possibility of clarifying the contrast between a global and a local degree of knowledge. To overcome this problem, Neumayr gives us a useful example. Let's assume that we come across a particular sedimentary rock. In its layers we can easily recognise the remains of floating animals and coral reef. They respectively compose the structure of the rock: the coral reef layer is between the two floating animal layers.

Sedimentation
Floating Animals
Coral reef
Floating Animals

Figure 22 A profile of a sedimentary rock composed of floating animals and coral reef.

If we better analyze the strata, we see also that "sich die erste und dritte Schicht nicht nur in der Faciesentwickelung gleichen, sondern in den einzelnen Arten ihrere Versteinerungen genau miteinander übereinstimmen." (Ibid.) We can therefore conclude rapidly and with certainty that "die in der Mitte liegende Korallenbildung nur eine Episode, ein Intermezzo innerhalb einer und derselben Entwicklung darstellt, daß sie also für eine allgemeine Gliederung ohne jede Bedeutung ist." (Ibid.) A global comprehension is thus the result of a process of abstraction. Only by curating the raw data offered by the local investigations, is the paleontologist able to construct a new theoretical frame for his new starting points. These in turn became the new raw data for his investigations. The element “coral reef” is nevertheless important for an understanding of the local phenomenon and as such should not put aside. Hence, Neumayr proposes that the local and global subdivisions have to run side by side. A mutual process of construction and abstraction takes place at the beginning of the paleontological studies. This mutual activity is able to reshape the raw data.

The global subdivision is only the first condition required and historical geology accomplishes this. As Neumayr has correctly identified, historical geology is mainly a descriptive discipline. Paleontology in the form of the history of the animal world finds its place immediately after. Only if both are inseparably woven[108], can they contribute to evolutionary theory. The task of historical geology seems to be quite clear. It aims to provide a global chronology of events. What seems so far not so clear is the role of paleontology. Neumayr clarifies that paleontology aims to develop *Formenreihen*:

> “wenn man die häufigsten und verbreitetsten Versteinerungen aus einer Reihe unterbrochen aufeinander folgender Schichtgruppen miteinander vergleicht, so gelingt es häufig, zu zeigen, daß ein und derselbe Typus durch mehrere Abteilungen hindurchreicht, und zwar nicht in ganz unveränderter Gestalt” (Ibid.)

The paleontologist must focus on the fossil record in order to put them into an ordered form, and so that differences between the single records can be discovered. Once all the data have been identified, they can be put neatly into a line of form that retraces their temporal development.

[108] In Die Stämme des Thierreichs, Neumayr clearly asserts that “Natürlich ist hier, wo es sich um die Veränderung der Arten im Laufe der Zeit handelt, vor Allem die Paläontologie im Bunde mit der Geologie dazu berufen, entscheidend einzugreifen, und in der That liefert sie auch Beweise für die Umgestaltung der Arten, wie sie vollständiger kaum erwartet werden können.” (Melchior Neumayr, 1889, p. 51)

Figure 23 The Formenreihen of the *Paludina*. Taken from (Melchior Neumayr, 1886, p. 16)

Following his teacher Waagen, Neumayr decides to name this line Formenreihe and the differences between the records within their vertical disposition, mutations. What seems to be merely a re-worked version of Oppel and Waagen's thoughts hides in its folds a deeper theoretical commitment. In fact, Neumayr is looking for instruments and methods to describe the possible evolution of the fossil record. That does not mean that he is interested in drawing out the causes of the evolution, at least not at this time and in this work (1886-67). He is, on the contrary, interested in pointing out the *mechanisms* of evolution and the fossil record offers the correct test bench. Neumayr is extremely clear about this point: the most important theoretical meaning of his analysis, "vor allem liegt es ob, den unmittelbaren und handgreiflichen *Beweis für allmähliche und schrittweise Veränderung der Organismen beizubringen*" (italics mine) (Ibid.). Neumayr is claiming that paleontology is able to show the *mode* of evolution. It can prove whether evolution is gradual and constant as Darwin proposed. This is very important. Neumayr is not contesting the validity of the evolution. On the contrary, his intent is rather to show the mode of its development. Paleontology is able to show the mechanism of this development and therefore to avoid speculative analysis on the causes of this process.

The *Formenreihen* can also provide important insights into the causes of evolution[109]. One such is selection, as Diener puts it,

> "Der Paläontologie erwächst die Aufgabe, genealogische Formenreihen aufzusuchen, deren einzelne zeitlich aufeinanderfolgende Glieder so eng miteinander verknüpft erscheinen daß sie al Beweise für die von der Selektionstheorie geforderte, schrittweise zu Umbildung einer Art in eine andere gelten können" (Diener, 1910, p. 53)

The fossil record in the form of the *Formenreihe* offers *evidence* for the evolution theory, its mode and its causes.

This layer of meaning would profoundly affect the direction of paleontological developments. In fact, Neumayr is stressing that paleontology can test the mode of evolution. This entails that it can achieve a global degree of knowledge. This result is made obtainable only by pushing Oppel's method further. It epitomizes the perfect sample for further analysis: "für jede geologisch selbständige Area ist eine Lokaleinleitung notwendig, die Zonengliderung bildet nur das universelle Schema, in das alle örtlichen Ausbildungen zum Zweck allgemeiner theoretischer Vergleiche eingepaßt werden können."

The meaning of the fossil record as evidence for evolutionary theory is therefore based upon a theoretical construction: a more general and theoretical comparison is the guiding principle behind Neumayr's formation of zone and *Formenreihen*. This general and theoretical comparison has a triple function. First, the comparison tied with a sophisticated abstraction is able to depart beyond local knowledge, exactly as I have shown above with the example of the sedimentary rock. Second, the comparison aims to destroy the possible errors incident to the nature of the fossil record. In fact, the paleontological observer is sometimes subjected to disadvantageous conditions, which make his perception not so immortal or favorable. Both different rates of sedimentation and a variety of environmental conditions warp the possibility of putting appropriate observations into a temporal order. The use of comparison can however facilitate this: "um Formenreihen zu verfolgen, muß man die Fossilreste von möglichst vielen weit voneinander entfernten Fundorten vergleichen; dann hat man Aussicht, diese Fehlerquellen zu vermeiden, und dann gelangt man auch wirklich zu einem günstigen Resultat" (ibid.). The comparison is able to cook the data, eliminating intrinsic errors: it constructs the new raw-data for the *Formenreihen*. Third, by comparing local subdivisions and the purified version of the fossil record, the paleontologist is finally able to narrate a history that can test the mode of evolution: he can show whether evolution is gradual or not. In the case of the Paludina, for example, Neumayr says that "durch die Beobachtung dieses Verhältnisses wird der

[109] As I discuss, Neumayr did not develop this point in Erdgeschichte, but in various papers and in his last and unfinished book. I will return to this point in the next section.

direkte Nachweis für die allmähliche Veränderung der organischen Formen geliefert" (Ibid.). In his *Stämme des Thierreiches*, Neumayr is even more explicit: "Für die hier zunächst uns beschäftigende Frage, ob die Art unveränderlich ist oder nicht, kann offenbar nur der Vergleich der zunächst miteinander verwandten Formen aus verschiedenen der Zeit nach aufeinanderfolgenden Schichten entscheidend sein." (Melchior Neumayr, 1889, p. 52) The comparison is thus what variously brings out the mechanism of evolution theory.

A last point needs to be underlined. Although Neumayr is struggling towards acquiring a global degree of knowledge—therefore spelling out the mechanisms of evolution—his data has only a local validity. He deduces the mode of evolution of the Paludina only by relying on "die keleinsten Abschitte einer universellen Gliederung der Schicthen" (Melchior Neumayr, 1886, p. 16). He is particularly clear about this point: the global degree of knowledge remains a constructivist product. The paleontologist cannot be sure of the conclusions deriving from it[110]: paleontological investigations can only be solidly grounded on a local level. Neumayr's epistemic practice of using local data to obtain a global confirmation of the mechanism of Darwinian evolution is a constructivist generalization and through this practice he is able to show a) the gradual character of evolution and b) the directionality of the modifications[111]. Neumayr claims that the *Formenreihe* has a particular and inevitable direction:

> "nicht einziger Fall ist, in welchem eine Formenreihe zu ihrem Stammtypus zurückkehrt; es kommen allerdings sogenannte rückläufige Reihen vor, [...] aber niemals findet dabei eine genaue Rückkehr zum Ausgangpunkte statt, sondern es entsteht immer eine neue, noch nicht dagewesene Form von durchaus selbständige Merkmalen" (Melchior Neumayr, 1889, p. 61).

The paleontological epistemic objects are thus the *Formenreihen*. They provide the local data from which the mechanism[112] of evolution can be inferred. Nevertheless, this epistemic object is locally limited: as I have shown, although the paleontologist struggles for a global degree of knowledge, he cannot obtain it. This is due mainly to the fact that the *Formenreihen* is a practice of reading the fossil record and does not take into account or investigate the ontological nature of this data. It does not delve into the classic ontological problems of the fossil record: i.e. its incompleteness and

[110] Concerning this point, Neumayr has been clearly influenced by both Waagen and Zittel. Indeed, all share a cautious approach toward the certainty and immutability of their conclusions.

[111] This last point does not mean that Neumayr accepted orthogenetic theories.

[112] As Neumayr summarized: "wir haben gesehen, dass ein genetischer Zusammenhang der gesammten Organismenwelt im höchsten Grade wahrscheinlich ist; allein damit ist nur die eine Seite der Gegenstandes erledigt, damit ist noch keine Erklärung des Vorganges gegeben, und diese Frage drängt sich unmittelbar auf, wir müssen Ursache und Veranlassung der Veränderung zu ergründen suchen." (Melchior Neumayr, 1889, p. 88)

imperfections. If, in order to obtain *Formenreihen*, paleontologists require qualitatively good data, they do not investigate their ontological structures and biases. This task will be undertaken by statistically treating the fossil record - a method which, nevertheless, will not find adequate followers. In the next section, I will deal with the relation between paleontology and the Darwinian theory of evolution to point out the dangerous, albeit pivotal, role of statistics.

Chapter VI. Paleontology and the Darwinian Theory of Evolution: The dangerous Role of Statistics

Introduction

Oppel's epistemic practice was pivotal in shaping paleontological investigations during the second half of the 19th century. Paleontologists took two distinct positions in interpreting Oppel's data. On the one hand, Neumayr, Benecke, Osborn, among others, emphasized the temporal interpretation of the concept of zone. On the other, Ludwig Ruetimeyer (1825-1895) stressed the spatial reading. The temporal interpretation was conceived in two different ways. Paleontologists emphasized either the constitution of *Formenreihen* or a statistical treatment of data. The first approach was used to support the Darwinian theory of evolution. In his textbook *Die Stämme des Thierreiches* (1889), Neumayr asserted that the paleontological task "die Aufgabe, welche vorliegt, besteht darin, nachzuweisen, dass die Gesamtheit der Thiere und Pflanzen sich aus einer oder einigen weinigen Grundformen durch allmälige Umgestaltung entwickelt hat, und die Ursachen aufzusuchen, welche diesen Vorgang bewirkt hat" (Melchior Neumayr, 1889, p. 30). Evolution is thus a process of *gradual diversification* and organization of living organisms from a common origin. This process is gradual and constant; paleontology is able to prove it and to elucidate its causes [*nachzuweisen und aufzusuchen*]. Neumayr's statement was challenged during the last decades of the 19th and the beginning of the 20th centuries. Few paleontologists questioned the validity of evolution, i.e. the modification of organisms over time, but most disagreed on its mode and mechanisms. Most of these objections arose via the mathematical treatment of paleontological data.

This chapter analyzes the dangerous role of statistics[113] in paleontological sciences at the end of the 19th and the beginning of the 20th centuries. Statistics offered a clear answer to the pivotal question of the second half of the 19th century: how to use the fossil record to investigate the theory of evolution without—on one hand—succumbing to metaphysical pitfalls and—on the other—achieving only a useless collection of facts? As I have exposed in the first chapter, the quantitative approach to the fossil record derived from the surveys and censuses undertaken by the public administration. Through Alexander von Humboldt's *botanical arithmetic* and Heinrich G. Bronn's *paläontologische Statik* it acquired a more specifically *biological* meaning. Statistics were consequently used to depict biological patterns and processes in deep time. I will argue that in paleontology, the quantitative method was abandoned by the first decade of the 20th century

[113] During the entire 19th century, paleontologists conceived statistics exactly as Gottfried Achenwall (1719–1772) used it: a descriptive and comparative study of particular objects presented in a specific area. See the first chapter.

because—as its opponents asserted—a statistical treatment of the fossil record was found to generate results openly in contrast with the Darwinian theory of evolution. For example, by statistically treating the fossil record, the Austrian paleontologist Theodor Fuchs (1842-1925) argued that the development of the organisms was not "a continuous and uniformly progressive change" as Darwin suggested, but instead characterized by a long timespan of "relative calm with shorter periods of transformation [*relativer Ruhe mit kürzeren Epochen der Umwandlung*]" (Fuchs, 1880, p. 39). Or, based on his tabular representation of the coal formations of North America, Charles Léo Lesquereux (1806-1889) claimed that there were no intermediate forms between the extinct fossils types and the following ones (Lesquereux, 1860c, p. 380).

Many leading German paleontologists successfully argued that paleontology could not accept this fact, because through Darwin it had acquired the necessary biological foundation to develop autonomy as a discipline, i.e. so freeing itself from geology. For instance, Karl Zittel published his two masterpieces in those years: *Handbuch der Palaeontologie* (1876) and *Grundzüge der Palaeontologie (Palaeozoologie)* (1895). These textbooks ensured the widespread conception of paleontological data as biological entities within the scientific community. In fact, Zittel claimed that the fossil record was meant not as a stratigraphic time marker to be put into numerical relations, but as the source for morphological and biological investigations that could support the Darwinian theory of evolution. Hence, the mathematical treatment of the fossil was strongly opposed and abandoned by the beginning of the 20th century.

Zittel did not utilize the statistical method in his textbooks; rather, he explicitly ignored it so as to fully embrace Darwin's theory as heuristic support for his investigations. Yet other paleontologists attempted to question and undermine this statistical treatment to save the *Descendenzlehre*. In fact, when the fossil record is considered as a record of data and mathematically treated, it provided some results in open contrast with the Darwinian model of evolution: "above all, it is the statistical method of geology and paleontology that has provided arguments against the doctrine of descent" (Melchior Neumayr, 1880, p. 83). The natural consequence of this was a strong reaction against the mathematical treatment of data: it had to be limited or even avoided in order to preserve the validity of the Darwinian model. Hence, Darwinism had expelled mathematical reasoning in from the paleontological science during the second half of the 19th century. The main objections to the Darwinian model of evolution derive therefore from the methods used to investigate the fossil record. These were so persistent in the German-speaking area that Neumayr introduced them also in his textbook. He claims—and it is worth quoting entirely—that

> "Wenn wir die Ergebnisse miteinander vergleichen, zu welchen die einzelnen Geologen und Paläontologen bezüglich der Abstammungslehre gelangen, so finden wir, dass, abgesehen von subjektiven Beweggründen, welche Gegenstand einer wissenschaftlichen Erörterung nicht sein können, das Ergebnis sich wesentlich verschieden gestaltet je nach der angewandten Untersuchungsmethode. Diejenigen, welche durch Vergleich der nächstverwandten Arten aus den häufigsten Gattungen Formenreihen aufzustellen oder auf morphologischen Wege die Veränderungen nachzuweisen suchen, kommen fast durchgängig zu einem der Darwin'sche Theorie günstige Ergebnisse; das Gegentheil finden wir, zwar nicht immer, aber doch in der Mehrzahl der Fälle, wo eine mehr oder Weniger rein statistische Behandlung angewendet wird, welche die Zahlenverhältnisse von Arten, Gattung, Familien u.s.w. in verschiedenen Ablagerungen, das erste Auftreten derselben, ihre Verbreitung in Raum und Zeit zum Ausgangpunkte nimmt, und lässt sich nicht leugnen, dass die Resultate auf diesem Gebiete bei geschickter Gruppierung der Thatsachen wenigstens auf den ersten Blick eine überwältigende Beweiskraft zu entwickeln scheinen." (Melchior Neumayr, 1889, p. 150)

Neumayr clearly asserts that different views on the value and validity of the Darwinian theory are product of the diverse methods used by paleontologists and geologists. On the one hand, support for the Darwinian evolution is found among paleontologists working with comparison of forms to arrive at a series of forms [*Formenreihen*][114]. Opposition to Darwin is found among those paleontologists who use the comparison between numbers and statistics as their main method. This opposition is not based on the distinction between geology and paleontology, but is concerned with the proper use of mathematical methods within the paleontological sciences. Since Neumayr was a direct student of Albert Oppel (1831–1865), Wilhelm Heinrich Waagen (1841-1900) and Karl Alfred von Zittel (1839-1904), he chose to follow the former 'Darwinian' method: he tried to develop *Formenreihen* based upon morphological identifications, actively rejecting the quantitative approach.

This chapter reconstructs the debate surrounding the use of statistics during the last decades of the 19th and the beginning of the 20th centuries. I will consider the arguments for and against the quantitative methods raised particularly in the German-speaking area. These were addressed mostly during the meetings at the *Kaiserlich-Königliche Geologische Reichsanstalt* in Vienna around 1880. The geological institute was established in Vienna in 1849 and it was one of the main centers for geology and paleontology in Europe (Bachl-Hofmann, 1999; Schübl, 2010). This debate went beyond Vienna however. The work of two paleontologists in the United States perfectly illustrates both the assumptions behind the statistical method, and as its potential pitfalls. I will use the

[114] As the paleontologist Carl Diener (1862-1928) affirms, ""Der Paläontologie erwächst die Aufgabe, genealogische Formenreihen aufzusuchen, deren einzelne zeitlich aufeinanderfolgende Glieder so eng miteinander verknüpft erscheinen daß sie al Beweise für die von der Selektionstheorie geforderte, schrittweise zu Umbildung einer Art in eine andere gelten können" (Diener, 1910, p. 53) Therefore the fossil record meant as a member of a *Formenreihe* offers the *evidence* for the evolution theory, its mode and its causes.

works[115] of Charles Léo Lesquereux (1806-1889) and Henry Shaler Williams (1847-1918) to compare the issue raised in Vienna with the *de facto* working of the statistical treatment of data.

Besides its methodological discussion the Vienna debate is also particularly interesting as a case study. It shows the social tensions within paleontology surrounding Darwin's theory at the end of 19th century as well as the variety of non-Darwinian alternatives emerging from the statistical treatment of the fossil record. On the one hand, we see paleontologists such as Heinrich Bronn, Joachim Barrande (1799-1833), Charles Léo Lesquereux, Henry Shaler Williams, and Theodor Fuchs who opposed the mechanisms of evolution proposed by Darwin. By statistically treating the fossil record, they questioned the understanding of evolution as a gradual phenomenon proceeding by means of natural selection. Consequently, they proposed different mechanisms in order to understand how biodiversity has changed through geological time. On the other hand, Melchior Neumayr and Karl Zittel defended Darwin's theory. They supported Darwin because he gave a stable form to the theory of evolution, thus increasing the importance of paleontology as a biological discipline: "so long as there was no stable belief in the variation of species the importance of paleontology could not be so exceptional as it is today" (Melchior Neumayr, 1889, p. 29). Hence, for the sake of saving the disciplinary autonomy of paleontology and its pivotal role, Neumayr and Zittel were particularly suspicious of any non-Darwinian mechanism of evolution. My analysis provides useful details to picture the various non-Darwinian theories that proliferated in paleontology during the late 19th and early 20th century.

The debate about the dangerous role of statistics cannot be understood without a remark on the paleontological perception of Darwin's theory. To first illustrate the perception, I will leave aside the question of its accuracy. I will then briefly survey the use of mathematics in paleontological sciences during the 19th century. Thirdly, I will explore the Vienna debate on the rejection of statistics circa 1890. Having illustrated how the mathematical treatment actually works by studying Lesquereux and William's investigation, I will then deal with Neumayr's criticisms to show why and to what extent the use of statistics was questioned. The final part of this paper focuses on the survivals from the statistical notion of data, namely the necessity of opening a discussion about the ontological nature of paleontological data.

The paleontological Perception of Darwin's Theory

In this section, I will briefly review how German paleontologists perceived the Darwinian theory of evolution. I will summarize the reception of Darwin's theory in the German-speaking paleontology

[115] I will examine also Herdman Fitzgerald Cleland's (1869-1935) dissertation. Cleland graduated at Yale under the supervision of Williams and it is extremely likely that he literally followed William's lead in his dissertation, rather than voice to his personal position.

purely in order to sketch out the common paleontological perception about Darwin's theory between1859 and the last decades of 19th century.

The German paleontologist Friedrich Rolle (1827-1887) was the earliest defender of the Darwinian theory in German speaking countries. On Saturday, 20th September 1862, he published a review of Darwin's *Origin of Species* in the *Wiener Zeitung*, in which he emphasized the novelty of the theory. He affirms that

> i) "Darwin behauptet, daß sämmtlische organische Wesen [...] in einem nicht figürlich genommenen, sondern im strengsten Sinne des Wortes verwandtschaftlichen Verhältniß zu einander stehen"; ii) "Die Vorgänge, welche dieser fortwährenden Veränderung der organischen Formen zu Grunde liegen, bezeichnet Darwin—und dies ist das Neu an seiner Lehre—mit dem Wort 'natural selection', natürliche Zuchtwahl" (Rolle, 1862, p. 272).

Here, Rolle underlines the two main characteristics of Darwin's theory: i) the common origins of the species and ii) the fundamental role of natural selection. These two elements characterize the paleontological perception of Darwinian theory. The best introduction to Darwinism as German paleontologists received it is presented in the first 150 pages of Neumayr's *Die Stämme des Thierreiches*. Neumayr accepts Rolle's description *in toto* and strengthens it by adding just one point: Darwin's evolution is a *gradual reorganization* of the organisms. Darwin's theory is therefore perceived as a gradual process of reorganization and speciation of the organisms from a common origin by the means of natural selection. A statistical treatment of the fossil record would attack both the gradualisms and the role played by natural selection, indicating why it was questioned and abandoned.

Statistical Treatment of Data: an Introduction

This section presents the statistical treatment of the fossil record in order to historicize this *practice*. Bronn used mathematical techniques to come up with biological patterns and processes. The "weight of his education" (Fleck, 1929, p. 425) played an essential role in this choice. From his study of public administration he learnt the importance of treating data as a record of data[116]. This quantitative treatment enabled narration of a complete history of past events: by virtue of a quantitative reading, Bronn produced biological patterns and came up with biological general laws. Despite sympathy for the Darwinian theory of evolution, Bronn's laws were not in agreement with Darwin's mechanism.

[116] Concerning this point, I would like to recall Car Already August Ludwig von Schlözer's (1725-1809) maxims: "statistics is history without motion; history is statistics in motion" (quoted in (Desrosières, 1998, p. 19)). This approach toward statistics and history has indubitably marked Bronn's thought.

Bronn, however, was not the only naturalist who used this method[117]. For instance, Christian Keferstein (1784-1866), Friedrich Sigismund Leuckart (1794–1843), Hermann Hoffmann (1819-1891), and Rudolf Wagner (1805-1864) developed a statistical treatment of natural data as well. This section deals only with Leuckart and Hoffmann because they use the fossil record in their analyses.

Leuckart completed his studies in Göttingen. He studied *Naturwissenschaften* and medicine under Johann Friedrich Blumenbach (1752-1840). For the next 10 years, he taught natural history in Heidelberg. He acquired there the reputation which would later recommend him as an editor of the massive *Naturgeschichte der drei Reiche* (Bischoff, et al., 1841).

Although he gave many courses on the history of the earth, we are not easily able to deduce his thought from any of his publications. We can, however, infer something of this from the lecture he gave for the Grand Duke Leopold's name day on 15th November 1833. This would be published two years later in a small, but very interesting book. The title in itself is stimulating. The book concerns the distribution of the remaining records [*übriggebliebenen Reste*]. In particular, the lecture deals with the geographical distribution of the past record of life in comparison with contemporary organic living organisms. The opening sentence is significant: Leuckart asserts that the zoologist, like the botanist, is drawn to the study of the fossil record in order to compare the quantity and the quality of the species of the former world with that of the present. The geognost, on the contrary, deals with the physical diffusion of these records. Although, the fossil record gives us an important tool for measuring the degree of diversity between the different epochs of nature, the investigation must proceed cautiously because too many sources of possible error inhere within the fossil record[118].

Leuckart begins by counting the fossilized species found in the diverse layers of earth and those that are currently present on the earth's surface. By numerically comparing the number of the fossil record with that of the living species, the geognosts can arrive at some general conclusions about the diversity and the history of the earth. For example

> "Es sind von ihnen kaum einige hundert Arten beschrieben, während die jetzige uns bekannte Pflanzenwelt zwischen 50 — 60,000 Arten, ja vielleicht noch mehrere, zählt. Während jetzt wenigstens 78 — 80,000 lebende Thierarten von den Zoologen entdeckt sind, kennt die Versteinerungskunde nur zwischen 4500 — 5000 fossil vorkommender Arten." (Leuckart, 1835, p. 18)

[117] Many paleontologists used the statistical method during the 19th century. For instance, Martin J. Rudwick in his *Charles Lyell's Dream of a Statistical Paleontology* (1978) deals with Charles Lyell (1797-1875) and Barthelemy de Basterot (1800-1887) and provides valuable considerations about their statistical methods.

[118] This is a classical trope within the paleontological investigation of that period. I will return to this point at the end of the section.

There are barely several hundred species of plant buried as fossils, whereas we can count thousands of plants present on the earth's surface. The same can be said for the animals: we have fewer species preserved as fossils than living species. After having counted and described the fossilized and living species, Leuckart related these numbers showing their *ratio* thus. The relation between the various epochs of nature can be numerically determined and it turns out that there is "a ratio of about 1:16" between the present and past epoch and, "among these, mollusks are by far the most." Or "a ratio of about 1:9 —10" between the mammalians preserved in the fossil record and those discovered elsewhere: Im Allgemeinen ist die Zahl der fossilien Meeresthiere am überwiegenden, dann folgend die Thiere, welche die sumpfige Gegenden und die Ufer der Meere, Seen und Flüsse liebten und bewohnten." (Ibid.)

By simply comparing the number of the collected fossils with that of the living organisms, the geognost acquires a degree of knowledge about the development of the earth and its environment. What Lueckart is trying to develop in his lecture is a method for discovering the laws of the geographic distribution of the species within the history of the earth. This is based upon two steps: first, comparing the pattern of distribution of the fossils with the current dispersion of the specimens. Second, identifying a degree of regularity behind the distribution of the records in the different epochs. For example, after rigorous investigation the geognost notices that the number of fossilized plants and animals has been in constant increase from the time of their creation. That means that the complexity of the organisms has been increasing since their origin: "die jetzige Schöpfung hat demnach offenbar unendlich viel mehr Arten und Geschlechter von organischen Wesen aufzuweisen als die Vorwelt." (Ibid.) Other important results can be obtained by comparing the numbers of gathered species. For example, there was an increase in the quantity and kind of organism during the various epochs: currently, there is a greater variety of species than in the previous epochs of nature. Or by carefully looking at the distribution of the fossil, Leuckart asserts that "immer die Wasserthiere, überhaupt die Wasser bewohner, früher da gewesen sind und in älteren Formationen auftreten als die auf dem Lande lebenden Wesen." (Ibid.)

It is worth noticing that Leuckart gave his talk a year after the publication of the *Allgemeine Einleitung in di Naturgeschichte* (1832). In the same year, Leuckart not only published the introduction to the monumental work on the three kingdoms edited by Bischoff, Blum, Bronn and himself, but also obtained a professorship of comparative anatomy, physiology and veterinary at the *Albert-Ludwigs Universität zu Freiburg*. He was therefore free to pursue his investigations without being labeled in a particular way: his lecture has to be seen under this point of view. Leuckart saw clearly that the fossil record could function to elucidate evolutionary processes and patterns: *whatever these particular material objects are, whatever their ontological features are, the* *geognost can operate with them to obtain a degree of knowledge about the distribution of the organisms within the immense deep past. He can put them to work by calculating the numerical relations between them and what currently is presented on the earth surface*. Nevertheless, he develops neither a definition of the fossil record nor a mechanism able to explain the numerous trends he points to. He mentions simply that organisms are subjected to numerous and gradual mutations before reaching their current status[119].

Leuckart's position can be understood in conjunction with his conviction about the degree of knowledge achievable from paleontology. He asserts that "ob alle die Bestimmungen der vorweltlichen Pflanzen und Thiere von den Petrefactologen richtig sind, kann wohl mit Recht bezweifelt werden." (Leuckart, 1835, p. 79). Only a synthetic knowledge based upon a unification of different disciplines can provide plausible insights into the development and distribution of the fossil records: "Manche von ihnen [Paläontologen] sind doch wohl nicht mit der Botanik und der Zoologie so recht vertraut, wie sie sein sollten, gar Manche wissen von der vergleichenden Osteologie nicht, was sie wissen sollten." (Ibid.) The problem is though that even Georges Cuvier, the "der grösste Zoolog und Zootom unserer Zeit", could be wrong. Thus, the work of the naturalist remains always in the domain of probable conclusions and arguments. This is a common place in the paleontological research during the 19th century and this epistemic and metaphysical instance will play a pivotal role in the development of the paleontological sciences and in refusing the statistical method.

To summarize the first historical starting point, the fossil record was used as raw material to narrate the history of earth at the beginning of the 19th century. This tells how the structure of the organisms and the complexity of the former world have changed. Beside it, another trend steps strongly onto the paleontological stage: enumerating the diversity and disparity of the forms of life in the earth[120]. This trend is a natural consequence of the first. In fact, Leuckart used the fossil record as mere raw material for differentiating and unifying the development of the diverse epochs

[119] "Nach den verschiedenen Metamorphosen, die sie [die organischen Wesen] bis zur jetzigen Entwicklung durchlaufen musste, wurde sie immer vollkommener ausgebildet und hiermit fand zugleich eine allmählig fortschreitende, vollkommenere Ausbildung der Pflanzen und Thiere der Vorwelt Statt." (Leuckart, 1835, p. 75) This point is particularly interesting. In fact, the statistical treatment of the data has been put aside, because it is openly against the gradual development of the species.

[120] Among others, I would like to recall the name of Christian Keferstein (1784-1866). He was a "commendable researcher and prolific writer" (Mayer, 1977) (Leuckart, 1835, p. 75) in the field of geognosy and mineralogy. In his *Die Naturgeschichte des Erdkörpers in ihren ersten Grundzügen* (1834), he drew up an alphabetic list of all the fossil record discovered. He divided those data into the species and genera and for each of them he listed the number of found fossils and living species.

of nature. His thought was certainly less evolutionarily oriented than Bronn's, but at the same time he anticipated methods which would find constant use in the historical geology from that point onward. The method is extremely simple: first, one collects fossils; second, one makes numerical comparison between them so as to reveal patterns of distribution; third – and most demandingly – one discovers the process behind these patterns.

Leuckart epitomizes perfectly all these steps which thus shape the German *milieu*. This practice particularly influenced Bronn: his paleontological *paläontologische Statik* is a continuation of this practice by use of more data. In fact, Lueckart used less data than Bronn did. This point is interesting, since it might seem that what distinguishes between paleontological investigations is the mere issue of quantity. Someone may argue that patterns can be generated only if we have enough data. The more data the paleontologist acquires, the more easily he can discover patterns within this data. This point is in part correct. Paleontology is a quantitative and data-oriented discipline. It requires a lot of data to come up with possible patterns and processes. Nevertheless, the quantity is not the key element in the paleontological work. The quality of the fossil record and how it is employed are equally responsible for the productive use of data. The mathematical treatment of the fossil record is not only about the quantity of the data; it is also, and mostly, about their quality. Hence, the paleontologist needs to come up with instruments and practice to shape and take advantage of the quality of the data. The German botanist Hermann Hoffmann (1819-1891) gives us some hints at this development. At the same time, he offers another interesting starting point for framing the use of mathematical techniques in paleontology during the 19th century.

Hoffman was professor in Giessen and published an outstanding book in 1852. The book is entitled *Pflanzenverbreitung und Pflanzenwanderung: eine botanische-geographische Untersuchung*. The powerful message of this investigation is encapsulated in the first page. The book begins by simply describing the work of the naturalist. When a naturalist seeks to define and delimit the borders of the diffusion of a plant, it might happen that this plant could suddenly disappear. Hence, Hoffmann continues, "entsteht die *Frage: warum fehlt gerade hier jene Pflanze?*" (Hoffmann, 1852, p. 1) This observation is extremely important. In fact, Hoffman wants to ask when, how, and why botanic investigations can legitimately begin. The inquiring begins with the loss of data. We ask accordingly under which conditions and what causes this absence is possible and what this is due to. Among the causes, Hoffmann points out the importance of climate as a factor in the development and diffusion of a species. Ecological causes are thus responsible for the appearance or extinction of a species. This etiological analysis is however incomplete if it is not supported by a historical investigation. Hoffman suggests that a fruitful investigation cannot be done without taking into account the historical development of the earth system. Only by seeing the trend in the context of all its historical development, can one begin to proceed to its analysis.

Leuckart and Hoffman show that Bronn was not the only one to use pseudo mathematical techniques to study the fossil record. At the same time, they pave the way for methodological analyses of the history of the earth. Their investigations aim to discover patterns and processes that may connect the epochs of the earth. These patterns and processes appear when a) the paleontologist has a great wealth of data, b) he is able to separate causes from accidental conditions, c) he follows the pattern in all its historical developments, and d) he investigates the quality of the data.

However, a crucial question arises and Bronn himself poses it: “should we attempt to institute a comparison between the distinguishable fossil beings and the present creation, what is the present creation? Does it consist of 100,000 or 200,000 species of animals, of 70,000 or 150,000 species of plants? And how many genera does it contain? What is a species? And what indeed is a genus?” (Bronn, 1849q, p. 43) Thus, Bronn backs up Leuckart’s conclusion: that a comparison between fossil species and living species is problematic. Even if the paleontologist is simultaneously a great botanist and an excellent zoologist, he will commit errors. Bronn is warning the zoological community of the risks related to such quantitative investigations. At the same time however, he replies to Leukcart that paleontologists can overcome doubts connected with the paleontological numerical research by preventively pointing them out [121]. The quantitative paleontological enterprise should not to be abandoned: “We are not bound to wait for [the solution of the problems raised]”, on the contrary we should keep in mind “when instituting this comparison that all the imperfections just mentioned attach to this comparison.” (Ibid.)

Through comparison of data, paleontology, or broadly speaking natural history, can discover trends and patterns despite the imperfections attached to comparative methods and to the notion of the fossil record. But how can this comparison be done? How can the paleontologist secure his discipline from all the imperfections and errors that inevitably seem to belong to it? The answer lies in the training of the paleontologist’s skill. On the one hand, the paleontologist has to improve his skills to avoid errors in narrating the correct history of the earth; on the other, he needs to reconsider the imperfections of the fossil record in order to acknowledge them, i.e. he has to reconsider the ontological features of the fossil record thus providing a new definition of this epistemic object. The next section deals with these developments in relation to the mathematical treatment of data after the publication of Darwin’s *Origins*. I will argue that a statistical treatment of data enables

[121] In order to criticize the statistical method, Neumayr will use the same argument reaching though conclusions different from Bronn.

reconsideration of the ontological nature of the fossil record. Nevertheless, paleontologists did not take advantage of this method between 1859 and the beginning of 19th century. Instead of developing and refining it, they put it aside to save the biological ground of paleontology, namely the Darwinian theory of evolution, and the paleontological descriptive method.

The Statistical Treatment of the Fossil Record

The research of patterns of disposition constituted a hot topic within the paleontological sciences of the 19th century. This was a method commonly employed within the geographical and botanical sciences. As Janet Browne shows in her *The secular Ark* (1983), "botanical arithmetic was to natural history what mathematics was to the study of electromagnetism, heat". The link between botanical arithmetic and paleontological data was Leopold von Buch (1774-1853). Some years before Leuckart or Bronn's investigations, he published his *Physikalische Beschreibung Kanarischen Inseln* (1825). It is a report of his travel to Canary. The first part of the book is entitled *Statistical overview of the Canary*. It gives an overview of the surface, population, and density of the island assisted by the statistical employment of data and tables. Buch's book did not offer particular paleontological insights; however, his status as an authority in geological sciences meant that his methods captured the attention of his colleagues[122].

In fact, geologists and paleontologists supported Buch's exposition. During the entire 19th century, geologists used tables and statistical tools to survey the objects of a particular locality. The aim of these works was mainly to take a census of the lithological and paleontological formations of a specific area. A few exceptions, such as the previously quoted works of Bronn, Leukart and Hoffman, were able to direct the aim of survey towards a more biological target. After the publication of Oppel's works on the *Die Juraformation Englands, Frankreichs und des südwestlichen Deutschlands* (1856–1858), the statistical method took a fresh analytical direction. The Oppelian notion of *zone* (an assemblage of fauna) was the concept required to strengthen the *modus operandi* of the statistical analysis. Thanks to Oppel's approach, statistics was finally used to put the various zones of the different lithological formations in relation. Due to the lack of a special mathematical formation, Oppel did not directly use this method; but he contributed to its further application.

For example, Carl Eberhard Struckmann (1833-1898) published a little book on the upper Jura in 1878 vividly supporting Oppel's zonal stratigraphy. He aimed to present a paleontological,

[122] As Zittel remarks "Leopold von Buch was rightly regarded as the greatest geologist of his time. He had studied in every domain of geology; he was familiar with a large part of Europe. Wherever he went, he willingly and freely communicated his own knowledge to others, and ever rejoiced to be able to assist by his money or his influence any one in whom he detected a true devotion to science." (Zittel, 1901, p. 64)

geological, and statistical representation of the surroundings of Hannover. The author referred his book as a *Petrefacten-Verzeichniss*, i.e. a list of petrified items. Struckmann observed 404 different species and for each of them he carefully listed their taxonomical name, the place of discovery, and the zone in which they belong. On concluding the list of petrified items, Struckmann unified the 440 species into wider taxonomical categories, namely in genera and families, in order to see the distribution of the species among the zones of the upper Jura. As a result, he was able to easily identify which zone contained the broader diversity of species.

By a simple application of mathematical relationships then, can general patterns of diversity and distribution be discovered. It turns out, for example, that "die Mehrzahl der Echiniden findet sich vom unteren Korallenoolith bis in den Mittleren Kimmeridge [...] Von den 180 Zweischalern sind nach den bisherigen Beobachtungen 110 Arten (62%) auf bestimmte Zonen beschränkt" (Struckmann, 1878, p. 74). The mathematical relationships among the data thus disclose possible patterns of distribution as well as important information on the evolution of this area:

> "von den 228 Arten, welche bisher in mittleren Hannoverschen Kimmeridge überhaupt nachgewiesen sind, finden sich 93 Arten auch in der unteren Abtheilung desselben, den so. unteren Pterocerasschichten. Darunter sind jedoch nur 8 Arten, welche bisher in der oberen Abtheilung nicht gefunden sind [...] Es ist jedoch höchst wahrscheinlich, dass, wenn nicht alle, doch mindestens noch ein Theil auch in den eigentlichen Pterocerasschichten künftig aufgefunden werden." (Ibid.)

By comparing *the number and the type of the species top-down and bottom-up,* Struckmann tried to identify the degree of (evolutionary) relations between the layers and the zones. This was an essential step towards establishing genetic relationships among the data and thus towards discovering the mechanisms of evolution. In fact, Struckmann followed both Oppel and Waagen: if the paleontologist can temporally dispose the rock layers (Oppel *docet*), he will be able to obtain the line[123] of development of the forms (à la Waagen). Interestingly, mathematical tools support this general idea in opposition to Neumayr's claim. However, Struckmann did not investigate in depth the evolutionary relations among the layers. He limited his investigations to a merely collecting data; not analyzing their meaning for the theory of evolution.

Although Struckmann gives an interesting example[124] of the statistical methods applied to geology, and his work was particularly well appreciated in the English-speaking countries[125] this

[123] It is worth recalling that the line is according to Waagen a tree. He in fact was a supporter of the Darwinian branching model of evolution.

[124] See also *Ueber den Parallelismus der hannoverschen und der englischen oberen Jurabildungen* (1881), where, with the help of statistics and tables, Struckmann compares the upper Jura in Hannover and in England.

[125] See the positive reviews of Struckmann's works in *Geological Magazine* (1879, 1881, 1883).

was not followed by a wider theoretical analysis on the principles of evolution. It is two other paleontologists who represent the new use of statistics within the paleontological sciences. They offer the correct case studies to see the statistical treatment of the fossil record working *de facto* and to understand in what sense Darwinian paleontologists took up a position against statistics in the last decades of the 19th century[126]. Leo Lesquereux (1806-1889) gives us the first case study; Henry Shaler Williams (1847-1918) has the leading role in the second case[127] study.

Lesquereux was one of the most important paleobotanists of the 19th century. If he was born in Switzerland, he received his scientific education in America, thanks to Louis Agassiz's friendship. Lesquereux took part in numerous surveys in mid-western American and Pennsylvania contributing to the identification of numerous plant species. He wrote a series of papers on *some questions concerning the coal formations of North America* between 1859 and 1863. In a letter to George Maw on February 28th, 1863, Charles Darwin recognized the validity of these papers. He wrote that "almost the best papers I have ever read on Coal are some lately published in late numbers of Sillimans American Journal by Lesquereux.— They would be worth your reading & you will like them all the better, *as they give the 'Origin of Species' a few little unpleasant kicks*.— " [italics mine] (Buckhardt, 1999, p. 186) These little unpleasant kicks are the result of a statistical treatment of the fossil record.

In the second part of this series of papers, it was Lesquereux's explicit aim to "merely expose the facts that appear surely ascertained by a long and careful exploration of the coal fields of North America, leaving the naturalist-philosopher to take from these facts any conclusion that may appear just to him." (Lesquereux, 1860a, p. 64) To accomplish this, he attempted to discover the relation between the plants in American and Europa as regards the same geological formation. To enable this, he listed the number of species peculiar to America, to Europa and in common to both in a table.

[126] Although Neumayr did not read those studies, his criticisms can be addressed also to Lesquereux and Williams without changing their value.

[127] As indicated, I will also discuss Cleland's dissertation. It was however entirely inspired by Henry Shaler Williams' method and interests.

Genera of Coal plants.	Species peculiar to America.*	Species peculiar to Europe.	Species common to both.
1. Noeggerathia Sternb.,	3 + 2*	5	1
2. Cyclopteris Brgt.,	1	2	2
3. Nephropteris Brgt.,	5	4	4
5. Neuropteris Brgt.,	18 + 1*	16	12
6. Odontopteris Brgt.,	4 + 1*	6	3
7. Dictyopteris Gutb.,	1	1	0
8. Sphenopteris Brgt.,	10 + 9*	41	12
9. Hymenophyllites Göpp.,	6	10	2
10. Rhodea Sternb.,	0	1	0
11. Trichomanites Göpp.,	0	4	0
12. Steffensia Göpp.,	0	1	0
13. Beinertia Göpp.,	0	1	0
13. Diplaxites Göpp.,	0	2	0
14. Woodwartites Göpp.,	0	2	0
15. Alethopteris Sternb.,	9 + 2*	20	9
16. Callipteris Brgt.,	2	1	1
17. Tecopteris Brgt.,	12 + 4*	49	12
18. Aphlebia Sternb.,	0	6	1
19. Caulopteris Brgt.,	4	4	0
20. Psaronius Brgt.,	10	6	0
21. Crematopteris Schp.,	1	0	0
22. Scolopendrites Lsqx.,	1	0	0
23. Whittleseya Newb.,	1	0	0
24. Cordaites Ung.,	1	0	2
25. Diplothegium Corda,	0	0	1
26. Stigmaria Brgt.,	5	2	5
27. Sigillaria Brgt.,	12 + 9*	37	17
28. Syrigodendron Brgt.,	0 + 1*	0	2
29. Diploxylon Corda,	0	0	1
30. Lepidodendron Brgt.,	14	10	11
31. Ulodendron Rhode,	0	4	2
32. Megaphytum Artis,	1 + 1*	4	0
33. Knorria Sternb.,	2 + 2*	1	2
34. Halonia Ll. & Hutt.,	0	2	1
35. Lepidophyllum Brgt.,	7	2	4
36. Lepidostrobus Brgt.,	?	1	2

Figure 24 Table of genera of Coal plants presented in America, Europa or in both of them. Taken from (Lesquereux, 1860a, p. 66)

By a simple comparison of data, Lesquereux showed the relations between the American fauna and the European one: from 654 species identified, about 160 were presented in America and 350 in Europa. Although the number of species is greater in Europa, we can find in America "peculiar forms or types, which are not seen in Europa". Successively, Lesquereux extended this numerical analysis to understand the stratigraphical composition of the formation. By unifying the different layers and the diverse ratios, he noticed a decrease in number of some species of trees: "As fast as these species of trees decrease in number, the ferns mostly of small size invade the coal-fields. They become predominant and show the greatest number of species at the base of the Mahoning sandstone." (Lesquereux, 1860c, p. 380) This statement is based upon a stratigraphical correlation of the strata with their numerical relations and at first glace it can be classified as a mere stratigraphic observation. However, Lesquereux immediately stressed its evolutionary meaning. As he wrote to Darwin, "I was just engaged in a general examination of the fossil Flora of the coal measures of North America and could not but try to test the value of some of your systematic conclusions in applying them to what I saw of the vegetation of this ancient world." (Lesquereux, 1864) The modality of substitution of these two species and particularly their numerical distribution offers the perfect test bench for the Darwinian theory of evolution: "Both genera [of plant, namely Lepidodendron and Lycopodites] appear or at least disappear at the same time, and are replaced by typical forms, which have no analogy whatever with them." (Lesquereux, 1860c, p. 380) After many observations, it turns out that

> "The distribution of the ferns in the coal-measures is equally contrary to the supposition of a change of species by successive variations. They appear, it is true, grouped together, in a kind of relation between contemporaneous species; but we do not see, either before or after any of them, a trace of an intermediate form between the lost types and the following ones." (Ibid.)

By means of a simple mathematical relation applied to the stratigraphical framework, Lesquereux showed a mechanism of development which is not in line with Darwin's theory. Leusquereux's study not only revealed a difficulty related to the gradualism of the Darwinian theory, but through to a mathematical treatment of data, one specifically pointed to natural selection:

> "Moreover, the numerous species of Neuropteris and Pecopteris appear at coal No.3 and 4 in the middle of the coal-measures, and do not ascend higher, while those species which should be considered as originators or parents and consequently ought to be destroyed (from the law of selection) by their offspring, continue to predominate to the top of the coal-measures" (Ibid.)

Lesquereux therefore addressed his doubts to both the mode and cause of Darwin's theory. This was possible by treating the fossil record as a record of data within a broader statistical framework. Lesquereux's case study is extremely interesting, since it is based upon paleobotany. This branch of science was the most influenced by Humboldt's *Tabellenstatistik* and hence the establishment of a quantitative method in paleobotany was easier than in the paleozoological sciences. Secondly, it shows the sense in which the statistical method works against Darwin's theory. Specifically, it contests two Darwinian cornerstones (as paleontologists perceived them): the statistical treatment of the fossil record does not confirm that evolution is gradual and by means of natural selection. The same happened in paleozoology, as the second case study will show.

As I have mentioned, the use of mathematics in paleozoology was largely restricted to the surveying of a particular area. After the publication of Oppel and Darwin's masterpieces however, the application of simple statistical techniques to data has steadily, albeit slowly, developed. I have already recalled Struckmann's contribution to this topic. Others paleontologists soon developed his method. Herdmann Fitzgerald Cleland (1869-1935) provides us with the second case study. He graduated at Obelin in 1894 and after a teaching position at Gate College decided to study under Henry Shaler Williams, "the outstanding exponent of stratigraphic paleontology" (Raymond, 1935). Under Williams's supervision, he obtained his Ph.D. in 1900. Although neither Cleland nor Williams took part in any meeting of the geological institute in Vienna, , they represented perfectly the target of Neumayr's criticisms.

Cleland's dissertation concerned the formation and fauna of the Hamilton formation (Mid-Devonian strata). It was further published in the U.S. Geological Survey Bulletin with the title *A Study Of The Fauna Of The Hamilton Formation Of The Cayuga Lake Section In Central New York*

(1902). Henry Shaler Williams (1847-1918) wrote a little introduction to the book in which he expressively emphasized that "the value of the investigation consists chiefly in the statistics it furnishes as to the approximate composition of each of the successive faunules making up the total fauna occupying the Hamilton formation of central New York." (Herdman Fitzgerald Cleland, 1903, p. 9) Williams described Cleland's work thus as an important statistical investigation into the Hamilton fauna. It aimed to represent both the faunas of the single strata (the zones, according to Oppel's terminology) and the total fauna of the entire formation. To accomplish this the fossil record should be gathered with mind to their further use: in collecting and cataloguing the fossils, the paleontologist has to see them as[128] numbers of distribution. Hence, Williams is claiming that the process of collecting the data on the field is inevitably based upon a theoretical framework and that this helps in deciding which fossil is adapted to a statistical treatment.

This statement might sound not new. In fact the paleontologists have been never *naïve* about their empiricism: no one of them could have possibly asserted that he collected his data without any theoretical assumption. It is worth underlining is the kind of assumption Williams proposed. In fact, collecting the fossil record under a particular point of view is one of the necessary conditions whereby the fossil record can be mathematically treated: "in making the collections" the paleontologist should give "special attention to the discovery of the relative abundance of the species found associated together in each rock stratum." (Ibid.) He should focus his attention on this aspect, thus bracketing off other features of the fossil record. If this observational rule is followed, "instead of attempting to discover rare species[129]" the paleontologist aims "to let the preserved collection represent as perfectly as possible the natural proportion of association. The working up of the collection was made to express this natural proportion expressed by the species." (Ibid.)

Williams is pointing out the value of the collection of the fossil record for further statistical treatment. This practice characterizes the paleontological work and at the same time differentiates it from the collector's work. Cleland's preliminary effort is thus to clean up the collected data so that

[128] The observation practice that Williams is underling is very closed to Bronn's *modus operandi*. See the first chapter. This remark entails also the active role of perception in the shaping of both the paleontological data and methods.

[129] It is interesting to notice that the Thomas Schopf describes exactly the same situation in the preface to *Models in Paleobiology* (1972). Here Schopf recounted a conversation with a student at the Atlantic City meeting of the Geological Society of America in 1969: "In answer to my casual inquiry about what he was working on, he stated that his professor had made a collection of brachiopods from a certain formation, that these fossils had never been described, and that this description would pose a good problem. The tacit assumption was that because the description had not previously been made, it was worth doing. […] I decided that this particular student was unaware of the various alternative strategies of research available in invertebrate paleontology." (Schopf, 1972a, p. 3)

an isomorphism between these data and their mathematical expression presented in tables can be possible: the fossil record expresses "natural proportions".

Williams concludes his introduction by asserting the value of Cleland's analysis and its utility:

> "The present investigation is a step in the direction of attaining the fullest possible perfection in recording faunal statistics, and in making these faunal analyses as perfect as they can be made, toward which end the contributions of many workers will be needed. With such statistics in hand we may hope to understand better the laws of evolution as affected by and related to the varying conditions of environment and time." (Ibid.)

By means of statistical analyses, the paleontologist understands the laws of evolution. In fact, statistics is able to place the environment in relation with a great number of species and this relation can be followed for a long span of time. Thus, Cleland, i.e. Williams, and Lesquereux shared the same aims: their intention is to uncover biological processes in the deep past.

Cleland based his analysis upon these assumptions. After having identified the correct zones and fauna of the entire Hamilton section, he used this data to calculate the relation between the Pelecypoda and Brachiopoda in a particular area - for instance the Cayuga Lake section. First, he recognized and divided the section in 24 zones. Second, he traced a diagram of relative abundance, both in respect to these zones and overall.

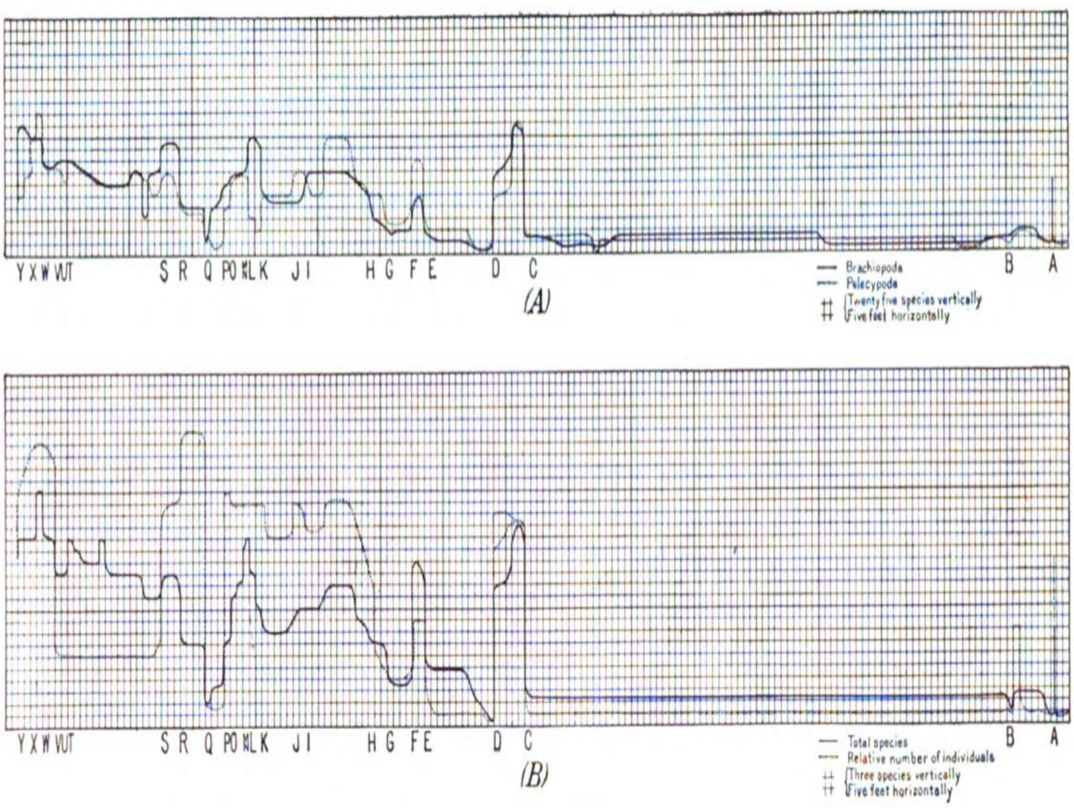


Figure 25 The first diagram shows the relative abundance of Pelecypoda and Brachiopoda in the Cayuga Lake Section. The second diagram represents the relative abundance of individuals and species in the same section of the Cayuga Lake. Taken from (Herdman Fitzgerald Cleland, 1903, p. 33)

Third, by the means of a graphical representation of these relations Cleland was able to describe patters of development and so reveal critical points of development: in the zone F of the second graph, for example, “there is a sudden increase in the number of species and individuals, which makes it a quite distinct zone.” (Ibid.) Fourth, he related the diagram of relative abundance to the lithological structures of the zone in order come up with an initial explanation.

Cleland’s investigation aims, however, to trace a comparative study between the Hamilton formations: the diagrams of the relative abundance of Pelecypoda and Brachiopoda are only a first result of his statistical treatment of the data. After having identified and listed all the 230 species of the Cayuga Lake section, Cleland can finally relate these numerical data to what has been catalogued from the other sections of the Hamilton. As a result, he generated a graph of the distribution of the fossil record of the Hamilton stage throughout all its appearances.

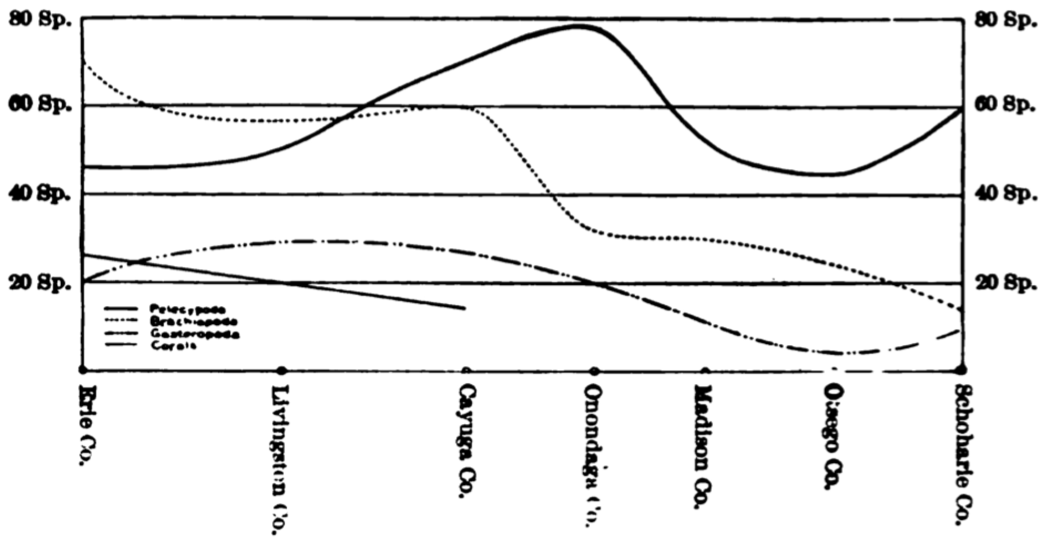


Figure 26 The graph shows the fossils of the Hamilton section. From (Herdman Fitzgerald Cleland, 1903, p. 87)

The graph shows the development, distribution, and the centers of abundance of all the Pelecypoda, Gastropoda, Corals, and Brachiopodea of the Hamilton section throughout New York. A great deal of evolutionary information can be derived from this graph. Specifically, I would like to point out its provision of reliable data for paleobiogeographic investigation. It shows, for example, that there is a change of both the number and kind of species from east to west. Hence, the graph obtained from a statistical treatment of the data gives useful data for further biological treatment.

All these results therefore contribute to the main aim of Cleland’s investigation: the understanding of the laws of evolution, as Williams affirmed in the introduction. In fact, Cleland’s last general conclusion concerns the Darwinian theory of evolution. It is worth quoting the passage in entirety:

> "If the statement 'natura non saltum facet' is granted, one should, with some confidence, expect to find many — at least some — evidences of evolution. A careful examination of the fossils of all the zones, from the lowest to the highest, failed to reveal any evolutional changes, with the possible exception of Ambocaelia praeumbona. Species varied in shape, in size, and in surface markings, but these changes were not progressive. The conclusion must be that, so long as the conditions of sedimentation remain as uniform as they were in the section under consideration, the evolution of brachiopods, gastropods, and pelecypods either does not take place at all or takes place very seldom, and that it makes little difference how much time elapses so long as the conditions of environment remain unchanged." (Ibid.)

Cleland gives us an interesting case study to understand the relation between the statistical treatment of the paleontological data and the Darwinian theory of evolution within paleozoology. By simply comparing the number of fossils found in the different zones he tests the Darwinian model of evolution and discovers that the mode of evolution is not gradual as sought by Darwin.

By using statistical tools, the French geologist Joachim Barrande (1799–1883) arrived at more radical conclusions: he was "intellectually by far the most dangerous opponent of evolution" (Marcon, 1883). Barrande presented his result in twenty-one quarto volumes entitled *Systême silurien du centre de la Bohême* (1852-1894). In this work, he described and classified all the fossils of the Bohemian Silurian basin portraying its stages and structures. The supplement to the first volume was extensively discussed at the *Kaiserlich-Königliche Geologische Reichsanstalt* (Melchior Neumayr, 1889; Tietzte, 1873) because Barrande numerically compared the Paleozoic with Triassic fauna to question the validity of Darwinian evolution. By means of tables and statistics, he calculated the number of the fossilized species found in every geological period:

Périodes	Formes spécifiques	Périodes	Formes spécifiques
1. Tertiaire	16970	6. Jurassique . . .	4730
2. Silurienne	10209	7. Triasique	1310
3. Crétacée	5500	8. Permienne . . .	303
4. Dévonienne . . .	5160	9. Cambrienne . . .	29
5. Carbonifère . . .	4901		

Figure 27 Tabular representation of the number of fossilized species found in different geological periods

Barrande used this simple statistical survey to challenge the Darwinian mechanism of evolution. The data show, in fact, that there is no gradualism at all. On the contrary, the greatest diversity can be found at the beginning and at end of the considered geological period (in the Silurian and Tertiary); whereas it decreased towards the middle ages (Barrande, 1872). Furthermore, based on numerical data, Barrande asserted that mutations are only special cases of variations within species: they play no role in the formation of new species. This last result was openly in contrast with the Darwinian framework adopted by several paleontologists. In fact, by distinguishing the changes in time (mutations) from the transformation in space (variations), Waagen claimed that evolution was a slow and gradual process exactly as Darwin had theorized it (Waagen, 1869).

Both Barrande and Lesquereux—and Bronn before them—showed, therefore, that the statistical method can generate results which contest Darwin. As Neumayr would lament, this happens "not always, but in the majority of cases" and unfortunately "it cannot be denied that the results obtained by this method seem to have an overwhelming evidence at least at first blush." (Melchior Neumayr, 1889, p. 150) The statistical approach to the fossil record has an apparently stunning evidential value; nevertheless, it was strongly limited, since it undermined the status of paleontology as an autonomous biological science. In the next section, I will analyze the main assumption behind the quantitative treatment of the fossil record. I will namely argue that a statistical treatment of fossils can be applied only if the fossil record is seen as complete data. Only if fossils constitute reliable and complete data, can they be inserted into a mathematical framework. Hence, the statistical treatment of the fossil record not only generated results in contrast with the Darwinian theory of evolution, but also re-conceptualized the notion of the fossil record: henceforth no longer an incomplete and imperfect entity.

Geological Biology

As I have mentioned, Cleland graduated under the supervision of Williams. It is therefore extremely likely that he followed William's lead in his dissertation, rather than express his personal convictions. In fact, Cleland published a textbook entitled *Geology, Physical and Historical* (1916) where the statistical treatment of data entirely disappeared[130]. Williams[131] graduated at Yale in 1868 and taught at Cornell University till 1892. In that year, he succeeded James Dwight Dana (1813–1895) at Yale. Williams published many articles and books on various geological topics. To better emphasize my point about the disappearance of statistics in paleontology, I would like to focus on his textbook *Geological Biology* (1895).

Furthermore, Williams' analyses offered important details in picturing the variety of non-Darwinian alternatives that emerged from the statistical treatment of the fossil record at the end of the 19th century. By using tables and statistics, Lesquereux pointed out the absence of intermediate forms and the marginal role of natural selection, Fuchs argued that evolution did not follow "a

[130] The only exception is given at page 505, where Cleland provided a table of distribution and relative abundance—the so called spindle diagram—of the life of the life of the Paleozoic. See (Herdman Fitzgerald Cleland, 1916)

[131] For a biographical sketch, see (Brice, 2000)

continuous and uniformly progressive change" (à la Darwin), and Barrande questioned the validity of the Darwinian model of evolution *in toto*. Williams not only challenged the role of natural selection, but also claimed that orthogenesis could better explain the data listed in tables and depicted in graphs.

Williams meant the textbook to be a fresh and valuable instrument for the researchers. It was conceived to supersede old textbooks and the dry statistical research in paleontology:

> "the attempt was made to replace the ordinary treatment of the dry statistics of historical geology and paleontology by something which would bring the chief problems of the history of organisms within the comprehension of the ordinary college student, and kindle in the special student enthusiasm for deeper research" (Williams, 1895, p. iii).

Williams points out in this way the necessity of overcoming the "dry statistics of historical geology and paleontology" (Ibid.), showing that the use of statistics was not a failed dream. It was, on the contrary, used so extensively that both Williams and Neumayr wanted—for different reasons—to delimit it. Williams insisted that paleontologists should stop using dry statistical tools to enumerate what can be found in rock layers. Statistics should not function to merely survey an area, but rather as *a reliable tool* for *understanding evolution*. New generations of students should learn the fresh function of statistics, as fundamental to the future development of paleontology. In fact, paleontology is necessarily related to the theory of evolution and these two aspects should proceed together: the statistical treatment of data is therefore an essential component of the new discipline Williams named "geological biology". This is characterized as "a scientific treatment of the observed facts of evolution" and especially aims to show which kind of theory of evolution is true. This point is particularly important. Williams—like many of his colleagues—did not doubt the truth of evolution. He was rather claiming that geological biology is able to provide the substantial evidence[132] for this phenomenon and consequently to discover and test the correct evolutionary theory.

It is important to differentiate Williams' starting point from that of the 'classical' paleontology available during those years. The leading paleontologist during the final decades of the 19th and the beginning of the 20th century was Karl Zittel. Zittel's textbooks (Zittel, 1876, 1895c) epitomized the common feeling among the paleontological community in that period: paleontology should not treat the fossil record as a mere mark of time and, *a fortiori*, it should not speculate on the evolutionary laws; it should, on the contrary, work to gather and classify facts for

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[132] "Evolution thus becomes one of the fundamental expressions of life force, requiring no theory to support it, but calling only for investigation to reveal its laws; and it is in geological biology that we find the direct evidences of the course of its operation." (Williams, 1895, p. iv)

evolutionary theory. According to Zittel, the paleontologist should protect his epistemic identity by abstaining from useless speculation on the nature of evolution, and focus rather on correctly cataloguing the fossil record. The Darwinian model of evolution was the normative hard core of paleontology that supported the morphological investigation and the realization of the series of form based upon this data. As a consequence, Zittel laid rules to identify morphological paleontological data and communicated them within the paleontological community. Their distinguishing characteristic is the absence of the vertical dimension of time, which is the essential feature for the stratigraphic and quantitative treatment of the fossil record. We find that Williams' starting point is entirely in opposition to Zittel. The American paleontologist asserts:

> "in defining our topic as geological biology, we are not proposing to investigate the anatomical organs and tissues of which particular animals are made [à la Zittel], but to review the facts and theories which have led to the belief that each living animal and plant is but the last of a long line of organisms whose remains can be recognized in more or less perfect fossils, and whose varying characters can be traced back into the immense antiquity of geological time." (Ibid.)

Geological biology does not deal with the recognition of morphological characteristics, but with a review of the theories of evolutionary change within organisms. Both these theories posit that what can be currently seen on the crust surface is the "last of a long line of organisms". The paleontologist's task is to "show the order of succession of life in the past". Williams frequently stresses the fact that paleontology aims to investigate how the long line of the fossilized organisms (the *Formenreihen*) is ordered and to define what kind of modality unifies these points. For instance, he asserts that "paleontology reveals to us a long series of organic forms, and when we speak of their history we assume that the series is connected genetically; the time-relations we read from the rocks, and in terms of subjacent strata." (Ibid.) Williams is saying here that – in order to show the order and succession of the series of forms - we must assume that the parts of the series under investigation are genetically connected to each other, i.e. that they are the result of evolutionary processes.

However, although this condition is necessary to understanding the notion of series, it is not fully sufficient. Other essential conditions appear: in order to study the history of a long series of organic forms, we need to treat the fossil record not as a single datum, but as a sample or an assemblage of data[133]. Williams was explicit about the necessity of studying the fossil record in bulk in 1903. He asserted that in order to understand under which conditions the stratigraphical or biological correlations are made, the paleontologist must take into account "the relations which

[133] This point is not new, but it receives a clear formulation in Williams' investigation. It will return *in auge* during the paleobiological revolution of the 1970s. See (D. Sepkoski, 2012; D. Sepkoski & Ruse, 2009; Turner, 2011)

fossils bear to one another, to the geological conditions of preservation, to the conditions of their living and continuing to live in the past, and, finally, to the value of fossils as means of distinguishing different periods of geological time as well as of identifying like periods of time represented by them." (Ibid.) The first relationship is genetic; the second is environmental, founded "on the basis of their relationship to environment, or to the conditions of life"; the third is temporal – it concerns the body of organisms belonging to the same period of time. Waagen defines the referent of this latter relation as diversity or, "to speak more abstractly, [it can be named] the geological range of the organisms"[134].

That means that Zittel's classifications and data give only *one layer of meaning* of the data used by geological biology. Or, to put it differently, Zittel's data is not enough for an understanding of the laws of evolution: by treating the fossil record quantitatively, geological biology can bring out other meanings of the fossil record which prove useful as we come up with biological patterns and processes. As Williams put it,

> "From the preceding remarks it follows that fossils, either as taxonomic aggregates based on genetic affinities or as aggregates associated on the basis of living together, can not be considered simply by morphological features, but that their chronological relations must be distinctly noted." (Ibid.)
> Or, "ever we make out of fossils, whether we consider them stones or organisms, however we account for their origin, whatever relation we conceive them to bear to each other, the fact is startlingly vivid to the paleontologist that the form of a fossil is intimately associated with the time in which it appeared on the earth" (Ibid.)

The time factor, which is intended as the geological range of organisms, is therefore essential. Time is as fundamental a part in the exact construction of the paleontological data as are morphological and geographical elements. Only by unifying these three components can data be statistically treated. But why is this step required? Upon which methodological, epistemic, and philosophical principles can this procedure be completed? The answer is centered on the notion of the fossil record: a statistical treatment of the fossil can be argued only if the ontological status of the fossil record has been previously, and intentionally, changed. Only if fossils constitute reliable and complete data, they can be inserted into a mathematical framework. Hence, the statistical treatment

[134] In discussing the differences (only superficial in paleontology) between the terms range and distribution, Williams endorses Waagen's distinction between mutation and diversity: "These facts lead to a discrimination of the idea of variation and to the application of that term to indicate differences expressed by specimens of the same species — differences arising coincidently with extension of geographical distribution and change in conditions of environment; while the term mutation is technically applied to those changes of form that are coincident with the passage of time, and hence to generational succession under conditions of life so nearly the same that extinction of the race does not result." (Ibid.)

of the fossil record not only generates results in open in contrast to the Darwinian theory of evolution, but also re-conceptualizes the notion of the fossil record.

To summarize, Williams' conclusion is in opposition to the Darwinian model of evolution: evolution is rapid and guided by an intrinsic law, not gradual and by means of natural selection. This conclusion is mainly due to the *examination of record of data* arranged in tabular and graphical form. Indeed, the graphical representation enabled the visualizing of both a different mode and a different tempo of development - both creating tension with Darwin's theory. Williams came up with biological explanations which disagreed with Darwin where he, as Fuchs, emphasized that the record of data arranged in tables or graphs is as significant as it appears. Therefore, they endorsed a literal[135] reading of the fossil record based upon quantitative relations between numbers.

On the Presumed Incompleteness of the Paleontological Tradition

In his investigations, Bronn set bio-stratigraphical charts whereby the fossil record can be read. Paleontological statics, i.e. a statistical treatment of paleontological data, was considered a predisposed means of reading the fossil record. This reading, however, could be accomplished only if the fossil record had been previously constructed. Fossils are, in fact, imperfect and incomplete material objects that require integration with other disciplines in order to be used fruitfully. Bronn's synthetic construction is thus a reaction to the imperfection of the material object called the fossil record. Williams conceives the fossil record oppositely. In his textbooks, *Geological Biology*, Williams affirmed that regarding the question "'What are fossils?' the concise answer is: "Fossils are traces of organisms buried in the rocks" that "chiefly represent the hard parts of organisms" (Williams, 1895, p. 80). At first glance, this statement seems quite obvious and common: it seems rather an admission of an epistemic sin. It is, in fact, quite well known that the materials from which animal fossils are derived consists mostly of the hard-parts of animals. This was the main source of embarrassment for paleontological investigations. However, Williams is not highlighting this epistemic fault, he is emphasizing, rather, the qualities of the fossil record:

> "Fossils represent organisms, but almost universally they represent the *hard parts* of living organisms; hence the most valuable lessons to be learned from fossils must be derived from the study of the hard parts of organisms. These hard parts are the parts which have attained definite and fixed form during the life development of the individual." (Ibid.)

[135] As David Sepkoski put it in a literal reading: the fossil record, "with all its notorious gaps and inconsistencies, was taken at face value as a reliable document. There never were, in other words, any missing pages or volumes: the discontinuities in the record existed because the history of life is discontinuous." (D. Sepkoski, 2012, p. 3)

Although the fossil record represents only the hard parts of organisms, they are the visible final results of a process of evolution and, as such, reliable sources for biological investigations. Williams went further stressing the differences between the soft and hard parts as presented in the fossil record: "soft parts, or organs, are adjustable to changing exterior conditions, but its hard parts are already adjusted, and, therefore, they are an expression of the working adjustment of the species, to the conditions of its environment, at the particular time in which it lived." (Ibid.) The weaknesses of the paleontological data are therefore simultaneously strengths: the hard parts represented in the fossil record are a *reliable* source for studying the line of biological development[136] with geological time, "the hard parts […] represent the royal line of succession for the geological ages."(Ibid.)

This point is essential because this influences what can be done with the fossil record and, *a fortiori*, the paleontological method. The argument is not circumscribed to Williams's thought alone, but has a global validity: many supporters of the quantitative treatment of the fossil share it, especially those who took part in the meetings at the *Kaiserlich-Königliche Geologische Reichsanstalt*. The Austrian paleontologist Theodor Fuchs (1842-1925) was a supporter of the statistical method and endorsed exactly the same position: he strongly defended the mathematical treatment of data and the related completeness of the fossil record. In fact, in a meeting at the *Kaiserlich-Königlichen Geologischen Reichsanstalt*, he vehemently endorsed the statistical treatment of the fossil record against his colleague Neumayr. A section of the meeting of the *geologische Reichsanstalt* on 16th December 1879 is dedicated to Fuchs' talk on *die präsumirte Unvollständigkeit der paläontologischen Ueberlieferung*. Fuchs began by asserting that if the incompleteness of the paleontological *Ueberlieferung* corresponded to reality, than "wir vollständig darauf verzichten müssten, allgemeine Fragen, wie die Darwinische Lehre sie aufwirft, an der Hand der Paläontologie zu prüfen". (Fuchs, 1879, p. 355) If we dub paleontological data and experience as incomplete, then not only is there no room for paleontology within the evolutionary theory, but also the Darwinian theory of evolution could not be validated by paleontology. On the contrary, Fuchs asserts that paleontological flora and fauna "in gewissen Theilen eine ausserordentlich vollständige [ist]".

To prove this point, Fuchs uses the same argument that Williams would about twenty years later: the importance of maintaining distinction between the hard and soft parts. The fossil record

[136] As Williams wrote, "the history of organisms, which we particularly trace in the study of fossils, is not the history of imperfect organisms struggling towards perfection, but it is the history, for each age and epoch, of the perfected adjustment of the organisms of the time to the particular conditions of environment in which they lived." (Ibid.)

contains two kinds of organisms: on the one hand, we have organisms with soft parts; on the other, organisms with resistant [*widerstandskräftige*] hard parts that must be treated as fossils from later eras [*Fossilien der Nachwelt*]. The former set of data is only fragmentary; whereas, the latter set, within the paleontological tradition, is "extremely complete" [*äusserst vollständige*]. Given the difference in the nature and kinds of data preserved, Fuchs made his point about the completeness of the paleontological *Ueberlieferung* by showing that the number of fossils gathered is representative of the former world. To drive his point home, he carried out a quantitative and statistical comparison using the collected data[137]. For instance,

> "Appelius fand im tyrrhenischen Meere 337 Arten schalen-tragender Conchylien, von diesen 337 Arten konnte er jedoch 300 auch in der quaternären Panchina von Livorno nachweisen und man hätte demnach die Fauna des tyrrhenischen Meeres aus den Fossilien mit grosser Vollständigkeit kennen lernen können." (Ibid.).

Hence fossils, which contain hard parts, accurately represent the former world and can be correctly used to draw conclusions about about evolution. If the Darwinian theory is correct as concerns those organisms with soft parts—as for instance jellyfish, insects, and birds—then it should be likewise for those with primarily hard parts such as corals or mollusks.[138]

Both Fuchs and Williams share a common argumentative schema: they need the fossil record to advocate its own completeness and its reliability, as is necessary for further statistical treatment. If 'raw' paleontological data is already biased, then a statistical treatment has no epistemic meaning at all. Although both paleontologists stressed and defended the reliability of the fossil record, they used slightly different techniques. Williams used the soft/hard part distinction to emphasize the reliability of the paleontological data for aiding evolutionary processes. His argumentative schema can be drawn in this way: given that i) the fossil record chiefly represents the hard parts of organisms and ii) the hard parts of organisms are "an expression of the working adjustment of the species", it follows from i) and ii) that iii) the reliability of the fossil is rescued. Fossils directly testify to the mechanism of evolution and therefore the paleontologist can put them into a statistical framework. In this way, Williams stresses that both vertebrate and invertebrate paleontology can say something about the theory of evolution. Fuchs, on the contrary, recognized this capacity only in invertebrate paleontology. By carefully distinguishing between the chemical components of the organism, he argued that "Korallen, Echiniden, Conchylien auch zeigen" the Darwinian principles.

[137] Unfortunately, only a few of them are reported in the printed version of the talk.

[138] As Fuchs explicitly asserts: "Sind die Darwinischen Prinzipien richtig, so muss sich dies an den Korallen, Echiniden, Conchylien u. d. g. auch zeigen."

The degree of reliability of the fossil record is thus fundamental, where the ability of paleontology to speak about evolutionary theory depends upon it. Again the quality of the data has more epistemic weight in a science that is at first glance merely quantitative. It is thus not surprising that the nature and the quality of the fossil record have prompted a rather heated debate during those years. To summarize, the fundamental issue at stake concerns the ontological nature of the fossil record. The supporters of the quantitative method are willing to give a new ontological status to the allegedly incomplete and imperfect fossils so that they can be employed in a statistical framework; on the contrary, the opponents stress the incomplete nature of the fossils to prevent their further statistical treatments. The ontological nature of the fossil record was indeed extensively discussed in the meetings of the Viennese geological institute. Any pronouncement about the features of the fossil record could have influenced further development of paleontological methods.

In a meeting on 13th January, 1880, the paleontologist Rudolf Hoernes[139] spoke in contest of Fuchs' concept of the fossil record. Hoernes's talk was in answer to Fuchs' claim regarding the completeness of the fossil record. He immediately underlined the matter of the debate, identifying that Fuchs's paper was, in reality, an attack on the Darwinian theory of evolution and should be read as an "Einleitung eines grösseren Feldzuges, gegen die Descendenzlehre". Fuchs — Hoernes asserted — had tried to make his point and to contradict the Darwinian theory on the basis of distorted and poorly interpreted statistical facts. Therefore, Hoernes questioned the validity of Fuchs' investigation by pointing to his biased assumptions. For instance, Hoernes asserted that if the interpretation of the external hard parts is based on isolated bones, then it "ziemlich unsichere ist und keineswegs die Kenntniss des ganzen Organismus ersetzen kann" (Hoernes, 1880, p. 18). Or again, "Niemand wird es heute wagen, 164i taller Bestimmtheit die vollständige Identität der zwanzig diluvialen und recenten Hufthiere blos aus dem Grunde zu behaupten, weil ihre Harttheile grosse Uebereinstimmung [i.e. a statistical considerable numbers] zeigen." Hoernes' conclusion is that the statistical proportion cannot neither prove nor save the quality of the fossil record. Furthermore, taxonomical problems are directly connected with a poverty in the paleontological material; therefore paleontological data are, in principle, biased and statistical methods should be avoided.

Four years later, Hoernes shored up this point in his textbook *Elemente der Palaeontologie* (1884). As he tells us in his introduction, paleontology deals with fossils and aims to discuss their

[139] Rudolf Hoernes (1850-1912) was an Austrian paleontologist, the youngest son of the famous paleontologist Moritz Hoernes (1815-1868). In 1856, Moritz Hoernes published a short paper in *Jahrbuch der Kaiserlich-Königlichen Geologischen Reichsanstalt* about *Die fossilen Mollusken des Tertiärbeckens von Wien*. In this paper, Moritz Hoernes accomplished one of the first gradual phyletic series of the *Cancellaria cancellata*.

biological relationships, their temporal and spatial distribution and their genetic relationships. However, Die Erreichung der idealen Zwecke der Palaeontologie wird wesentlich durch die Unvollständigkeit und Unvollkommenheit des Materiales, mit welchem sie sich beschäftigt, gehindert." (Hoernes, 1884, p. 1) The incompleteness and imperfections of the fossil record strongly hinder the achievement of paleontology's ideal aims. This situation is not temporary: paleontological tradition has been and will always be characterized by traces of incompleteness and imperfections[140]. Acknowledging that the paleontological tradition is incomplete, the paleontologist is thus exposed to error in his judgments and classifications and therefore "Wer die Beziehungen zwischen Abstammungslehre und Palaeontologie richtig beurteilen will, der muß sich vor allem Rechenschaft geben über die Mängel, die dem palaeontologischen Material anhaften." (Hoernes, 1911, p. 457) The paleontologist has to keep in mind the degree of imperfection related to his material: the statistics Fuchs proposed are useless and can be used neither to prove the completeness of the fossil record nor to establish evolutionary patterns. On the contrary, the main aim of paleontology is identifying the series of forms [*Formenreihen*], which are signs of the gradual and Darwinian process of evolution.

The debate about the completeness of the fossil record is therefore an essential step in the development of the notion of paleontological data and in the rejection of statistics. Williams and Fuchs both stress that the fossilized sample of life of the past is as significant as it appears: the gaps in the fossil record should not be seen as evidence of the incompleteness of the paleontological data. Therefore, they endorsed a reading of the fossil record based upon quantitative relations among numbers. This is particularly interesting because it entails a new feature of paleontological data: the gaps in the fossils function as data just as does the morphological information obtainable from a fossilized ammonite[141]. That means that the paleontologist should also take the absence of fossils into account: if only 20 species had been gathered in a specific area, the paleontologist must assume this number is consistent for his biological investigations of that area. The paleontologist should no

[140] Concerning this point, Hoernes changes his mind between the talk given in Vienna (1880) and the publication of the textbook (1884). In the proceedings of meeting, he writes that Es ist demnach Aufgabe der Geologen und Paläontologen, diese, Lückenhaftigkeit durch Ausdehnung und Vertiefung ihrer Studien zu bekämpfen". That means that, in principle, the paleontologist will obtain soonrt or later a higher degree of reliability for his data. Four years later Hoernes affirms that "die palaeontologische Ueberlieferung stets eine unvollständige bleiben muss, selbst dann, wenn grössere Theile der Erdoberfläche geologisch durchforscht sein werden, als dies heute der Fall ist" (Hoernes, 1880, p. 20).

[141] By stressing this point, Williams will mark the development of paleontology at Yale. See for instance reflections presented in Richard Swann Lull's *Organic Evolution* (1917) or Simpson's *Tempo and Mode in Evolution* (1944). For Simpson, the "incompleteness of the paleontological record is an essential datum and… it, as well as the positive data, can be studied with profit" (Simpson, 1944, p. 105)

longer distrust the reliability of a sample. This stands openly against the "literal" reading of Darwin's theory of species. It is just at this point that Hoernes, among others[142], vigorously emphasizes the incompleteness of the fossil record: by stressing the data's incompleteness, he aimed to discredit the use of fossils in a statistical framework. As I have shown by discussing Lesquereux and Williams, this statistical treatment of the fossil record appears to endanger paleontology's epistemic status, because it might prove that the mechanisms of evolution are not properly Darwinian. If, in fact, the fossil is used as a valid source of investigation for statistical analysis, its mostly anti-Darwinian results should also be accepted.

Rapid Evolution is difficult to Account for by any Working of Natural Selection.

The debate about the nature of the fossil record marked a turning point within the paleontological investigations, since Fuchs or Williams's solution gives—at least it is meant to give—stable source for further theoretical inquiries. As a consequence, the reliability of the fossil record is saved and it does not require any kind of construction in order to be used: the fossil record can be read by stressing its perceptual features. However, this 'literal reading' of data is deeply influenced by the ontological nature of the fossil record. Indeed, it requires a synthetic approach. As I have shown in the previous section, the fossil record contains a mine of information which has to be put together. Williams writes that what we call the fossil record is "the morphological combination of characters" (Williams, 1895, p. 83). For example, according to Zittel there are 448 genera of Zoantharia, that means that "there are 448 different combinations of form of the stony corals, which are sufficiently sharply defined and constant in their character to be classed under distinct genera." (Ibid.) Given that the fossil record chiefly represents what happened on the earth's surface, the paleontologist can use those data to generate possible patterns of development. Historical geology has already opened the way to generate such patterns. In his investigation Oppel has indicated that by unifying and confronting the local data, i.e. the zones, we can obtain an ideal profile. Williams proceeds in exactly the same way[143]. He lists the kind and number of fossils found presented in a particular temporal period and from this data he draws a graph to depict the rate of distribution of that genera.

[142] I would like to recall Nuemayr's statement that "wenn man aber, wie es in der Regel geschieht, ohne jede Rücksicht auf die ausserordentliche Lückenhaftigkeit des Materials verfährt und geradezu blind die Richtigkeit der Zahlen annimmt, deren Unvollständigkeit und Ungenauigkeit auf der Hand liegt, so ist eine Beweinung auf diesem Wege absolut unzulässig und muss zu den schwersten Irrthümern führen".

[143] Williams explicitly that "if we only note the numerical relation of these genera to the successive geological periods of time the law above referred to becomes at once apparent." (Ibid.) This means that to come up with laws of development or distribution, the paleontologists needs to put his data into numerical relations.

		C.	O.	S.	D.	Cr.	T.	J.	K.	Ty.	Q.	R.
Tetracoralla	81 genera	5	4	42	10	19	0	0	0	0	1	
Hexacoralla	367 genera	0	4	17	11	7	22	72	75	81	78	
1. Favositidæ		0	3	14	8	3	0					
2. Poritidæ		0	1	2	0	2	1	2	5	8	3	
3. Madreporidæ		0					0			1	1	
4. Pocilloporidæ					2	1				1	1	
5. Eupsammidæ				1				2	2	6	7	
6. Fungidæ							6	13	9	9	19	
7. Astræidæ					1	1	13	46	44	33	28	
8. Styloporidæ								2	0	1	1	
9. Oculinidæ								6	2	4	4	
10. Dasmidæ										1	0	
11. Turbinolidæ							2	1	13	17	14	
Total Madreporaria	448 genera	5	8	59	21	26	22	72	75	81	79	

Figure 28 The table numbers in families the first appearance of Madreporaria within the geological time. From (Williams, 1895, p. 84)

The table than can be transformed into a graph to better point out the features of this pattern.

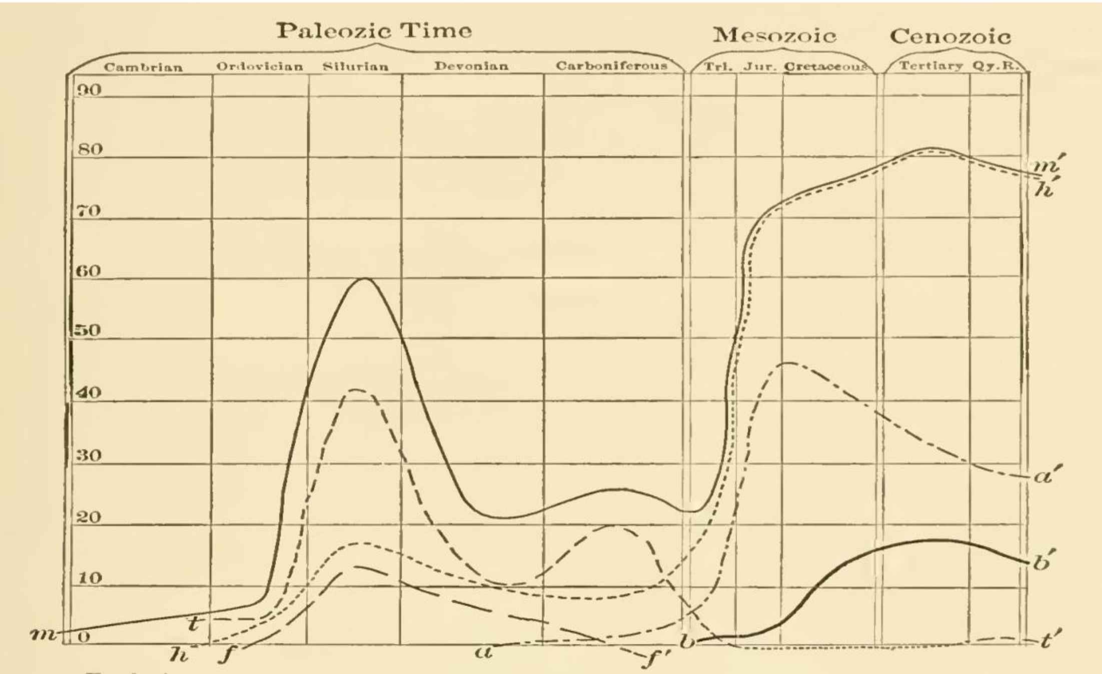

Figure 29 The diagram shows the evolutionary curves of the families Madreporaria. It is based upon the data of the previous figure. Taken from (Williams, 1895, p. 87)

The graph shows the growth of the suborder Madreporaria during the entire Phanerozoic. Moreover, it illustrates the overall degree of development and differentiation of the entire family. Following Williams we notice that "the irregularities of the curve [m] suggest at once that it is compounded of at least three independent curves, of which the nodes are at the close of the Silurian, Jurassic, and Tertiary." (Ibid.) That means that something happened in the proximity of these periods. Second, this investigation is based on too great a timespan, and therefore may only be accepted with difficulty. Although Williams started his analysis by following quasi step-by-step the pure stratigraphical approach, he unified the local points too rapidly. As a result, the graph is a vague representation of what can be done with a statistical treatment of data. Williams did not investigate the curve further. Apart from noticing that the curve *m* can be divided in three different phases, he did not try to describe it. This case is nevertheless important, because it clearly elucidates William's statistical method, its negatives and its positives.

In his textbook, Williams did not recognize the representational problems related to his curve, while he clearly stated the incompleteness of the graph during his correlation studies of the Devonian fauna (1903). As I have shown above, Williams considered the union of the following three factors fundamental for correct use of the fossil record: "In discussing fossil aggregates of organisms we have to consider, therefore, this threefold relationship they bear, viz, (a) to zoological and botanical classification, (b) to geographical distribution, and (c) to geological range" (Williams, 1903, p. 15). Williams unified the information derived from the morphological classifications with the temporal range of the fossil record - bearing in mind that the wider the timespan considered, the more incomplete the generalisation[144]. As a result, "fossils, either as taxonomic aggregates based on genetic affinities or as aggregates associated on the basis of living together, cannot be considered simply by morphological features, but their chronological relations must be distinctly noted" (Williams, 1903, p. 19). This first point is important, since it implies that the paleontologist should not only consider the species' modifications within a span of time, but also "*the length of time during which generation continues in the race with retention of the specific characters. The idea of continuity of race is an element in the geological study of species*." (Ibid.) In other words, what should be included is "*also the length of time through which the fauna persists without loss of the characters essential to the fauna*." (Ibid.)

The second element of Williams' characterisation of paleontological data is that it also represent a continuity of characters through time. The stasis should be taken into account and explained. As I have argued in the previous section, this point is a direct consequence of Williams' ontological position on the nature of the fossil record. Graphically, both a table that shows the kind and number of species against the geological time and what has been called a spindle diagram can represent this point.

[144] This is a key point as regards the epistemic problems of the paleontological sciences. Williams however continually repeats that this pitfall can and will be overcome only if new statistics [i.e. fossils elaborated through statistical treatments] are provided. That means that, as I will extensively argue in the next pages, a) Williams identifies paleontological data with the record of statistical data; b) he fully supports and welcomes a quantitative expansion of the paleontological data.

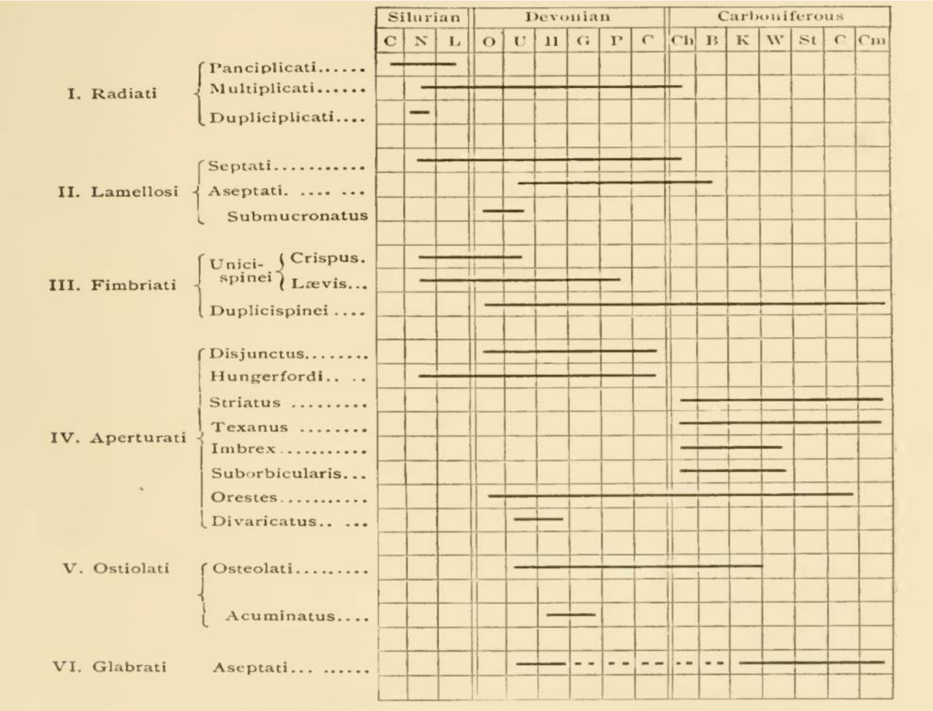

Figure 30 The figure shows the range of Spirifer through geological time. From (Williams, 1895, p. 313)

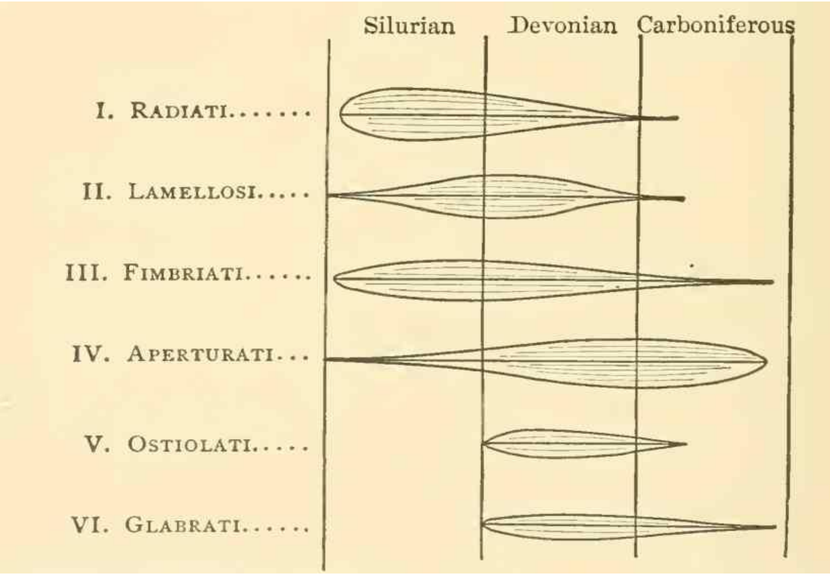

Figure 31 The spindle diagram represents the expansion of the Spirifer in its subgenera. Taken from (Williams, 1895, p. 314)

However, these graphs must be associated with the geographical dispersion of the data: "in order, therefore, to exhibit the full time value of fossil faunas, it becomes necessary to observe all those relations which the individual fossils bear to the environment in which they lived and to each other as they were associated as living individuals of a composite fauna" (Williams, 1903, p. 20). Morphological characters, geological range, and geographical dispersion are tightly connected in order to use the fossil record in statistical analysis.

Williams' main intention is to explain under which conditions can the fossil record be fruitfully used to understand the laws of evolution. This can only be done "if we…note the numerical relations" among the data. This is the only way to depict the history of organisms. In order to accomplish any statistical treatments of the data however, *we need to secure the reliability of the starting point: as Williams reiterates, fossils are not incomplete data*. On the contrary, they chiefly represent evolutionary processes. That means that the gaps in the fossil record should be treated as valuable data and not as an element of embarrassment. This however is not enough. The fossil record contains a great deal of information and in order to read it correctly, the paleontologist needs to take all these elements into account. By unifying the morphological characters with the temporal and geographical dispersion, another meaning of the fossil record emerges: the morphological continuity in time and environment; stasis has exactly the same value as variation. Hence, fossils are particular epistemic things which need to be put into work in bulk, and studied in terms of both variation and stasis.

To better emphasize this conclusion, let us consider the fauna of the middle and upper Devonian of New York province. This can be used to "illustrate the laws of faunal history" (Ibid.). The steps that the paleontologist has to follow to correctly use the data are as follows: first, it is necessary to collect data, i.e. the paleontologist unearths the material objects called the fossil record; second, according to the three above cited elements, all the kinds of information derived from the fossil record need to be treated statistically. As a result, some patterns of development can be described and can be utilised to illustrate the growth and the history of the fauna and hence the law of evolution. The first step is made possible only by "dissecting the faunas into faunules, and analyzing the faunules, more or less perfectly, into their specific values" (Ibid.). The gathering of fossils is thus already directed toward the further statistical treatment. It is already theory-laden: it is first and foremost a numerical expression of the "frequency of appearance in successive stratigraphical zones or at distributed geographical stations" (Ibid.) of the fossil collected. This preliminary statistical treatment can be summarized in a table and the numbers contained in it become the new data.

	Number of localities at which found.	Number of groups of localities.	Abundant.	Common.
1. Spirifer pennatus	113	30	26	33
2. Tropidoleptus carinatus	89	27	22	30
3. Spirifer granulosus	59	28	11	15
4. Chonetes coronatus	57	26	10	16
5. Palæoneilo constricta	56	27	2	5
6. Nucula bellistriata	42	23	4	8
7. Ambocœlia umbonata	40	22	4	8
8. Nuculites triqueter	38	22	1	7
9. N. oblongatus	35	21	1	3
10. Nucula corbuliformis	33	17	4	3
11. Athyris spiriferoides	32	24	2	5
12. Phacops rana	32	18	1	4

Figure 32 The table shows the species occurring most frequently in the Hamilton formation. From (Williams, 1903, p. 51)

In fact, the second statistical process is directed to the numbers contained in the table. These in turn become the new raw-data. It becomes possible to point out the distribution and frequency of the species: concerning, for example, the distribution:

> "analysis of these two sets of statistics shows that the 12 species of the list have all been reported from 32 or more of the 140 localities, nearly 22 per cent of the whole. When the distribution is based on groups of five localities the frequency reaches 17 out of 30 times, or nearly 59 per cent […] It is safe to assume, therefore, that the first 12 species of this list give a fair representation of the dominant fauna of the Hamilton formation as it is expressed in eastern New York and Pennsylvania." (Ibid.)

Once distribution has been studied, statistics on the frequency of the species can be produced. These statistics are necessary because they open up the possibility "to ascertain what were the dominant species. Dominance is a relative term, and implies an equilibrium among the several constituent members of the community" (Ibid.). Knowledge about the dominant species is fundamental "in order to get a definite conception of a fossil fauna". (Ibid.)

To discover the dominant species, other statistical analyses are required: the species has to be compared "on the basis of frequency of occurrence in geographical distribution for a region in which the formation is typically expressed" (Ibid.) and "the basis of frequency of recurrence of the species in vertical range through the successive zones of a continuous section, passing from the bottom to the top of the formation." (Ibid.) The result of the vertical and horizontal investigation is a table of the dominant species for a fauna.

	Per cent of bionic value.		Per cent of bionic value.
1. Spirifer pennatus	79	7. Spirifer granulosus	36
2. Phacops rana	58	8. Chonetes coronatus	36
3. Tropidoleptus carinatus	56	9. Nuculites triqueter	33
4. Ambocœlia umbonata	54	10. Nucula corbuliformis	33
5. Athyris spiriferoides	47	11. Nuculites oblongatus	31
6. Palæoneilo constricta	45	12. Nucula bellistriata	20

Figure 33 List of dominant species expressed in percentage for the New York-Ontario province. From (Williams, 1903, p. 60)

The statistical treatment of the data is thus able to obtain valuable information from the fossils. This conclusion—and it is worth emphasising it again—is possible because fossils are intended as reliable data: "they *represent*, as accurately as can possibly be reported at the present stage of knowledge, *the essential elements* of the fauna" [italics mine] (Ibid.). To put it in other words, they are a representative and reliable sample.

But which kind of conclusion about "the laws of faunal history" can be inferred from these data? The answer is key because the reaction of the Darwinian paleontologists is against the biological conclusions achieved by this method. Williams listed many conclusions stemming from his statistical treatments of the fossil record. I would like to point out just one. He pointed out that evolution is not a gradual process: evolution is a relatively rapid process and this rapidity is difficult to account for by any work on natural selection. Let us analyse this answer step by step. In *The Correlation of geological Faunas: a Contribution to Devonian Paleontology*, Williams stated that he had observed a correlation between the abundance of species and their variability. He went on to argue that:

> "Relatively speaking, the variability is almost in proportion to the vigor and abundance of reproduction of the individuals. Here at once we see a means of rapid evolution. If a species varies and the variation is augmented by favorable conditions of livelihood, the change from one environment to another necessitates the modification of some of the species almost immediately, and the variability of the fauna will be strongly expressed when migration of the species takes place." (Ibid.)

Williams is saying that evolution can be rapid or even quasi-immediate under favourable conditions of livelihood. This point chiefly emerged through the statistical treatment of data: "Thus we see that so far as the evidence testifies, the evolution of those characters which mark the differences between separate classes, orders, sub-orders, and even some families of organisms, has taken place in a relatively short period of time" (Williams, 1895, p. 268). The rapidity of evolution is difficult to explain, if we rely only on the natural selection: "the law of natural selection, suggested to explain the evolution from the first point of view, calls for an extremely slow rate of modification, but uniform and continuous. The facts of the history itself point to the reality of rapid strides at critical points" (Ibid.). Williams concludes,

> "the facts we have examined do not support the hypothesis that the chief factor in organic evolution is either external environment or natural selection. […] The facts examined—and we believe that *fuller examination of other statistics, both fossil and recent* [italics mine], will support—show that evolution is rather an intrinsic law of all organisms, and is to be discovered in the phenomena of variation, which appear to be constantly active, rather than in any accidental operations dependent upon the conditions the conditions of external environment." (Ibid.)

Hence, Williams' conclusions oppose the Darwinian model of evolution. This is mainly due to "the *examination of other statistics*". Although Williams reached the same conclusion both in this textbook and in his papers, it appears most founded in the study on Devonian fauna[145]. In *Geological Biology* Williams supported the inferences emerging from statistical analyses with a broader philosophical argument, namely Alpheus Hyatt's law of evolution[146]. He asserts:

> "thus we see that so far as the evidence testifies, the evolution of those characters which mark the differences between separate classes, orders, sub-orders, and even some families of organisms, has taken place in a relatively short period of time; taking as measure either the rate of general progress in the differentiation of organisms, or the length of the life-period of each particular genus or family." (Williams, 1895, p. 268)

Williams is also explicit in affirming that "the sudden or rapid differentiation [of characters] is a fact, and is not due to imperfect evidence" (Ibid.): however we represent our data, they will always show "a rapid and early expression of the differences in structure which have served as the means of distinguishing different families, subfamilies, and genera; and a close inspection of the figures seems to indicate that in proportion to the higher taxonomic rank of the characters, the earlier or more rapid was their initiation." (Ibid.)

Williams's treatment of data generates thus a limitation of the Darwinian theory of evolution. It limits "das Neu an [Darwins] Lehre—mit dem Wort 'natural selection', natürliche

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[145] William R. Brice noticed that Williams also developed this idea also during his lectures. Indeed, as Williams wrote in his in class lecture notes "If therefore, it be general law it could be said truthfully as far as the [fossil] record inform us that in many cases genera do arise suddenly, geologically speaking, and not by slow and gradual process of evolution. […] Whatever may be the cause of the initiation of new generic characters, the study of the records leads me to believe that the new characters called generic are not solely the product of accumulated variations of specific characters by slow and gradual modification, as is the commonly accepted notion of the requirement of evolution hypothesis, but that they frequently appear suddenly, using as criteria, either geological time, or the total length of the history of the genus." (Brice, 2004, p. 35)

[146] This point might be quite misleading. It is thus important to stress again that Williams' partial endorsement of Hyatt's orthogenetic theory is a consequence of his statistical treatment of data and not vice-versa.

Zuchtwahl" (Rolle, 1862, p. 272). This point could not be accepted, since many paleontologists wanted to preserve the biological status of paleontology as backed up by Darwin's theory. Williams in fact involuntarily points out the differences between paleontology and biology, once he has admitted the limits of natural selection:

> "**The Geological Evidence does not Emphasize the Importance of Natural Selection as a Factor of Evolution**—What has already been said is sufficient to show that the emphasis of the testimony brought forward differs from the emphasis drawn by the embryologist, or by the student of living organisms, as to the relative prominence of the several factors in the evolutional history of organisms." (Ibid.)

Despite his orthogenetic inclination, Williams' results are against the Darwinian theory of evolution: the rapidity of evolution, as it emerges from statistics, creates some problems for the defender of the natural selection. Hence, many paleontologists argued against it.

Neumayr's Reaction: the Rejection of the statistical Treatment of Data

The statistical treatment of fossils generated data and conclusions that were in opposition to the Darwinian theory, as paleontologists perceived it[147]. This opposition is more dangerous than it appears at first glance. Indeed the foremost matter at issue here is not the validity of Darwin's theory of evolution; this is only secondary. What is at stake is rather the autonomy of paleontology, as a discipline. The Darwinian theory had given paleontologists the required support to free their discipline from geology and consequently to enter study of the fossil record into the biological curriculum[148]. Hence, statistics undermines both the autonomy and status of paleontology and so should not be utilized. The debate between Fuchs, Hoernes and Neumayr within the *geologische Reichsanstalt* centers on this: statistical analyses are subversive, for reason of their use against Darwinian theory and, as such, should not be utilized in paleontological sciences. As I have mentioned in my introduction, Neumayr put forward this conclusion even in his textbook to make aware the new generations of paleontologists.

One week after the aforementioned talk at the *geologische Reichsanstalt*, Fuchs gave another presentation. It was entitled *Über einige Grunderscheinungen in der geologischen Entwickelung der organischen Welt*. This talk was intended as a continuation of the arguments expressed the week before, namely that paleontologists could obtain "certain principles" concerning the geological development of the organic world through statistical treatment of the fossil record.

[147] The conclusions are opposed to the paleontological reception of Darwinian thought. It is worth emphasizing again that I am treating the Darwinian model of evolution as paleontologists received it.

[148] It is not a case that no statistics are presented in Zittel's *Handbuch* and on the contrary statistics are widely used in stratigraphic investigations.

These principles, Fuchs said, are "sogar in direktem Wiederspruch mit den Lehren der Darwinistischen Schule." (Fuchs, 1880, p. 39)

The first point he raised in this new talk is that the development of the organisms does not follow "a continuous and uniformly progressive change" (Ibid.), but it is characterized by a long timespan of "*relativer Ruhe mit kürzeren Epochen der Umwandlung*" (Ibid.). This conclusion is very similar to that proposed by Williams[149] and it could not be accepted in paleontology. Conversely Neumayr was strongly convinced that, as according to Darwin, evolution is the development of organisms from "*Grundformen durch allmälige Umgestaltung*"[150] by means of natural selection (Melchior Neumayr, 1889, p. 30).

Neumayr could not approve these Fuchs' conclusions since statistics completely undermines the Darwinian biological core of paleontology:

> "diejenigen Palaeontologen, welche ihre Folgerungen auf die Zahlenverhältnisse von Arten und Gattungen in den successiven Gesammtfaunen oder in einzelnen Typen, Classen, Ordnungen derselben, ferner auf die Art des Auftretens und der Verbreitung neuer Formengruppen stützen, die mit einem Worte eine mehr oder weniger rein statistische Methode anwenden, kommen in der Regel zu dem Ergebnisse, dass die Arten constant seien. […]Auf der anderen Seite finden wir in der Regel der Darwin'schen Lehre günstige Resultate da, wo vom vergleichend anatomischen Stand- punkt aus vorgegangen wird, wie z. B. in den Arbeiten von Gaudry, Gegenbauer, Huxley, Kowalewsky, Rütimeyer und anderen." (Melchior Neumayr, 1878, p. 37)

As Neumayr affirmed in many meetings of the *geologische Reiehsanstalt* and in his *Die Stämme des Thierreiches*, the conflict between defenders and opponents of the Darwinian theory stemmed from the question of statistics: use of the statistical method suggested the expulsion of Darwinian results from paleontological research. There is no union at all between paleontology and Darwin, or to put it otherwise, between paleontology and the biological sciences if the paleontologist unconditionally uses statistics. A secure integration is however practicable if the paleontologist draws *Formenreihen*. Series of forms in fact, provide the evidence for the Darwinian theory of evolution.

To limit the validity of statistics and to promote the construction of *Formenreihen*, Neumayr developed a comparative analysis of the sources of error related to both methods. This analysis

[149] Williams indeed argued that by statistically treating the fossil record evolution seems to be a rapid process and "rapid evolution is difficult to account for by any working of natural selection." The metaphysical assumptions behind it are though different. Fuchs did not argue under the influences of orthogenetic theories.

[150] He is even more explicit: "nachdem ich durch die Untersuchung verschiedener Formenreihen mich von dem thatsächlichen Vorkommen allmähliger Transmutationen überzeugt zu haben glaube" (Melchior Neumayr, 1889, p. 151)

aimed to ascertain which method was worth pursuing. Without any surprise, he asserted that the *Formenreihen* offered less source of error by far than did numerical relations [*Zahlenverhältnisse*]. Neumayr proposed this argument also in his *Die Stämme des Thierreiches* in a section dedicated to the opponents of the theory of evolution[151]. His argument is based upon a) the availability and reliability of the data used in each methods; b) the possibility of detecting and correcting possible errors during the application of the methods to the collected data.

Concerning the *Formenreihen*, the paleontologist has the materials for their realization clearly in front of him: he only has to collect and classify the fossil record. However, he may be mistaken about a particular morphological judgment. Although "eine Täuschung in besonders schwierigen Fällen oder bei ungeschickter Handhabung möglich ist, aber in der Methode selbst ist kein Anlass zu Irrthümern gegeben, sie kann in Gegentheil als seien sehr sichere bezeichnet werden" (Melchior Neumayr, 1889, p. 150). This method is therefore very safe and reliable. Also the control during its application can be simply done: it is easily possible "in der morphologischen Methode eine wichtige Fehlerquelle zu entdecken" (Ibid.). On the contrary, an incomplete and unreliable material characterizes the statistical method and "und nur schwer kann es gelingen, durch sehr sorgfältige Beachtung aller Fehlerquellen Mängel in dieser Richtung auszugleichen" (Ibid.).

Neumayr's conclusion is that the statistical method has to be laid aside until our knowledge about the nature fossil record can be more complete[152]. Only in this way can the epistemic status of paleontology be preserved.

Conclusion

This chapter has shown the *subversive* role of statistics in paleontological sciences between the final decades of the 19th and the beginning of the 20th centuries. I have characterized this method and argued that it was abandoned because it generated results contra the Darwinian theory of evolution. Essentially, the statistical method questions the gradual mode of evolution and the role of natural selection. The aim of a statistical treatment of the fossil record is to draw the numerical relations between the various zones entombed in rock layers. The method's applicability is guaranteed in the nature of the fossil record. If the fossil record is seen as a reliable source, then it can be inserted into

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[151] Symbolically Neumayr considers opponents only those paleontologists who use statistics.

[152] That means until we will be able to establish, "ob und an welchen Stellen Lücken in der Reihenfolge der Faunen existiren und bis zu welchem Grade wir die Bevölkerung in jedem einzelnen Zeitpunkte kennen. Dann erst wird es für alle Formationen möglich sein, so wie es hier für den Jura geschehen ist, festzustellen, unter welchen Thierclassen und an welchen Stellen das Auftreten von Formenreihen erwartet, und unter welchen Bedingungen das Fehlen derselben als ein Argument gegen die Descendenzlehre betrachtet werden kann" (Melchior Neumayr, 1889, p. 38)

statistical procedures. Furthermore, the application of statistics entails a new concept of the fossil record, where that record a) is a reliable sample of the past world, b) contains a wealth of information (for instance, morphological, ecological, geographical), c) may be studied in bulk within a numerical framework, and d) can be identified with the record of a statistical analysis.

This innovative concept of the fossil record was nevertheless put aside because it was openly against the Darwinian model of evolution: paleontologists decided to secure their discipline by providing morphological data for the Darwinian theory of evolution (à la Zittel). Hence, the future paleontological agenda was set in these years: German paleontologists conceived paleontology as a taxonomical discipline which deals with morphological data, American paleontologists studied the tempo and mode of evolution by developing the statistical treatment of data introduced by Williams and his colleagues at Yale.

The statistical notion of the fossil record necessitates broader reflection upon the quantity and quality of paleontological data. Since its origin, paleontology has been a quantitative science. It aims to collect a great deal of data and to catalogue and/or explain this data. However, with the introduction of statistics, the quality of the data has become the subject of much focus. The promoters of the statistical method emphasized the quality and the reliability of their data. This had affect upon the opponents of the *Zahlenverhältnisse*: during the second International Geological Congress (1881), Neumayr proposed to draw up a *Nomenclator palaeontologicus*[153] to order and judge the quality of the fossil record. This massive work aimed to reconsider the quality of the paleontological data, providing a shared source of data for both statistical and morphological investigations.

With the rejection of the statistical method by the first decades of the 20th century, the quality of the fossil record became the hot topic of the paleontological sciences. The paleontologists started to reflect on the epistemic limits and virtues of their data. These reflections would greatly influence the paleontological renaissance of the 1940s and 1950s and the American 'paleobiological revolution' (D. Sepkoski, 2012; D. Sepkoski & Ruse, 2009).

[153] "The proposal of publishing a list of all the fossils described so far is essentially for practical purpose. Paleontological literature is growing in such a frightening way, it is almost impossible to consider all genres and all species, and indeed this is one of the main difficulties of the paleontological work […] In addition to this practical purpose the work has some theoretical interest because it gives the first materials for a statistical treatment of the organic life of the past ages." (Anonymous, 1888, p. CXII)

Chapter VII. On the Notion of Paleontological Representation: The Levels of Constitution of the Paleobiological Data

Introduction

In the previous chapters, I have traced the historical treatment of paleontological data in German paleontology between the mid 19th and the early 20th century. I have pointed out the main features of the data as it emerges from German stratigraphy and paleontology. I have argued, namely, that the fossil record was conceived in at least two different ways: on the one hand, it was identified as a set of facts, on the other as an event in deep time. The former conceptualization was typical of paleontology; the latter, of stratigraphy and historical geology.

I have analyzed the origins, characteristics, qualities, and shortcomings of both approaches in depth and have concluded my historical epistemology by arguing that, and explaining why, neither method is able to contribute to evolutionary theory. I locate this failure in the meaning each assigns to the fossil record. Zittel and his contemporaries identified paleontological data with facts – to the detriment of the temporality of the fossils. Accordingly, fossils are no longer time-makers and the geological time they carry is put aside: they stop being narrative units; they are rather points in deep time. This conceptualization puts paleontology on the same level as biology, but does not explain how to read and connect these facts. As a consequence, the paleontologist cannot draw any kind of biological generalization or law from the data.

We encounter a similar problem with Albert Oppel and historical geology. The German paleontologist was able to create and spread bio-stratigraphic zones by using the fossil record as a local source of evidence. Following Bronn, he conceived the fossil record as an event requiring narration within the local lithological space of its appearance. This has the quality of proposing what, and to what extent, must be improved if the paleontologist wants to come up with causal explanations of the history of earth. Nevertheless, the degree of knowledge is only local: global evolutionary patterns are on principle excluded. Since statistics are required in order to obtain global patterns of evolution; since this method then generates results openly opposed to the Darwinian model of evolution, search for a global pattern could not feature in paleontological investigation. Knowledge in deep time can be obtained only locally. It depends *in toto* on the contingent features of the places where the well-preserved fossils have been found.

In this chapter, I will engage with how the conceptualizations of the paleontological data so far exposed were reformulated; further, how then used as starting points for studying patterns of life diversity in deep time during the American paleobiological revolution. Explicitly, I will stress the philosophical assumptions behind, and the conditions of possibility for, this transformation. I will argue that the ‘coming into being’ of paleobiological[154] data was possible only through reconsideration of the two conceptualizations of data available in that period. The main finding of the paleobiological revolution was an understanding that the fossil record provides global evolutionary patterns only if its perceptual features have been previously destroyed and redefined in another way. A new categorial framework[155] was used to conceptualize the perceptive inputs and this constitutes the core of the paleobiological paradigm. I will track this practice by showing how the main actors of the paleobiological movement have used and re-elaborated the meaning of the fossil record as defined by German stratigraphy and paleontology.

By radicalizing and pushing my historical epistemology into a meta-reflection on the paleontological results, I will reconstruct in detail the possibility of transforming this allegedly incomplete and misleading material object - the fossil record as viewed in a museum - into a reliable source of knowledge. In fact, I will argue that paleobiological data is not a ‘given’ at all. They are, on the contrary, the end product of a complex activity of construction and deconstruction of observational features of the material fossil record. The fossil record for a paleobiologist is not something which can be admired in a natural history museum; it is rather a stabilized version of the past. I will describe the levels of this constitution step by step, emphasizing the element of continuity and fracture with German paleontology.

This chapter aims to describe the levels of constitution of paleobiological data to shed light on its applicability, *de facto* and *de jure*. I will use a Neo-Kantian approach[156] to understand how the conceptualization of paleontological data was reformulated and taken as the starting point for studying the patterns of the diversity of life in deep time between the 1940s and 80s. I will characterize my analysis as a meta-reflection on the fact of paleobiology. I will reflect on the

[154] As I have discussed in the introduction of this dissertation, a distinction needs to be drawn between paleontology and paleobiology. To reclarify, Paleobiology is a new approach to the fossil record originating from the 1970s. It aims at “1) making paleontology more theoretical and less descriptive; 2) introducing models and quantitative analysis into paleontological methodology; 3) importing ideas and techniques from other disciplines (especially biology) into paleontology; 4) emphasizing the evolutionary implications of the fossil record” (Sepkoski, 2012). Or according to Derek Turner: “1) Paleontology has to contribute to biology than to geology; 2) Study fossils in bulk — individual specimens don’t tell you much about evolution; 3) Paleontology needs theories; 4) If you can’t experiment, then simulate.” (Turner, 2011). Of course, this does not mean that all of these features are literally invented by paleobiologists. One of the aims of my dissertation is to show the roots of some of these characterizing points. It is nevertheless undeniable that although the origins of the paleobiological revolution are rooted in the past; the supporters of that revolution consciously re-elaborated those roots as Turner’s points 3 and 4 suggest.

[155] Michael Friedman affirms that a constitute framework defines a space of empirical possibilities. (Friedman, 2001) I will trace how this space has changed and evolved over time.

[156] See for instance (Cassirer, 1940)

products of the paleontological enterprise in order to identify their nature and their conditions of possibility. Through the study of a particular concrete object, i.e. the notion of paleontological representation, I will show that paleontological data are always mind-dependent entities on several layers. Paleontological data does not "objectively exist independently of the mental" (Devitt, 1991, p. 24): to ask "*what objects does the world consist of?* […] makes sense [only] *within* a theory or description" (Putnam, 1981). Hence, the notion of paleontological data is embodied in our cognitive activities and our representations of the perceptual stimuli. Our cognitive activities dictate what can be legitimately done with the fossil record.

The historical development of paleontology shows that as soon as the paleontologist renounces defence a metaphysical and 'naïve realism', he is able to *represent* the fossil record in order to come up with evolutionary explanations[157]. Based on this, the relevant questions of this chapter are concerning the notion of paleontological representation: i) which notion of representation is required in order to use the fossil record to identify evolutionary patterns and processes? ii) which assumptions and conditions are necessary to represent the fossil record in a biological framework? iii) which kinds of functions does the paleobiological self[158] need in order to identify, find, determine, and use the paleontological data? iv) how has the paleontological categorial framework changed over time?

In the following subsections, I will consider four concrete, simple, and significant paleontological representations, which exemplify four different paleontological approaches, in order to acquire their conditions of possibility. I will consider how and to what extent the so-called 'raw-data' are shaped into a representational form. I will then identify the required assumptions for, the layers of construction and the conditions of possibility of, the paleobiological representation. These are understood as the constraints that a paleontological community imposes on empirical contents in order to obtain epistemic access to their *explanandum*. First, I will consider Zittel's description of *Psiloceras planorbis*. Second, I will deal with Waagen's *Formenreihe* and Williams' representation of fauna. Third, I will analyze Raup and Sepkoski's representation of periodicity in mass extinctions within geological time. This last representation is one of the significant findings of the paleobiological revolution. In fact, the evolutionary biologist John Maynard Smith welcomed paleontology back to the evolutionary 'high table' on the basis of Raup and Sepkoski's results (J. M. Smith, 1984).

[157] In other words, "for, so long as men thought that *real* things subsisted without the mind, and that their knowledge was only so far forth real as it was conformable to *real things*, it follows they could not be certain they had any real knowledge at all. For how can it be known that the things which are perceived are conformable to those which are not perceived, or exist without the mind?" ((Berkeley, 1988) §86)

[158] See (L. Daston & Galison, 2007)

The study of these representations illustrates how the paleobiological movement reformulated the notion of the fossil record. The proponents of that revolution destroyed and redefined the notion of the fossil record as a ready-made entity. The fossil record for a paleobiologist is not something to be admired in a natural history museum; it is rather a stabilized version of the past, actively constituted as a set of relations. By virtue of an active constitution and a backpack (Leonelli, 2009) the fossil record becomes a nonlocal source of information. Paleobiologists thus actively imposed formal constraints on the perceptual contents to obtain reliable starting points.

Few scholars could deny the theory-laden nature of paleontological data. However, I will not merely defend this nature of the paleontological perception; I will rather depict the nature and layers of this ladenness by identifying the categorial framework related to it. In other words, I will not question the theory-laden nature of the paleontological perception, but stress the philosophical assumptions behind, and the conditions of possibility for, it. The ‘coming into being’ of paleobiological data was possible only when the two conceptualizations of data available at that time were reconsidered. A new categorial framework was used to conceptualize the perceptive inputs and came to constitute the core of the paleobiological paradigm. The fossil record can provide global information and patterns of evolution, only because it has previously been materially destroyed and redefined in another way.

I will argue that paleontologists began to use their data to uncover biological and global patterns and processes when they renounced a realist approach to paleontology and deep time. In other words, they “comprehended that reason has insight only into what it itself produces according to its own design” (Kant, 1999). Thus, the paleobiological community constitutes paleobiological data: they impose on the perceptive inputs strong formal schemas. Indeed, with more formal inputs from the scientists, the four representations become more abstract and complex; only by actively imposing formal constrains were the paleobiologists able to acquire epistemic access to deep time. I will describe in detail the layers of this constitution; also, and the necessary premise contained in every valid judgment concerning paleontological facts (Cassirer, 2000).

Hence, the question about what an object—for example the fossil record—is, has a meaning only *within* the categorial framework chosen to describe and constitute it. By studying the notion of paleontological representation, I will describe the categorial framework employed by German paleontologists and American paleobiologists at the beginning of their enterprise. For both of these groups, I will make explicit “(i) [their] categorization of objects, (ii) the constitutive and individuating principles associated with the maximal kinds of [their] categorization, (iii) the logic underlying [their] thinking.” (Körner, 1970, p. 10)

My approach is therefore different from, if albeit very close to, the enquiries of Norwood Russell Hanson (1924–1967) or Willard Van Quine (1908-2002). Indeed, Hanson famously asked, whether "*Kepler and Tycho see the same thing in the east at dawn?*" and Quine answered that "the so-called observations vary from observer to observer with the amount of knowledge that the observers bring with them." (Willard Van Orman Quine, 1969, p. 88) My approach is similar in as much as both philosophers underline that "the possibility of having *sensate esperienze* depends on the particular logical relation instituted by observation and theory from time to time"(Cardani & Tamborini, Under review); it is distant, because they do not investigate the nature, the role, and the assumptions behind the principles that guide epistemic perception.

In other words, although my investigation is deeply concerned with the debate about the theory-laden nature of scientific observations, I am not simply claiming that an observation of x is always shaped by prior knowledge of x (à la Hanson). Rather, I argue that paleobiological data, i.e. what is given, is the final and complex product of a step-by-step constitution, which exchanges the concreteness of the fossil record—i.e. its perceptive, but incomplete qualities—with a higher technical reliability. The paleobiological community imposes this exchange. In fact, according to Gaston Bachelard (1884-1962), the process of scientific construction generates a technical object implying an epistemic rupture between "sensual knowledge and scientific knowledge. […] Science *realizes* its objects without ever finding them readymade. A concept becomes scientific according to the proportion to which it has become technical, to which it is accompanied by a technique of realization." (Bachelard, 2002, p. 239) In the following pages, I will both describe this rupture and point out how data are constrained, constructed, and constituted. Namely, I will analyse the strong formal constrains imposed by paleontologists and paleobiologists on their object to emphasize the principles that constitute the concept of the paleobiological object (Reichenbach, 1920, p. 48).

Representation by Ostension or Description

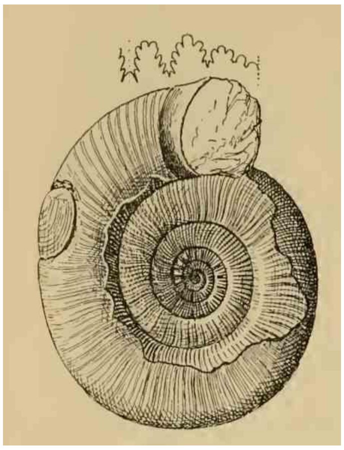

Figure 34 Zittel's representation of *Psiloceras planorbis*.

The first notion of representation (figure 1) represents a *Psiloceras planorbis* and it is printed in Zittel's *Handbuch der Palaeontologie*. In drawing it, Zittel generates a possible rule for further identifiability. When a paleontologist comes across a material object which has the same perceptual characteristics, he can then apply the label *Psiloceras planorbis* to it. This epistemic practice is a possible mode of representing the material object and has been used quite successfully. It generates a *Denkkollektiv*, able to spread pure paleontological data. In order to use this data, a paleontologist first learns how to look and recognize the material fossils. I.e the paleontologist learns how to represent the fossil record, so that he can find it again even when this object is no longer directly under his perceptual activity. In fact, most of the time the paleontologist deals with data that he cannot immediately perceive. Roughly speaking, the organism *Psiloceras planorbis* is not a direct object of his perception, since it was wiped out during a mass extinction. At the same time, *Psiloceras planorbis* is a natural kind name. When the paleontologist uses it, he does not - perceptively - have all the sets of its objects to hand. Zittel's enterprise aims at decoding a practice to represent something which is no longer presented: it aims to present for a second time what has been experienced.

The status of representation within Zittel's practice is pivotal, because Zittel strives to acquire intersubjective, thus communicable, data through representing the fossil record. But what kind of representation is involved in this practice? Moreover, what does this form of representation say about the notion of paleobiological data? We need to make an initial remark: that the representation involved in this practice is *not* a *mimetic presentation of experienced contents*. It is not a copy of what can be gathered from a particular area. It should be clear from the very start that to represent does not mean a mimetic presentation of the contents of experience [159]. The representation is not a copy, an image, or a mirror of private experience. On the contrary it is an active re-elaboration of what is perceived. To state this clearly: "representation is always an exercise in portraiture, albeit not necessarily one in mimesis". (L. Daston & Galison, 2007, p. 382)

Having discussed that representation is not a mere image or copy of the "world out there", I can now focus on a first example. The paleontologist James R. Beerbower can help to elucidate the qualities and pitfalls that underpin this first notion of representation. A teacher at Lafayette College, he describes the typical stream of consciousness of a paleontologist juggling with a "three-inch square of rock, collected last summer in West Virginia":

> "It is a piece of coarse sandstone […] on one surface I can see a dark blue structure consisting of a button-like base and two prongs perhaps a half an inch long. Is it a fossil? Well, perhaps it is […] What else can I observe? […] Seen under a

[159] See, among others, Cassirer's arguments against the identification of concepts with *Abbildungen*.

> hand lens it is very dense but not too hard. […] It must be a tooth. What kind? Perhaps a shark's tooth? Comparing it with those illustrated in Romer's Vertebrate Paleontology, I find it very similar to one type named Xenancanthus—if not that group, at least something very close to it" (Beerbower, 1960, p. 2)

Taken from Beerbower's extremely popular textbook *Search of the Past* (1960), this perfectly represents the mental process of the paleontologist who deals with a fossil not yet described and catalogued. "If it had been a shell or a leaf impression, the process would have been the same: *to observe and compare*. This is the basic method, the skeleton, of paleontology" [italics mine] (Ibid.). The student has therefore to learn this descriptive and taxonomical practice, since it constitutes the historical skeleton of paleontology. Zittel would have written a comparable passage to illustrate his understanding of paleontological research.

The same process is followed in the examination of the material object *Psiloceras planorbis*. Once the paleontologist has recognized that the "three-inch square of rock" is a fossil, he starts to represent it. He sifts and orders namely "what counts for him as experience" (See, L. Daston, 2005) and in doing so, produces facts, i.e. represented versions of his experience. He provides the necessary conditions for the further identifiability of this "three-inch square of rock" and he baptizes it as *Psiloceras planorbis* by pointing to it during, for example, a lecture[160]. It is not improbable that Zittel had structured his "boring lectures" on the same practice. The sign or image *Psiloceras planorbis* then replaces the material object becoming the paleontological *explananda*. Indeed, the paleontologist seeks to explain, for instance, the morphological structures of the represented objects and not the features of the "three-inch square of rock, collected last summer in West Virginia". Even this kind of representation, which seems to be a mere image of what the paleontologist has perceived, does not create a copy of the object. It rather re-elaborates its formal structure: it is an exercise in a particular kind of portraiture. For instance, the paleontologist represents for a second time the morphological relations of the material object by stressing some of these features and reconstructing others. To represent is thus first and foremost a matter of choice. The paleontologists choose which aspects to emphasize of the material fossil record. Let me briefly re-emphasize this point from another point of view.

Briefly putting aside Zittel's *Psiloceras planorbis*, it seems intuitively impossible that what is illustrated in Zittel's *Grundzüge* is a mere copy of the fossil record. Let us consider figure 2.

[160] I will return to this point in a few pages.

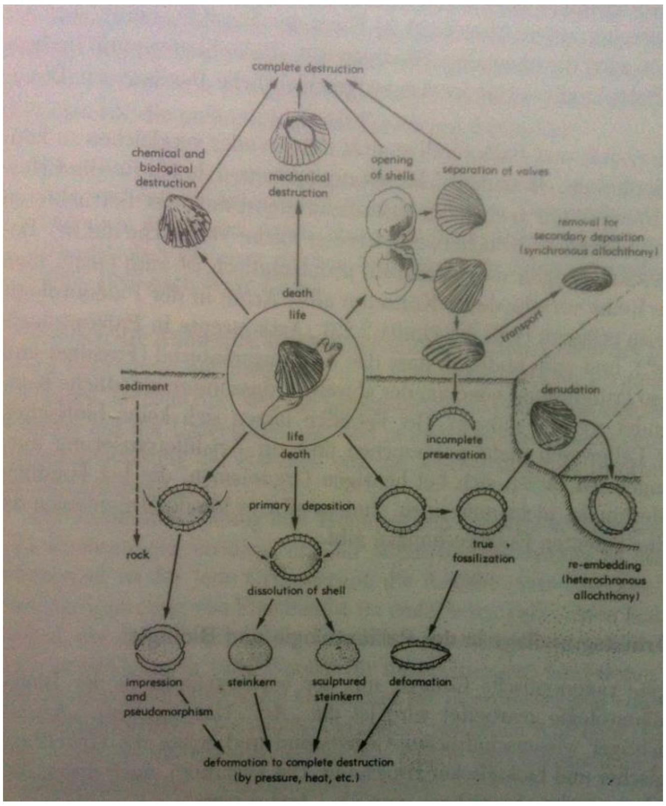

Figure 35 Possible taphonomic processes.

The diagram shows the possible "transitions of animal remains from the biosphere into the lithosphere" (Efremov, 1940, p. 85). In most cases, the organism is subjected to numerous diagenetic processes, which transform and destroy it. In the end, only a little fragment of the original organism has been preserved. The paleontologist deals exactly with this transformed form by attempting, for instance, to classify or reconstruct it. From an intuitive point of view, it is certainly evident that what is represented in a taxonomical collection does not resemble its material footprint. In fact, the fossil record is hardly given in such a form: "even a large and complex system of representations, both verbal and visual, still does not have an *intrinsic*, built-in, magical connection with what it represents – a connection independent of how it was caused and what the dispositions of the speakers or thinker are." (Putnam, 1981, p. 5)

It has been largely, and I think reasonably, argued that an innocent eye or "God's Eye point of view" is a myth: "the eye comes always ancient to its work obsessed by its own past and by old and new insinuations of the ear, nose, tongue, fingers, heart, and brain" (Goodman, 1968, p. 7). Few scholars would deny the theory-laden nature of epistemic perception. Goodman implies that in representing the species, the paleontologist "selects, rejects, organizes, discriminates, associates, classifies, analyzes, constructs." (Ibid.) This is indeed what a paleontologist does every day: he *observes, compares, sifts, and orders* what counts for him as experience. In this activity he does not merely copy the object; he makes it[161]. The prefix *re-* in representation is thus "essential: imagine that to strive for representation is to present again what already is" (L. Daston & Galison, 2007, p. 382) and to present again means to create a slightly different version of what already is.

Let us return to Zittel's *Psiloceras planorbis*. I have so far pointed out the factual condition of this epistemic practice. Namely, I have pointed out—from a *de facto* point of view—why Zittel stressed the importance of representation. This first analysis has already shown that the paleontological world does not "consist of some fixed totality of mind-independent object[s]?". (Putnam, 1981, p. 50) I can now address the question about the validity of this process, elucidating thus Zittel's categorial framework. This will help to understand why Zittel's notion of data is unhelpful in paleontology[162]. Asking about the validity of a process means tacklling with the "necessary premise[s contained] in every valid judgment concerning facts" (Cassirer, 1923, p. 269). Following Goodman[163] again, we can claim that "in representing an object, we do not copy such a construal or interpretation—we *achieve* it" (Goodman, 1968, p. 9). That means that for "a picture to represent an object [it] must be symbol for it, stand for it, refer to it […] A picture that represents—like a passage that describes—an object refers to and, more particularly, *denotes* it". The first figure represents a *Psiloceras planorbis* in virtue of the fact that it denotes it and is "independent of resemblance". Goodman's remark summarizes what I have being arguing so far: i) the notion of similarity does not constitute the center of representation, but "denotation is the core of representation"; ii) to represent does not mean to create a copy of the object, but to remake it. This is Zittel's position exactly. Zittel in fact conceives the representation of *Psiloceras planorbis* as a symbol[164] that denotes the - more or less completely preserved - material object *Psiloceras planorbis* by remaking and achieving it. By identifying representations with symbols, Zittel is also able to spread stable facts. These in turn say something about the denoted objects. Hence, the first "necessary premise" concerns the identification of a representation with a symbol.

Goodman's analysis underlines another essential feature of representation, which Zittel appears not to take into account or perhaps does not want us to take into account. According to Goodman, there is a distinction between what an image represents and what it denotes and this distinction should not be confused. Let us follow Goodman: "saying that a picture represents a

[161] From another perspective, Hans-Jörg Rheinberger stresses my same point in (Rheinberger, 2011)

[162] See the introduction and the chapters 2 and 3.

[163] It is important to stress that although I am arguing with Goodman, I do not accept *in toto* his arguments.

[164] According to Goodman, "'Symbol' is used here as a very general and colorless term. It covers letters, words, texts, pictures, diagrams, maps, models, and more". (Goodman, 1968, p. xi). Goodman's symbols therefore can be assimilated to the notion of scientific data as proposed by Bogen and Woodward. Bogen, particularly, extends the notion of data to images. See (James Bogen, 2009)

soandso is thus highly ambiguous as between saying what the picture denotes and saying that what kind of picture it is" (Ibid.). We must separate two elements in the structure of a representative image. On the one hand, a picture is able to denote; on the other, a picture shows us what it represents. The picture that represents a unicorn does not denote a unicorn; it is rather only a 'unicorn-picture'. It represents only a particular kind of picture, namely the 'unicorn-picture'. The picture that represents a book denotes it; "a picture that represents a fictional man is a man-picture; and a picture that represents a man as a man is a man-picture denoting him". (Ibid.)

We are able therefore to distinguish what a picture denotes from what it represents. Figure 1 is a *Psiloceras-planorbis*-picture and denotes a set of *Psiloceras-planorbis*. This distinction is essential and accordingly should not be confused. Goodman concludes his analysis thus: "for the denotation of a picture no more determinates its kind than the kind of picture determinates the denotation. Not every man-picture represents a man, and conversely not every picture that represents a man is a man-picture" (Ibid.).

This point entails a major consequence: the first figure denotes something (a set of *Psiloceras planorbis*) and this does not depend on the characteristics of the *Psiloceras-planorbis*-picture. The kind of representation could have legitimately been different and it would have nevertheless denoted a set of *Psiloceras planorbis*. Hence, there is a deep fracture between the features of the represented *Psiloceras-planorbis* and its ability to denote the "three-inch square of rock" named *Psiloceras-planorbis*. As Goodman puts it, "representations, then are pictures that function in somewhat the same way as description. Just as objects are classified by means of, or under, various verbal labels, so also are objects classified by or under various pictorial labels". He concludes by asserting that "the labeling of labels does not depend upon what they are labels for." (Ibid.) Hence, there are two levels whereby we can deal with the notion of representation. We can deal with 1) what it denotes; and 2) what it represents, i.e. the kind of representation it presents to us. In other words, not every *Psiloceras-planorbis*-picture represents a *Psiloceras planorbis*, and not every *Psiloceras planorbis* is a *Psiloceras-planorbis*-picture. This is an important point[165]. It also means that behind an intuitive comprehension (see above) there is no "*intrinsic*, built-in, magical connection" between representation and what it represents. I can employ different language to make the same point: the way in which we intentionally refer to something is not sufficient to determinate what we denote. An extra-linguistic element seems to be involved.

These two levels are distinct and the connection cut between what the first figure represents and what it denotes. According to Goodman, this connection can be made only by the means of

[165] As I argue in the final subsection, the paleobiologists put it as the cardinal point in the characterization of the paleobiological data.

stipulations and habituation. This is Goodman's extra-linguistic element: "application and classification of a label are relative to a system, and there are countless alternative systems of representation and description. Such systems are the products of stipulation and habituation in varying propositions." (Ibid.) This is an essential point and it will help us to clarify the second and third notions of representation. It states that i) to represent is a matter of intervention and therefore it makes no sense to speak of ready-made data or phenomena ii) the validity of a representation is only such within a system, iii) systems are the results of stipulations and habits. However Zittel only partially understands this distinction between the representation and the denotation of an image. Or rather, he understands that the system, in which a representation is inserted, is a product of a stipulation—as Zittel's notion of species indicates—but not the further two points. He particularly refuses the notion that the relation between symbols and what they denote is a matter of stipulations and habits. As I will show in a moment, he bases the extra-linguistic element upon metaphysical realism.

Indeed, the separation between what a picture represents and what it denotes has many consequences. In addition to the three points already indicated, I would like to focus on two more. The implication is that iv) "almost any picture may represent almost anything…given the picture and object there is usually a system of representation, a plan of correlation, under which the picture represents the object" (Ibid.); v) "whether an object is 'really fixed' or a picture is realistic depends at any time entirely upon what frame or mode is then standard. Realism is a matter not of any constant or absolute relationship between a picture and its objects but of a relationship between the system of representation employed in the picture and the standard system" (Ibid.). Both these conclusions are important and they will constitute the "necessary premise" under the other two notions of representation, but exactly as i-iii, they do not play a key role in Zittel's practice.

Indeed, Zittel does not comprehend *in toto* the consequences related to the identification of two levels in the notion of representation. He claims, on the one hand, that the relation between the *Psiloceras-planorbis*-picture and what it denotes is a matter of convenience, since we can name the picture differently; on the other, he does not recognize that "application and classification […] are relative to a system" or that "almost any picture may represent almost anything" and *a fortiori* he does not understand that "realism is a matter not of any constant or absolute relationship between a picture and its objects". To put it concisely, Zittel does not recognize that the notion of representation, which he was endorsing, requires the provision in turn of a metaphysical concept of realism and meaning.

This is the central point in Zittel's notion of representation. Zittel does not take the notion of representation to extremes. This is mainly due to the fact that, in order to secure paleontology from speculation, he believes that metaphysical realism can better support paleontological practice. Zittel then characterizes the extra-linguistic element in the initial baptisms. The reference is fixed in an initial baptism “by ostension or a description” (Kripke, 1972). This baptism, according to Devitt, is founded on the object “being perceived. […] The appropriate grounding thought for, say, ‘cat’ includes a demonstrative representation of the object perceived and a mental representation of the sematic type ‘cat’. An example, […] ‘That is a cat.’ It is in virtue of the casual link to that particular cat that the term ‘cat’ appearing in the thought is grounded in cats.” (Devitt, 1981, p. 190) ‘This is a *Psiloceras planorbis*’ is thus grounded on the ammonite ‘out there’ that fixes the reference. Hence, Zittel’s notion of representation is supported by metaphysical realism: “the world consists of some fixed totality of mind-independent objects”. For Zittel there is finally “constant or absolute relationship between a picture and its objects” and this provides a secure foundation for his practice. This relationship is more than ever important because the nature of the fossil record is incomplete and imperfect; an erroneous reading or representation of these records generates dangerous speculations. Therefore, paleontologists should be the most realist of realists. The “constant or absolute relationship between a picture and its objects” is the only ground, which is able to save paleontological phenomena[166]: it provides the required metaphysical foundation.

Zittel thus aimed to secure the paleontological domain from speculation; to accomplish this he chose to represent the fossil record under a particular circumstance. He does not represent the temporal dimension of the fossil record, because it would have allowed many paleontologists to treat the fossil record as an event in the deep time. He only *sees*[167] the material object and he seeks to represent it in accordance with its particular morphological structure, so that the particular system of symbols, in the form of the entries in his textbooks, can univocally denote the material object. He dubs these symbols, facts and identifies them as paleontological epistemic items. The representation brackets off all disturbing temporal factors, but leaves the material features of the fossil untouched. These features are important, because they guarantee the “constant or absolute relationship between a picture and its objects”. As above, the baptism comes from the fact that something can be perceived.

To summarize, Zittel’s epistemic practice implies that a) by carefully choosing what is worth representing, the paleontologist achieves his objects. In fact, he realized a stabilized and communicable version of the fossil record, i.e. the system of symbols printed in textbooks. B) Although he understands *de facto* that what the figure represents is based upon stipulation and

166 Bronn in part cut the link between the “picture and its objects” and this, according to Zittel, caused speculations. See the first chapter.

167 On the importance of perception for paleontology, see the third chapter.

habituation and thus it might not be what the picture denotes, he does not permit himself to sever the connection. In order to abide by metaphysical realism, which seemed to him the best way to save the epistemic status of paleontology, he founded his *practice* on the ontological features of objects. The first figure is ultimately correct because its structure corresponds to our-sense data. When the paleontologist speaks "of a fact […] [he] mean[s] the kind of thing that makes a proposition true or false". (Russell, 1985, p. 6) Or "In order to tell whether a picture is true or false [or rather correct/incorrect] we must compare it with reality" (Wittgenstein, 2001) It is a *Psiloceras-planorbis*-picture because it is based upon the constant or absolute relationship between a picture and the morphological features of the object exhibited during a lecture.

I can now draw some conclusions about the first notion of representation and, consequently, Zittel's categorial framework. Zittel, and many paleontologists following him, oscillates between two antipodes. In his two masterpieces, *Grundzüge der Paläontologie* and *Handbuch der* Paläontologie, he tries to spread stable paleontological data by representing the material fossil record. He was able to spread a stable and communicable version of it in the form of facts. In this way, the representation achieves its object and it becomes the new *explanandum*. From this point, generations of paleontologists will struggle to explain the features of these facts. Thus, selective representation of the material fossil record is the first condition of possibility of paleontological investigation. By representing the fossil record, the paleontologist creates an epistemic object that has a degree of autonomy. This forms the skeleton of Zittel's constitutive framework.

However, Zittel's notion of representation is not radical enough because it requires the presence of an object 'out there' not only at the beginning of the process, i.e. in its initial baptism, but also at its end. This is meant to give the required (metaphysical) stability of the representation. Although Zittel's representation achieves the object[168], it always requires the presence of the material object to provide its last foundation. Instead of saving the epistemic power of representation, this last foundation destroys it: Zittel's data is unable to provision evolutionary explanations[169]. These share the same ontological biases of the material objects and only in this sense are they a mere copy of them. The philosopher Nicolai Hartmann (1882-1950) incorrectly raised an objection against the neo-Kantian notion of object [*Gegenstand*] that perfectly and

[168] Cassirer stresses this point as follows: "The concept of the phenomenon itself differs, according as it is applied to an indefinite object of sense perception or to the theoretically constructed object of mathematical physics; and it is precisely the conditions of this construction which give rise ever anew to the epistemological question." (Cassirer, 1923, p. 139)

[169] See the second and third chapter.

paradoxically describes Zittel's confusion: Zittel confounds "the concept of thing, with the thing itself."[170] (Hartmann, 1931, p. 14)

This last point implies another philosophical conclusion. Even if Zittel's practice is unable to provide evolutionary explanations, it establishes *de facto* pure paleontological data, able to separate paleontology decisively from geology. If the paleontologist simply aims at collecting and classifying species, then Zittel's notion of representation and *a fortiori* his categorial framework has complete validity. This defines a space for possible empirical knowledge: the classical ideographic paleontology is entirely based upon it. This entails that the data are layered [*mehrgliedrig*] depending on different logical points of reference [*Bezugspunkten*] taken (Cassirer, 2000, p. 297).

How Representations Literally Construct the Ontological Features of their Objects

The second group of figures identifies paleontological data with events. This identification has historically taken two different paths: on the one hand (figure 3) the fossils are events, which can represent a highly precise, albeit local, evolutionary history. Figure 3 represents a series of form [*Formenreihe*]. On the other, the event-fossil record narrates a global history when it is transformed into a mathematical record: figures 4 and 5.

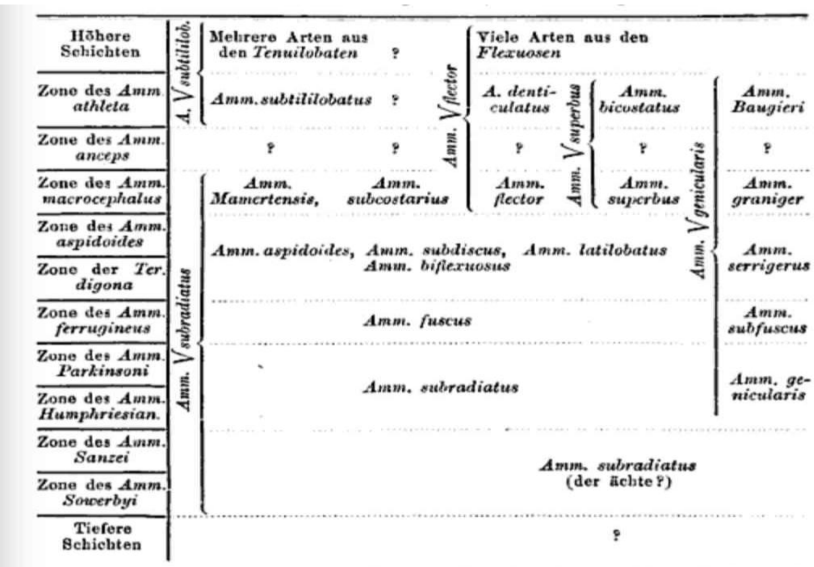

Figure 36 A formal representation of the *Formenreihe* of *Ammonites subradiatus*. Taken from (Waagen, 1869, p. 192)

[170] It is rather interesting to note that Devitt used the same argument against anti-realism.

		C.	O.	S.	D.	Cr.	T.	J.	K.	Ty.	Q.	R.
Tetracoralla	81 genera	5	4	42	10	19	0	0	0	0	1	
Hexacoralla	367 genera	0	4	17	11	7	22	72	75	81	78	
1. Favositidæ		0	3	14	8	3	0					
2. Poritidæ		0	1	2	0	2	1	2	5	8	3	
3. Madreporidæ		0					0			1	1	
4. Pocilloporidæ					2	1				1	1	
5. Eupsammidæ				1				2	2	6	7	
6. Fungidæ							6	13	9	9	19	
7. Astræidæ					1	1	13	46	44	33	28	
8. Styloporidæ								2	0	1	1	
9. Oculinidæ								6	2	4	4	
10. Dasmidæ										1	0	
11. Turbinolidæ							2	1	13	17	14	
Total Madreporaria	448 genera	5	8	59	21	26	22	72	75	81	79	

Figure 37 The table numbers in families the first appearance of Madreporaria within the geological time. From (Williams, 1895, p. 84)

Both representations are based upon the fact that "as the chisel of a sculptor obliterates in succeeding blows its earlier marks, so these processes [natural processes of the earth] obliterate the traces of their own action, leaving the paleontologist only the *smallest sample of the past on which to base his reconstruction*" [italics mine] (Beerbower, 1960, p. 7). The natural processes destroy the trace of the past and the paleontologist needs to come up with a solution to use this data. Although this is exactly Zittel's starting point, the meaning of the fossil record is quite different. Waagen and Williams[171] in fact *do not* consider the fossil record as an isolated point, but as a sample of the past. That means that they treat the fossil record in bulk and not as a single point. By quickly comparing the first two groups of figures we can notice that the quantity of data they use is remarkably different. The first figure represents a single species, whereas the second group of figures represents a set of species. At first glance, this first difference might not seem significant at all. It might be merely a contingent fact that Zittel used less data than Waagen or Williams. However, this is not a merely contingent instance, since both paleontologists aimed to detangle biological issue; yet only Waagen and Williams were able to discover evolutionary processes. The fact that the second figure represents more fossils than the first one is thus an essential feature for its further application: in order to come up with evolutionary processes or patterns, the paleontologist needs to study the fossils in bulk[172].

The first "necessary premise" for this notion of representation is the importance of working with a bulk quantity of data to obtain evolutionary patterns and processes. But what kinds of assumptions are needed for operating with this data? Two different kinds of assumptions are essential when using the fossil record in bulk. First, the fossil record has to be considered as an event, requiring narration. This assumption has deep and ancient roots: Cuvier, d'Orbigny, Bronn, and Oppel all shared the same conception of the fossil record (see fourth chapter). They considered

[171] See the previous chapters for a more precise historical context.

[172] As I have argued in the previous chapter, this means that one of the slogans of the paleobiological revolution (see (Turner, 2011)) finds its root in the second half of the 19th century.

the fossil record as an event and hence try to develop an epistemic practice to read and trace its narration. The second assumption concerns the conditions required to narrate an evolutionary history: the set of data has to assume narrative form in order to be used. It is not enough to identify the fossil record with an event; a narrative form should also be supplied. That means that these data are woven into a particular order in order to narrate an evolutionary history[173]. The results of this connection are the two representative forms presented in figures 3 and 4.. They are based upon a *Zuordnungsprinzip*, which functionally connects together the elements of a set. This principle of coordination is a strong constraint imposed by the paleontological community in order to come up with evolutionary explanations. However, the kind of principle that connects the set of fossils is quite different. The figures of the second group provide, in fact, two different examples of data linked to the end of a representation able to narrate a true evolutionary history.

This point leads us to another conclusion concerning the nature of paleontological practice, to emerge at the end of this section. In order to use his data within a biological context, the paleontologist has shifted his representative target: he has slowly understood that he must fix not the referential burden, but the epistemic conditions for making declarative statements.

Formenreihen

Figure 3 represents a series of forms [*Formenreihen*] and the paleontologist engages with this in order to reconstruct the past. He considers his starting sample as incomplete and imperfect and he tries to develop a practice to obtain a high degree of knowledge from this biased material. Due to the imperfection of the paleontological data, the degree of knowledge which this epistemic practice can obtain is locally confined: it is restricted to a tiny span of time in which well-preserved fossils can be found. It is nevertheless extremely reliable. Through this epistemic practice Waagen was able in fact to use the *smallest and imperfect sample of the past* to obtain reliable information. For instance, he was able to point out that evolution is a gradual Darwinian process of descent with modification. But what kind of representation is it? What does it denote and represent? And again, does this notion of representation offer a proper change in respect to Zittel's approach?

Historically, the *Formenreihen* are temporally ordered representations of the *smallest, imperfect sample of the past*. They show the kind of relationship that exists between the materials composing the sample. Furthermore, they state that what they represent is a true image of the past world. Figure 3 thus represents the gradual mode of evolution; it denotes an event in the earth's history. It is furthermore a declarative symbol (*sensu* Goodman). That means that it is either true or

[173] Derek Turner underlines this point by asserting that the paleobiological movement of the 1970s and 1980s was able to "to study [a] huge collection of fossils in order to identify patterns. " See note four.

false. It provides a strong index to what happened, and how, in terms of the history of earth. This aspect is important, because—as I will argue—Waagen uses a correspondence theory of truth to support his notion of representation. Waagen partially overcomes Zittel's epistemic impasse. Indeed, Waagen's theory seeks to contribute to the theory of evolution and as such it provides some rules for reading paleontological data. For example, it states i) that the paleontological data should be considered in a bulk; ii) that to contribute to the theory of evolution, one should, at basis, dispose this data into a particular order so that it can show a change within time: the paleontologist needs to identify a *Zuordnungsprinzip*.

On the other hand, this takes us a step back. Zittel perceived the ontological difficulties related to the notion of fossil record and he tried to overcome them by establishing an epistemic *medium*. By means of represented versions of his data, he facilitated epistemic access to the past. Zittel's facts are indeed an attempt to overcome the imperfection of the material fossil record: although Zittel embraces a metaphysical realism, the paleontological *explanandum* is a set of stabilized facts. Waagen, on the contrary, accepts the incomplete nature of the sample and resigned himself to it. He simply developed an epistemic procedure to read, - as best possible from this starting premise - the well-preserved fossil record. This practice has many practical advantages, but they all aim to fix the referential burden. It is therefore based upon the same assumptions that characterize Zittel's notion of representation: it has *a fortiori* the same validity. Waagen simply refines a notion of representation founded on the connection between the morphological structures of well-preserved material objects and his data. Doing so, he cannot overcome all the implications tied with the notion of representation stated in the first subsection. Indeed, he confuses what representation represents, i.e. the mode of evolution, with what it denotes, namely an event. He uses the latter to define and to metaphysically support the former.

Yet the problem is that Waagen following Zittel endorses a realistic foundation to back up his investigation and to fix the reference of his statements. Zittel supports this practice by ostension; Waagen by a correspondence theory of truth. According to both Zittel and Waagen, paleontological data can be found in museums or in private collections and as such is ready-made, out there. These ready-made data are the last foundation for both the theory of truth and the reference. Waagen supported a 'correspondence' theory of truth where the "constant or absolute relationship between a picture and its objects" is not able to assign a truth-value to his statement. Or rather, it is not able to assign a truth-value to overcome the mere *hic et nunc* of the incomplete data. It works perfectly within a tiny span of time where well-preserved fossils can be found. As a consequence, Waagen was not able to come up with a global degree of knowledge: exactly as with Zittel's data, the *Formenreihen* are not able to go beyond the mere *hic et nunc* of the patchy paleontological data.

They can achieve only a local degree of knowledge, or in other words, they are not able to reveal global biological patterns.

As I said, Zittel endorses this practice by ostension; Waagen by a correspondence theory of truth: "truth involves some sort of correspondence relation between words or thought-signs and external things and sets of things." (Putnam, 1981, p. 49) Hence, Waagen prefers to endorse a modified version of the Aristotelian correspondence theory to fix the referential burden of representation:

> "Spoken words are the symbols of mental experience and written words are the symbols of spoken words [or of material objects]. Just as all men have not the same writing, so all men have not the same speech sounds, but the mental experiences, which these directly symbolize, are the *same for all, as also are those things of which our experiences are the images*" [italics mine] (Aristoteles, 1963, pp. 16 a 14-18)

Waagen would also embrace *in toto* Michael Devitt's characterization of scientific realism. As above, Devitt characterizes "the general doctrine of realism about the external" as "committed not only to the existence of this world but also to its 'mind-independence': it is not made up of 'ideas' or 'sense data' and does not depend for its existence and nature on the cognitive activities and capacities of our minds" (Devitt, 2007). According to both Zittel and Waagen, paleontological data can be found in museum or private collections and as such they are ready-made, out there[174]. They are the last foundation for both the theory of truth and reference. Waagen asserts that

> "Das zu Grunde gelegte Material [for the investigation] habe ich theils unserem von der Staatsregierung so grossartig geförderten kgl. *paläontologischen Museum*, theils meiner eigenen Sammlung entnommen. Von einigen Stücken lagen mir auch nur Schwefelabgüsse vor, zu denen sich die Originalien in der fürstlich von *Fürsten-bergischen Sammlung* zu *Hüfingen* befinden. Ein Stück von *Amm. Mamerlensis* endlich stammte aus der Sammlung des Herrn Obermedizinalrathes von *Fischer* hier." (Waagen, 1869, p. 182)

Neumayr endorses this metaphysical realism as well. He is even more explicit about this point in his textbook (1889): he asserts that "Bei der systematischen Methode, bei der Aufstellung von Formenreihen liegt das thatsächliche Material *in handgreiflichster Form vor Augen*" [italics mine] (Melchior Neumayr, 1889, p. 150). That means that both data and the world are ready-made, out there, independent from the cognitive activity and capacity paleontological mind. Paleontology aims at seeking a correspondence between the sign-thought and the world given *in handgreiflichster Form vor Augen*. This correspondence fulfills the referential burden. Zittel would have claimed the

[174] I am not claiming that they do not realize that what can be found into a museum is a reconstruction. I am rather saying that they consider their starting points as ready-made, despite the fact that these data are constructed.

same. The problem is, however, that Waagen's representation declares something about the earth history and a correspondence theory of truth based upon ready-made patchy and incomplete data is not able to justify this declarative demand.

To summarize, the second notion of representation shows the difficulty of supporting a correspondence theory of truth based upon a realist foundation in paleontology. If the paleontologist embraces a theory of truth based upon non-epistemic data, he is no longer able to come up with global evolutionary patterns because the fossil record is imperfect and incomplete. It will further show that there is a gap between a) the paleontologist's epistemic practice and aim (i.e. to contribute to the theory of evolution) and b) his method of endorsing his choices. Through a meta-reflection on the conditions of possibility in Waagen's representation, I have shown that paleontologists can save either their biological aims or their realism[175]. In fact, although they conceive a representation as a functional relationship, which involves a modification and an achievement of the object, "die 'Wirklichkeit', auf die sich diese Funktionen als ihr Objekt beziehen, in ihrem Sein wie in ihrer Struktur fertig gegeben ist — und daß es sich für den menschlichen Geist nur darum handelt, diese gegebene Wirklichkeit einfach im Besitz zu nehmen" (Cassirer, 2004, p. 111). This is the main point. Considered closely, both Zittel and Waagen's representation is based upon a ready-made reality and each forgets what has been achieved with their representational practice. If asked to show some fossils, Neumayr would have proceeded to the museum-hall of the *Kaiserlich-Königliche Geologische Reichsanstalt* to point out the mind-independent fossil record. Data based upon this assumption is useless. Paleontology can acquire only a local degree of knowledge. It is thus necessary to rethink both the notion of data and truth in paleontology.

This notion of representation makes an important point however. Waagen is able to provide useful insights into the theory of evolution. For although the degree of knowledge he can access is only local, there is a "necessary premise [contained] in every valid judgment concerning facts" in his representational practice. Waagen's biological insights are possible only because he uses both qualitatively well-preserved data and a great number of fossils. Both quantity and quality are essential conditions[176] for using paleontological data to produce evolutionary patterns and processes.

[175] It is not the case that Neumayr stresses the ready-made nature of the fossil record as an argument against the mathematical treatment of the paleontological data. See the previous chapter.

[176] As I will show in a few pages, the paleobiological movement will put both these conditions at the centre of their categorial framework. The mathematical treatment of the fossil record of the 19th century emphasized exactly this point. See the previous chapter.

Williams' Tables

Figure 4 represents a fauna and denotes the set of organisms found in a particular time and space. It illustrates a particularly confused relation between what a representation and a denotation or rather does not satisfactorily spell out the implications of this distinction. This is due mainly to a historical and polemical agenda: Williams wanted to obtain a global degree of knowledge and hence he developed an epistemic practice openly in contrast with Zittel's investigations[177]. This treats the data mathematically and as such generates results opposed to the Darwinian theory of evolution. The data presented in the second figure are in fact records of data: they are starting points for further mathematical treatments. To what extent and under what conditions can this representation be used to obtain a global degree of knowledge?

First and foremost, I have situated this representation in the second group of images, since it shares its premise with Waagen's *Formenreihe*. If we recall, this treats the fossil record in bulk and requires a principle of coordination to connect its data. Beyond these shared premises however, the differences are consistent. Williams links the relationship between representation and material objects so closely that he considers "the smallest sample of the past on which to base his reconstruction" as reliable and no longer incomplete. In other words, Williams' representation literally constructs the ontological features of its objects: to the question " 'What are fossils?' the concise answer is: Fossils are traces of organisms buried in the rocks" (Williams, 1895, p. 80) where they "*chiefly* represent the hard parts of organisms" [italics mine] (Ibid.). Williams goes on to claim that despite the fact that "soft parts, or organs, are adjustable to changing exterior conditions…hard parts are already adjusted, and, therefore, they are an expression of the working adjustment of the species, to the conditions of its environment, at the particular time in which it lived." (Ibid.) Fossils are thus presented as reliable and no longer misleading sources. Fuchs (1842-1925), endorsing the same notion of representation as Williams, asserts that the fossil record "in gewissen Theilen eine ausserordentlich vollständige [ist]" (Fuchs, 1879, p. 355).

Both Zittel and Waagen's initial premise was the incompleteness and imperfection of the fossil record. Consequently, that record may not support further analysis concerning the theory of evolution. Accepting these premises, Zittel and Waagen renounce any discovery of global patterns and processes. At the same time, they use a realist foundation to preserve their local epistemic practice. Williams saw that the only possible solution to overcome this impasse was to reconsider the ontology of the material objects. This was only made possible by accepting all the implications related to Zittel's notion of representation. Where the paleontologist obtains a global degree of knowledge by mathematical treatment of the represented form of the fossil record, it follows that

[177] For a useful historical analysis see the previous chapter

the record is no longer imperfect and incomplete. A global degree of knowledge can be achieved and thus paleontologists need to reconsider the nature of the fossil record in the light of its representational form. If we represent the fossil record as record of fossils?(figure 4) and successively if we treat it statistically (figure 5), then we can no longer call it an incomplete source of knowledge. Williams' notion of representation thus denotes a set of fossil records - not meant as a misleading source of knowledge. Let us now uncover the essential premises behind this notion.

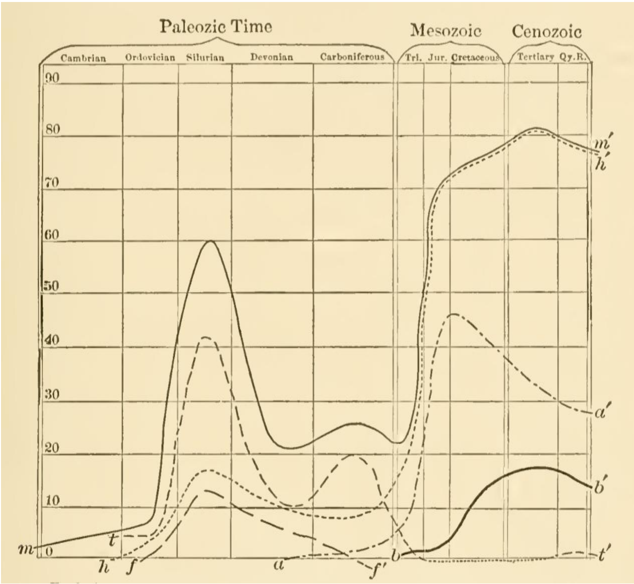

Figure 38 The diagram shows the evolutionary curves of the families Madreporaria. It is based upon the data of the previous figure. Taken from (Williams, 1895, p. 87)

Williams pushes Zittel's notion of representation further, or rather, engages with what Zittel chose not to. He explicitly understands that to represent is a matter of invention and of choice. Furthermore, he conceives that "the object itself is not ready-made but results from a way of taking the world. The making of a picture commonly participates in making what is to be pictured. The object and its aspects depend upon organization; and labels of all sorts are tools of organization." (Goodman, 1968, p. 32) This is the central point. In fact, both Zittel and Waagen share the idea that objects, namely fossils, are ready-made. This metaphysical claim has many empirical costs: namely, paleontology cannot acquire a global degree of knowledge. If paleontology uses this categorial framework, then the area of empirical knowledge it can define defined is extremely narrow. In fact, it remains stuck in a local validity, i.e. in the presence of well-preserved objects. In order to avoid these limitations, Williams stresses the constitutive and constructive value of representation. This underlines the prefix re- in representational practice. Williams' representational practice is in fact able to change the ontological nature of the fossil record: "the shift from image-as-representation to image-as-process wrenched the image out of a long historical track. No longer were images traced *either* by mind's eye *or* by 'the pencil of nature.' Images began to function at least as much as a tweezer, hammer, or anvil of nature: a tool to make and change things." (L. Daston & Galison, 2007, p. 383) In other words, Williams proposed another foundation for the paleontological constitutive framework.

A fauna-picture thus changes the nature of fauna: it works exactly as a hammer does in excavating the fossil record from the earth's layers. The making of this data participates in what the data are. Williams emphasizes this connection so strongly that his epistemic practice is able to stabilize the alleged imperfections of the fossil record. Indeed, fossils become at the same time both stable starting points and new paleontological *explananda*. In fact, once the paleontologist has represented them in a table, he does not much care about what they represent. He severs any strong connection between representative and represented. From a factual point of view, he operates only with the latter and not with the former: the represented version of the fossil record has replaced the features of the material records: "Nature is a product of art and discourse" (Goodman, 1968, p. 33). Hence, Williams' notion of representation, based upon a constructive categorial framework, reshapes and constructs what it denotes: the paleontologist is able to construct his world[178]. This world is made, not found out there.

There are nevertheless many philosophical and empirical problems with this notion of representation, viz. categorial framework. For instance, it seems to present a degree of truth too humble for the paleontological sciences. If the paleontologist makes up his world, he is no longer able to decide whether the constructed evolutionary patterns are correct. Why in fact should we accept Williams' results, when they are openly opposed to the Darwinian theory of evolution? In other words, if "almost any picture may represent almost anything" why and to what extent is this kind of representation able "to make and change things"? And furthermore, what kind of truth-value does this epistemic practice obtain?

Neumayr raised the same issues. He argued against the statistical treatment of the data, since it generates results opposed to the Darwinian theory of evolution. He proposed conversely to accept the realism of the *Formenreihen*. The skeptical argument about the loss of truth and complete incommensurability in the created world is a classical philosophical objection to Kuhn's paradigm shifts. As Carl Gustav Hempel (1905-1997) puts it, "If adherents of different paradigms did inhabit totally separate worlds, I feel tempted to ask, how can they ever have lunch together and discuss each other's views?" (Hempel, 1996, p. 129) The answer is very simple. They can lunch together only if at least one of them learns the other's language. Indeed, Neumayr did criticize the statistical

[178] As Goodman put it "Cervantes and Bosch and Goya, no less than Boswell and Newton and Darwin, take and unmake and remake and retake familiar worlds, recasting them in remarkable and sometimes recondite but eventually recognizable—that is re-cognizable—ways." (Goodman, 1978, p. 104)

notion of data, since he had previously learnt this language. This does not mean that there is a common metaphysical foundation out there which can be used to compare the two practices. The paleontologists do not confront what they claim with a world "undescribed, undepicted, unperceived" out there in order to control the truth of their statement. On the contrary, a biological pattern or process within geological time is "taken to be true when it offends no underlying belief and none of its own percepts." (Goodman, 1978, p. 17) There is no 'adequacy to the facts': the rightness or wrongness of statistical patterns and processes is not a matter of observation. It is rather a matter of coherence between the underlying beliefs and percepts of the community: it is created and accepted within the system. Williams shares the same point, as he puts it, "the determination of the true relations of cause and effect in nature is therefore not a matter of observation, but interpretation of cause is founded upon the philosophy we apply in the interpretation of the course of nature." (Williams, 1895, p. 379) The explanation of phenomena depends on, and it is inscribed in, our conceptual schemes. Truth is thus an epistemic matter within a system. It depends upon complex relations within the selected system[179].

Another, more compelling, problem with this notion of representation is that this epistemic practice confuses the possible determination of data with its reliability: if the paleontologists are able to identify the fossils, i.e. to put them into a chart, then these are meant to be reliable sources of knowledge. As above, this is compelling objection, since it concerns the validity of the constraints that we can rightly impose on nature. Williams attempts to overcome the ontological imperfections of the fossil record in order to stress that the paleontologists can use the fossil record within a biological framework. By doing so, he pretends to impose constraints on the matter and not on the forms of representation[180]. However, this constructivist move is not possible and it was one of the reasons why many paleontologists were led to reject a mathematical treatment of the data. The paleobiological revolution reshaped Williams' notion of representation in light of its limits: the authors of that revolution developed a kind of representation that imposes constraints on the formal structures of data and not on the matter[181]. The *construction* of paleontological data was replaced by a *constitution*. It deals with the formal constraints and it is able, as I will show, to treat the reliability and identifiability of data as two distinct and formal issues. The result of the

[179] I will return to this notion of truth in the final part of my dissertation.

[180] See Kant's rejection of Berkeley's idealism for a like argument against this notion of categorial framework.

[181] To anticipate a conclusion of the next section, the paleobiological categorial framework is "an interesting and fruitful interaction of nomothetics and ideographics. The form of the model remains nomothetic – the ''real'' pattern arises as an interaction between two general curves of the same form, but with different parameters. Ideographic factors determine the parameters and then enter as boundary conditions into a nomothetic model" (Gould, 1980, p. 115).

paleobiological revolution is indeed that the fossil record might "be patchy, but it is not necessarily misleading." (D. Sepkoski & Ruse, 2009, p. 52).

Before dealing with this move, it is worth emphasizing another interesting point, which emerges from Williams' categorial framework. Williams' notion of representation and data was abandoned by the 1910. On the contrary, Zittel's metaphysical realism was the predominant position among the paleontologists until the so-called paleobiological revolution of the 1970s. The proponents of this revolution develop Williams's constructivist approach, but unlike Williams, they were able to successfully establish this notion of representation. This means that social support is one condition of possibility for using the paleontological data within an evolutionary framework: as Fleck put it, "das Gewicht der Erziehung" and successively "die Wirkung der Reihenfolge des Erkennens" (Fleck, 1929, p. 425) play a pivotal role. These are fundamental factors for the development and justification of a scientific practice. In developing its historical narration, a meta-reflection has thus to consider these social factors: in this sense there is only a difference of degree between historical epistemology and meta-reflection. Let us now focus on the last notion of representation.

To Represent is to Constrain

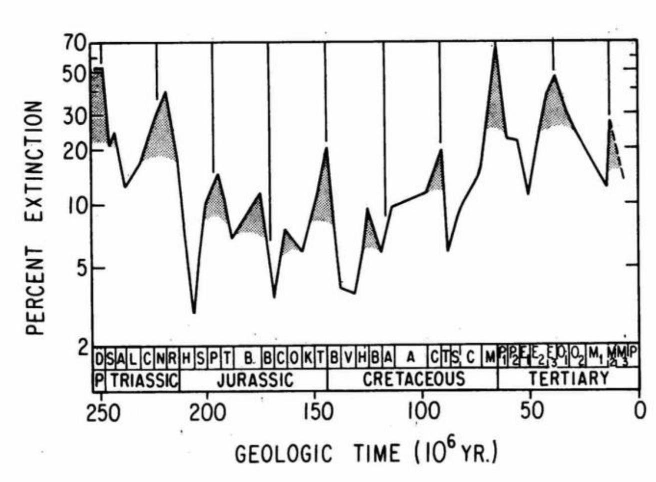

Figure 39 Raup and Sepkoski's graph of periodicity in mass extinctions

Figure 40 Pablo Picasso's portrait of Gertrude Stein, 1905–6.

Figure 6 represents periodicity in mass extinctions within geological time. This representation has many interesting peculiarities, which are related to the notion of paleobiological data. In this section however, I will only characterize which essential features the paleobiological representation has (both de facto and de jure) so that the paleobiologist may use the fossil record to come up with evolutionary patterns and processes.

Despite John Philips's recognition of the three main discontinuities in the Phanerozoic fossil record in 1860, the study of these ruptures was laid aside until the 1960s. Indeed if we quickly browse the table of contents of the main paleontological textbooks published between 1895 (first edition of Zittel's *Grundzüge der Paläontologie*) and 1978 (second edition of Raup and Stanley's *Principles of Paleontology*), we can see that an entire paragraph or chapter on mass extinctions appears only in 1978. This gap in paleontological education is due primarily to the nature of the phenomenon. Indeed, mass extinctions can be recognized only by studying the patterns of biodiversity within geological time. This study in turn requires at least two important conditions: 1) a large amount of data and 2) a compilation of a model of data, i.e. a formal relational structure, that is able to promote surrogate reasoning upon the data and thus a working version of the past. Williams' notion of representation stressed both features, but was not able to emphasize the positive qualities of his method.

Due to Alvarez's team discovery (1978) of the iridium anomaly in rocks formation at K-T boundary, mass extinction became the hot topic of paleontology in the 1980s. One of the main questions during those years was concerning the number and intensity of the mass extinctions. According to Jack Sepkoski, at the Snowbird Conference on mass extinction in 1981 "there was a question from the floor after one talk about how many mass extinctions there had been and how big they were" (J. J. Sepkoski, Jr., 1994).

This issue was resolved in two famous papers written by David Raup and Jack Sepkoski. Using Sepkoski's database (1982), Raup and Sepkoski identified the number of mass extinctions and the periodicity of this phenomenon. The two papers were published respectively in Science (1982) and PNAS (1984). The latter is about periodicity in mass extinction, whereas the former individuates the number of these events within the geological past; it further *declares* that something happened on the earth surface within a particular span of time[182]. It is entitled *Mass Extinctions in the Marine Fossil Record* and by using "approximately 3300 fossil marine families, of which about 2400 are extinct" the authors identified five biologically relevant mass-extinction events (Raup & Sepkoski, 1982, p. 1501). They plotted the huge number of fossil marine families against geological time and found that five mass extinctions clearly occurred in the history of the earth as "statistically distinct from the back ground extinction levels"[183]. These "five extinction events are seen as sharp drops in standing diversity" and therefore they were easily detected. A mass extinction is thus an event in which a "large number of organisms have disappeared over relatively short time" (Sepkoski, J.J., Jr., 2001).

The fourth notion of representation represents at the same time a model[184] of data and a phenomenon, which needs to be explained. The peculiarity of this figure resides in the fact that paleontological data are represented and the possible *explanandum* appears and takes a stable form through this representation: the unobservable phenomena is saved. This fourth representation is a drop-diversity-picture and it denotes an event. Moreover, it declares that this event happened.

[182] It declares that something happened not how it happened: "the data do not tell us, of course, what stresses caused the mass extinctions". (Raup & Sepkoski, 1982, p. 1502)

[183] To be precise, they assert that only four of the five mass extinctions are statistically distinct from the background extinction levels in their data.

[184] I am using the word 'model' as equivalent to notion of 'form of representation'. Edgar Frank Codd used this word in exactly the same way. See (Müller, 2009, p. 658). I will connect this form of representation with Patrick Suppes' hierarchy of models in the next section.

Exactly as in Williams' notion of representation, the way in which something is denoted modifies and shapes what is denoted. The modality of this modification and the assumption behind it are nevertheless different.

To begin with, it is important to stress the line of continuity between Williams' representation and the paleobiological one. Williams' representation was, in fact, one of the first attempts able to determine global patterns and processes of evolution and, as per the previous subsection, the paleobiological notion of representation shares plenty of features with it. One such shared feature is the notion of the constructive power. Both representations construct what they wish to explain: phenomena are not ready made, out there. Goodman stresses this point, "to a complaint that his portrait of Gertrude Stein did no look like her, Picasso is said to have answered, 'No matter; it will'" (Goodman, 1968, p. 33). Goodman thus underlines the constructive power of his notion of representation. Gertrude Stein will look like Picasso's representation as soon as this portrait is accepted and recognized by a community. Picasso representation will even replace - and indeed replaced - Gertrude Stein's face in course of time. Similarly, Williams' representation was meant to replace the ontological features of the fauna under study. A paleontological community was, nevertheless, absent and so this transformation was - *de facto* - impossible. On the contrary, the fourth notion of representation was able to impress the concept of denotation through representation in scientists' minds. After Raup and Sepkoski's representation of the periodicity of mass-extinction, the mass-extinction phenomenon looks like Raup and Sepkoski's representation[185]. It seems to say: here is the perceptible evidence of the phenomenon, now what is the hypothesis? (Kell & Oliver, 2004) Or as Raup and Sepkoski claim "if periodicity of extinctions in the geologic past *can be demonstrated*, the implications [and its causes] are broad and fundamental" [italics mine] (Raup & Sepkoski, 1984, p. 805). Hence, the phenomenon of mass extinction is saved from the dark abyss of deep time as Picasso saved one aspect of Gertrude Stein (namely her face) from the flow of time. Raup and Sepkoski's graph is a stable scene from deep time[186].

This subsection spells out assumptions made about the constructive power of paleobiological representation so as to identify the features of paleobiological data and the related

[185] My claim is easily verifiable. It is enough to google mass-extinction and the first images that appear look exactly like Raup and Sepkoski's representation.

[186] Quoting Shapin and Schaffer's *Leviathan and the Air Pomp* (1985), Martin J. Rudwick affirms that "any scene from deep time embodies a fundamental problem: it must make visible what is really invisible. It must give us the illusion that we are witnesses to a scene that we cannot really see; more precisely, it must make us 'virtual witnesses' to a scene that vanished long before there were any human beings to see it." He used Shapin and Schaffer's term "virtual witness" to emphasize the "similar 'making real' of a scene that even a scientist could not really witness". (Martin J. S Rudwick, 1985)

paleobiological categorial framework. I will namely examine the nature of the paleobiological data presented in this representation *de facto* to understand the assumptions upon which these are based. In the next pages, I will argue that the paleobiological representation creates its own phenomenon, because the paleobiologist imposes *formal* constraints on his data. As a consequence, data acquires a nonlocal nature without modifying its ontological features. This is the main difference between the paleobiological representation and Williams' construction. In order to create the paleontological *explanandum*[187], the latter pretends to create new ontological features for its data; whereas, the former only puts formal constraints on them, so that they can be statistically treated: it constitutes its data. This new categorial framework defines a space of empirical knowledge much broader in comparison with the other two systems analyzed. Its effect was to invite, paleontology to the high table of evolution (J. M. Smith, 1984).

This fourth notion of representation is based upon Sepkoski's *A Compendium of Fossil Marine Families* (1982) and we can find the essential assumptions for using paleobiological data in this database. Sepkoski's *Compendium* in fact marks a complete[188] turning point within the paleobiological notion of data. It rejects a naïve realism for a relational mind-dependent notion of data. Only by accepting this notion, was the paleobiological community able to use data within a biological framework. Sepkoski's *Compendium* lists ca. 3500 marine family fossils according to their first and last occurrence. The times of the first and last occurrence generates "81 stratigraphic intervals ranging from 1.6 to about 20 m.y. long" (J. J. Sepkoski, Jr., 1994). This *Compendium* is a model of data. It is namely a tool provisioning information for complex operations on its entries. It is similar to the Oppel's ideal profile and Williams' representation of fauna. Both representations are in fact able to reshape the features of their data according to their epistemic aims. Nevertheless, Sepkoski's *Compendium* does not require a realist foundation to support its claims. Upon which assumption is it then based?

Sepkoski's *Compendium* is a simple database, i.e. "*a structured collection of operational data together with a description of that data*" (Stanczyk, 1990, p. 4). This definition emphasizes three important aspects of this epistemic tool: 1) it has an internal structure; 2) only operational data are presented; 3) these are valid only if they are associated with a description. Let us quickly focus on these points.

[187] Just as remind, I will deal on the paleontological necessity of creating and recreating its *explanandum* in the next section, where I will explicitly deal with the notion of paleontological phenomena.

[188] Especially, the social factors were able to create a turning point because Sepkoski's *Compendium* is similar to Bronn's enterprise.

A database contains data, which can be interrelated under certain conditions and operations. The data acquires meaning through a series of operations. A single datum alone has no sense. It assumes a meaning only when it takes a determinate place within a wider operational context. There is both "an easy way and a difficult way by which to compile taxonomic data based on fossil organisms […] the easy one is simply to use data gleaned directly from a standard source […] the difficult method is to ignore previous compilations and go directly to the primary literature." (J. J. Sepkoski, Jr., 1994) In order to identify and use the data a valid description is required. Either a taxonomical textbook, for example Zittel's *Handbuch*, or the "paleontological literature" can provide it. A description both lays the ground on which the database can work and the characteristics of its data. For example, Sepkoski's *Compendium* is a taxonomic database and only fossil marine families are presented. Operational data are therefore chosen and set by following descriptive analyses. What is entered into a database is thus cooked data. Moreover, a database has an internal structure[189] which characterizes the operations it is able to conduct. The internal structure of Sepkoski's *Compendium* is relational: "Loosely speaking, a relation is a simple tabular structure." (Darwen, 2012, p. 33)

Codd characterized the relational models of data in a famous paper of 1970. These models can be both mathematically and intuitively defined. I will focus on this latter characterization. A relational model of data can be represented as a collection of tables related by some operations. The tables are univocally defined and some attributes are chosen in order to make the data operational. Now, "Given sets S_1, S_2, …, S_n (not necessarily distinct) R is a relation on these n sets if it is a set of n- tuples each of which has its first element from S1, its second element from S_2 , and so on" (Codd, 1970, p. 379). The central element of this model of data is its relational power. It is able to relate the attribute values of an entry so that the data can be univocally detected and defined.

Let us closely focus on Sepkoski's database.

[189] It is worth emphasizing that the internal structure of the database is an essential feature. It determines the system according to which data assume a stable nature.

Order	Genus	FOP	FOS	LOP	LOS
protoconodontida	*Amphigeisina*	Cm	Atda-u	Cm	mMid
protoconodontida	*Ganloudina*	Cm	Tomm	Cm	Tomm
protoconodontida	*Gapparodus*	Cm	Atda-l	Cm	Dres
protoconodontida	*Kijacus*	Cm	Tomm-l	Cm	Atda-u
protoconodontida	*Leguminella*	Cm	Tomm-u	Cm	Tomm-u
protoconodontida	*Maldeotaia*	Cm	Tomm-l	Cm	Tomm-l
protoconodontida	*Mongolodus*	Cm	Boto-l	Cm	Boto-l
protoconodontida	*Protohertzina*	V	N-Da-l	Cm	Boto-l
uncertain	*Incertae sedis*	Cm	mMid-l	Cm	mMid-l
uncertain	*Paucijaculum*	C	Mosc-u	C	Mosc-u
uncertain	*Titerina*	O	Aren-l	O	Aren-l

Search Again
FOP = Period of first occurrence
FOS = Stage of first occurrence
LOP = Period of last occurrence
LOS = Stage of last occurrence

Stage abbreviations follow Sepkoski (2002).

Figure 41 Entry of Sepkoski's Compendium about the genera assigned to the phylum CHAETOGNATHA.

According to Sepkoski, "taxomomical databases in paleontology are compilations of taxa of various ranks, relationships, and regions accompanied by the time of first appearance and final disappearance in the fossil record" (J. J. Sepkoski, Jr., 1993, p. 43). As we have seen, these "taxonomical data bases" can be materially represented as a collection of tables. The column names correspond to the attribute name in the database; whereas the values presented in each column are the attribute values. In figure 7, attribute names are *Order, Genus, Period of first occurrence, Period of last occurrence, Stage of first occurrence*, and *Stage of Last occurrence*. The attribute values are, for instance, Ordovician, Cambrium or Protoconodontida. Once this division is completed, the paleontologist can analyze the relations that emerge from the table. These are tuples composed by numbers of attributes listed in a particular order. One tuple is for instance <protoconodontida, Ganloudina, Cm, Tomm, Cm, Tomm>. What does this representational form tell us about both the nature of both its epistemic objects and categorial framework?

It tells us that paleobiology does not deal with a notion of object independently given, out there. The notion of raw and ready-made data is indeed misleading in paleontology. Paleontological data depends *in toto* "for its existence and nature on the cognitive activities and capacities of our minds" (against Devitt's realism): "Objects' do not exist independently of conceptual schemes. We cut the world up into objects when we introduce one or another scheme of description. Since the objects and the signs alike are internal to the scheme of description, it is possible to say what matches what" (Putnam, 1981, p. 52) As soon as paleontologists realized that an external reference was not needed to support either their data or their declarative statements, they began to use these data to come up with biological processes. This was possible only by imposing strong formal constraints on the data. Thus, the principles that guide this practice are constitutive of the concept of the object of [paleobiological] knowledge (Reichenbach, 1920).

As we have seen, this happened also in Williams' representation. Williams nevertheless misunderstood the meaning of these relations. He thought that the tabular representation was able to correct the ontology of the fossil record. The paleobiological movement, on the contrary, accepted the incompleteness of the fossil record and tried to formally overcome its nature[190]. The attribute names of the database impose strong constraints on the domain in which the paleontological data can appear and "predetermine the sorts of biological relationships that can be 'discovered'". (Stevens, 2013, p. 168) One point in particular signifies about the constraints imposed. The paleobiological categorial framework, embodied in a database, establishes also the particular time in which the fossil record may legitimately appear. It chooses and reshapes, so to speak, the timeframe of its appearance. This implies that in a further treatment of the fossil record, deep time does not play its allegedly destructive role[191]. As a result during the 1970s and 80s, the paleobiological movement emphasised that although the fossils are incomplete, they could provide basis for global biological statement on, for example, the number and size of mass extinctions.

This was possible once data was global entity. In fact, Sepkoski's *Compendium* stressed that the fossil record is a set of relations. By posing the formal attributes which stretch the fossil record, the paleobiological movement identifies the fossil record with a tuple into a table. This entails that data become nonlocal[192] entities through an "apposite packaging" (Leonelli, 2009)[193]. Sepkoski tells us: "in the latter? letter of submission [associated with the compendium] I wrote that the data could

[190] This point can also be stressed according to Kuhn, when he says that "my structured lexicon resembles Kant's a priori when the latter is taken in its second, relativized sense. Both are constitutive of *possible experience* of the world, but neither dictates what that experience must" (Kuhn, 2000, p. 245). Williams' categorial framework dictates, on the contrary, what the experience must be.

[191] The temporal dimension involved in paleontological sciences is so vast that the human spirit seems to *lose its way* (Rossi, 1984). Deep time is immense: "in quantities no mind had yet conceived" (McPhee, 1981). This dimension is extremely difficult to comprehend and it caused many epistemic impasses. The history of paleontology can in fact be written by answering a simple question: how is it possible to overcome the abyss of deep time? The paleobiological answer marks a turning point. There is indeed a substantial difference between Sepkoski's *Compendium* and Bronn's enterprise. Bronn relied on a notion of time as a given ready-made. He did not understand that in order to overcome the infinite extent of deep time, paleontologists have to reconstruct it step-by-step. They have namely to decide which kind of entity can appear in it.

[192] "The taxonomic data compilation of the late J. John Sepkoski Jr. are broad in their scope and profound in their impact on biology, geology, and paleontology" (Jablonski & Foote, 2002)

[193] "This [packaging] is a way to 'free' data from its context and transform it into nonlocal entities since the separation of data from information about their provenance allows researchers to judge their *potential relevance* to their research." (Leonelli, 2009)

constitute a basis for studies of 'mass extinction, evolutionary rates, and patterns of diversification'. Diversity—the very reason the database existed—had been relegated to last place" (J. J. Sepkoski, Jr., 1994, p. 140). The turning point within the history of paleontology is evident. Paleontologists struggled for decades to understand how to obtain global information from incomplete and imperfect materials. They were searching for at the wrong solution. Fossils become? nonlocal entities only if the paleontologist imposes formal constraints which transform these entities into pure relational strings. Indeed, Paleobiology is able to investigate the trends and patterns of evolution, because 1) it decides what a datum is, 2) how that datum can be read, and 3) it constructs through it working versions of the past that are able to bring out some biological characteristics. The nonlocal identifiability of the data should not be confused however with its reliability: this would be Williams' mistake. The matter of reliability is statistical and theoretical and plays a role once the *explanandum* has been identified[194].

[194] "The reliability of data has to do with its trustworthiness as a sign or indicator of the phenomenon under investigation" (Jim Bogen & Woodward, 1992, p. 592).

Conclusion

In this chapter I have analyzed four concrete paleontological representations, which exemplify four different paleontological methods. All these methods have characterized the development of paleontology during the last two centuries. By studying these four different notions of representation, I have illustrated the features of the paleontological and paleobiological data as well as their epistemic conditions[195]. I have namely analyzed how they were used *de facto* to understand the assumptions upon which they are grounded *de jure*. Many philosophical consequences emerge from the meta-reflection on the notion of representation accomplished in this chapter.

First, the paleobiological and paleontological notions of representation have a different constitutive power. They differently constitute their data and *explananda*. Zittel's representation achieves a modified version of the fossil record and spreads it as the paleontological *explanandum*. Nevertheless, the space of empirical knowledge based upon it was extremely narrow. By grounding its data on a metaphysical notion of the fossil record as a ready-made entity, paleontology cannot enunciate evolutionary patterns and processes. How then can paleontology contribute productively to evolution? The resolution of this quandary lies in "the principle of relativity": "reference is nonsense except relative to a coordinate system" (Willard Van Orman Quine, 1969, p. 48). This is the central philosophical turning point. Both Williams and the paleobiological movement acknowledge that is meaningless to speak of a reference without the background knowledge required to fix it. They explicitly refuse the idea that their epistemic thing is ready-made. In other words, they refuse to assimilate the paleontological enterprise and language to a mythological "museum in which the exhibits are meanings and the words are labels. To switch languages is to change the labels." (Ibid.) As I have extensively shown, they understand that meaning, reference, and truth are only relative to a conceptual framework, and therefore changing the labels implies change of the ontological nature of the exhibits as well as the space for empirical knowledge. The passage between the paleontological and paleobiological notion of representation is indeed pivotal since it implies two different conceptual frameworks. These are in turn based upon different assumptions and conditions and open up diverse spaces for empirical knowledge.

However, this first point does not simply mean that our observation of x is always shaped by a prior knowledge of x (à la Hanson) or by "a fabric of sentences accepted in science as true, however provisionally" (Willard Van Orman Quine, 1981, p. 40). It entails a general philosophical

[195] Following Allison, "by an epistemic condition is here understood a necessary condition for the representation of objects, that is, a condition without with our representations would not relate to objects or, equivalently, possess objective reality." (Allison, 2004, p. 11)

conclusion: what there is is inseparable from how we think, determine, and know it and this connection is not ontological but epistemic. As my analysis has shown, Williams' conceptual framework creates a room for empirical knowledge by literally changing the ontological features of the fossil record. The paleobiological revolution replaces this ontological notion of mind-dependence with an epistemic one: by constituting their data, paleobiologists were able to come up with biological patterns and processes. The important philosophical question is accordingly how the conceptual framework can legitimately dictate a form to the data. Even if the responses to this philosophical problem can be variously articulated, this paper has argued that there is a continuity between the advocates of a epistemic notion of mind-dependence: all they consider problematic the epistemic relation between data and conceptual framework and try to comprehend it. However, this continuity should not be confused with an identity of thought. In fact, they differently go through the arc that "penetrates the real from the surface of the given and then returns from this depth to the given" (Herbart, 1829, p. 8): Quine and Putnam do not arrive at the same depth reached by Kantian tradition. The study of the notion of representation has indeed shown the efficacy of Kantian and Neo-Kantian's approach to comprehend the nature of the scientific enterprise. It describes, explains, and logically founds epistemic changes in the uses of different conceptual frameworks. In fact, it is able to explain the transition from an ontological mind-independence of paleontological data to an epistemic dependence. Hence, according to Cassirer, the general philosophical conclusion can be that "the most general expression of 'thought' is the same as the most general expression of 'being.' The opposition, that metaphysics could not reconcile, is resolved by going back to the logical function from the application of which both problems arose, and in which they must finally find their explanation." (Cassirer, 1923, p. 246) Hence, "even the individual 'a posteriori' judgment always contains an 'a priori' element in the necessity of the connection, which it affirms." (Ibid.)

Second, paleobiology, viz. paleontology, no longer needs a metaphysical notion of the fossil record, as a ready-made entity out there, to come up with evolutionary patterns and processes. That means that

> "we do not know 'objects' as if they were already independently determined and given as objects, but we know objectively, by producing certain limitations and by fixating certain permanent elements and connections within the uniform flow of experience" (Cassirer, 1923, p. 303)

The paleontologist investigates only the objects that he has previously inserted into a complex relational system. The representation shapes and makes the form of the epistemic objects.

Third, the representation of the fossil record is not the *terminus a quo*, but rather the *terminus ad quem* (Cassirer, 1985, p. 125) paleontologists can come up with biological explanation.

There is a hierarchy of epistemic objects within paleobiology. The represented data are, simultaneously, explananda: they are representations and presentations. The three images investigated (first, third and fifth figures) are the paleontological explananda. This peculiarity can be comprehended by looking at the features of the conceptual framework used to constraints the fossil record. In this regard, my approach is distant to Daston's historical epistemology (L. Daston, 2014): what Zittel knows depends entirely on how he knows it exactly as what a paleobiologist knows depends on how he knows it. Therefore, "not *what* is given but *how* it is *given*" (Goodman, 1978, p. 6) is essential to paleontological investigations and the fossil record is never given independently of a conceptual framework. It is related to an entire system[196].

This implies a shift from what an object is substantially and perceptively, to the relations and structures which can legitimately be represented in accordance with the chosen system. There is a "data independence" between the observable features of the fossil record and its logical structure. As it emerges from Sepkoski's database, the fossil record is a relational structure composed, for instance, from the chosen attributes. There are three main findings here: a) to contribute to biology, paleontology becomes interested in bringing out the structural relations among the relata and not the characteristics of the relata *per se*; b) the definition of paleontology should accordingly emphasise this turning point: that paleontology "is the study of ancient life, not just about fossils" (Beerbower, 1960, p. v), i.e. beyond fossils, paleontology studies the complex structures and relations between them; c) truth is an epistemic concept: the real and true structures are only those derived from our abilities to recognise, classify, and justify: "Truth, far from being a solemn and severe master, is a docile and obedient servants" (Goodman, 1978).

Last, the previous points entail that it is no longer important to list the referential conditions of metaphysically ready-made entities, "but rather [it is important to fix] the epistemic conditions under which we can reasonably and justifiably (albeit fallibly) make assertions", i.e. it is important to express and justify relations (Massimi, 2011, p. 10). Since paleobiology is about interpreting the significance of structural relations, the philosopher should investigate how to fix the epistemic conditions of paleobiological assertions and their degree of validity. This is a complete turning point if we compare with Zittel's approach. Where he identified the notion of epistemic truth with a changeable and instable concept[197], he refused to fix the epistemic conditions under which we can

[196] Cassirer made the same point, "we are not concerned with what a definite experience 'is', but with what it 'is worth;' i.e., with what function it has as a particular building-stone in the structure of the whole." (Cassirer, 1923, p. 277)

[197] Zittel firmly believed that the scientific truth is "a constantly changing concept. It depends on our knowledge. What is regarded as well-founded truth today, it is often recognized as a gross error after a few decades." (Zittel, 1902, p. 13)

make assertions. In order to avoid any possible metaphysical pitfall, he prevented paleontology from making declarative statements. Conversely, paleobiology took advantage of this unstable concept and proposed that the main paleontological aim is to make statements concerning the deep past.

Chapter VIII. Paleobiological Data and Phenomena

Introduction

In the previous chapter, I have analyzed the notion of paleontological data through four concrete and simple representations. I have pointed that the paleontologist constitutes his data so that he can use it to elucidate biological patterns and processes. He imposes formal constrains on the biased material object called the fossil record so as to use it in broader and different contexts: he produces "certain limitations and [fixes] certain permanent elements and connections within the uniform flow of experience" (Cassirer, 1923, p. 303). By analyzing Sepkoski's *Compendium*, I have concluded that paleobiologists read the material-perceptive stimuli through principles of coordination. Given a set of fossils S (a, b, c, d) and a specific principle of coordination F( ), the paleobiologist is able to produce a series F(a, b, c, d) that gives a new meaning to the initial set of fossils. He imposes constraints so that appearance can be "intuited as ordered in certain relations" (Kant, 1999). He then uses these fossils within a biological context by applying the chosen function to the arguments presented in set S. These principles of coordination play a pivotal role in determining how and which kind of objects can be taken into account in paleontological investigations. Hence, in line with Cassirer, we do not have paleontological facts separated from paleontological concepts, "but we possess the 'facts' only by virtue of the totality of concepts, just as, on the other hand, we conceive the concepts only with reference to the totality of possible experience." (Cassirer, 1923, p. 147) Indeed, as soon as the paleontologists abandon a position of realism as regards the nature of data, they are able to come up with biological patterns and processes [198]. These are the paleobiological *explananda*. The paleontological notion of data depends therefore on the modality of constitution selected by a paleontological community: it depends on the kind of constraints the paleobiologists impose on them. Although, in fact, paleontological data are always constituted, there is a difference in the degree and in the weight of this constitution. Zittel's data are based on and constrained by different structures from Sepkoski's ones. Consequently, the paleontological explanandum is always inserted into and emerges from a relational system. This can have a more or less explicit role: although Zittel, for instance, constitutes his data, he founds this practice on a metaphysical notion of ready-made objects. Zittel, so to speak, "throw[s] away the ladder, after he has climbed up on it". (Wittgenstein, 2001)

[198] It is worth briefly noticing that this happened also in archaeology. I thank Derek Turner for having pointed this out to me.

Moreover, in the previous chapter I have historicized this conclusion by showing to what extend Williams, Fuchs, and Cleland anticipated the paleobiological turn. By studying a concrete object, namely the notion of paleontological representation, I have stressed that these paleontologists literally constructed these objects. This constructivist practice lead to many empirical and theoretical problems and it was replaced by a less radical constitutive approach. The new paleobiological approach to the fossil record does not construct its data, but it imposes different formal structures upon it.

This chapter takes a second look at the notion of paleobiological phenomenon to see its limits, how it should be understood, upon which assumptions it is based, and what relationship there is between it and data. All these reflections will contribute to understanding why, *de jure*, the paleobiologists need to reconstruct their phenomena. To anticipate the conclusions of this chapter, the paleobiologists construct their explananda to overcome the dark abyss of deep time[199]. Following Zittel's method, paleobiologists understand that they should reconstruct their explananda in order to draw out patterns about the past. They comprehend that their main aim was to save the unobservable phenomena[200]. Deep past is immense time "in quantities no mind had yet conceived" (McPhee, 1981) and it has a degenerative nature. As Nicholson wrote

> "the few thousand years of which we have historical evidence sink into absolute insignificance beside the unnumbered aeons which unroll themselves one by one as we penetrate the dim recesses of the past. [...] Even speculation droops her wings in the attenuated atmosphere of a past so remote, and the light of imagination is quenched in the darkness of a history so ancient" (Nicholson, 1877, p. 9)

It is an abyss that damages[201] the evidence available for the paleobiologist. Therefore, the only way to save the paleobiological phenomena is to construct a possible explanandum[202] from the evidences gathered and inserted into a data model. To accomplish this aim, the paleobiologists follow a complex constructivist path. First, they impose formal constraints on the material gathered. These then become the new starting points. As I have noticed in the previous chapter, the temporal

[199] As is well known, Buffon introduced this term in his *Les époques de la nature* (1778). As Paolo Rossi notices, Buffon proposed a "shortened outline of time span", because he felt that "his contemporaries of the end of 1760s were not yet capable of imagining the *sombre abîme* of so interminable an antiquity for the world" (Rossi, 1984, p. 108). One hundred years after Buffon's *Les époques de la nature*, paleontologists and geologists are still unable to image this span of time. See below and the first chapter.

[200] (Duhem, 1969; Massimi, 2007)

[201] (Turner, 2005, 2007)

[202] As I will point out in the next pages, for most of the time, paleobiologists cannot construct a single explanandum. They have to deal with a plurality of explananda that necessarily derives from the constituted data.

dimension is one constraint imposed by paleobiologists. By deciding, for instance, which attribute value the fossil record should assume, stretched in a database, at the same time the paleobiologist is "capable of imagining the *sombre abîme* of so interminable an antiquity for the world" (Rossi, 1984, p. 108). Second, the paleobiologist constructs representational versions of the past from those constituted starting points by mathematically connecting the data. These representational versions of the past appear in the spatially constrained form of a graph and are able to offer a possible scenario of what happened in the past, saving thus the epistemology of such phenomena. The constructed versions of the past can be described as complex data models (Suppes, 1966): they are probable patterns produced in previously constituted sets of data and they have the power to modify the nature of what they refer to. The construction of these patterns is the result of a mathematical treatment of data in conjunction with a web of conceptual schema which characterizes a particular community. To put it concisely, they are *conceptually determined appearances* (Massimi, 2008). As result of this constructivist practice, the phenomena are saved and they find a reality within their conceptual system.

Let us briefly consider an example. Paleontologists have been struggling to understand the development of species during the Phanerozoic since the 19th century. The study of diversity in the Phanerozoic became particularly important during the 1970s and 80s. During these years, diverse paleobiologists proposed different patterns to describe the Phanerozoic diversity. This dispute ended with the publication of a consensus paper in 1981. In this paper, the authors considered the five problematic estimates of the diversity of lower taxa in the marine fossil record (figure 1) and it turns out:

> "These five sets of data on Phanerozoic marine diversity have been reduced to the common stratigraphic resolution of this geological system and plotted on a normalized vertical scale […] the strong similarities among the data set lead us to conclude that all five estimates of Phanerozoic taxonomic diversity are measuring of a single underlying pattern" (J. J. Sepkoski, Jr., Bambach, Raup, & Valentine, 1981, p. 365)

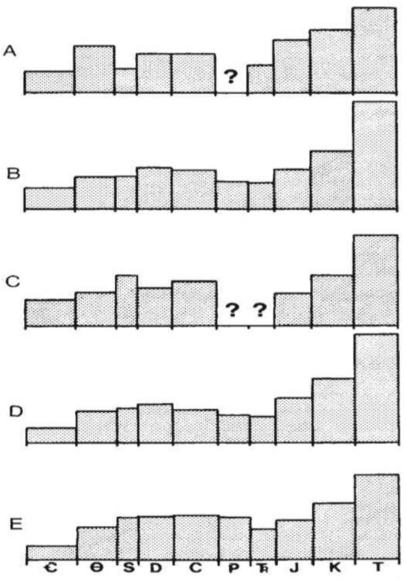

Figure 42 five data sets show the relative magnitude of the marine animal diversity in geological time. From (J. J. Sepkoski, Jr., et al., 1981)

Let us look at this example closely. The five data sets are not composed by ready-made entities that can be encountered out there; they are models of data set according to the particular constraints imposed on the perceptive inputs. The data sets presented in figure 1 are, in fact, the result of a construction of the previously stretched data. In figure 1b, for example, Raup constructed the curve from the data previously constituted in his *Zoological Record*. Sepkoski did the same (figure 1e) by using "2800 fossil families and 91 classes". First, he constituted the perceptual objects through the formal structure of his *Compendium*. Among the many constraints that Sepkoski imposed on his data[203] was a constraint on temporality - so as to obtain epistemic access to deep time. He imposed a precise temporal dimension to fill the temporal gaps: "several modification[s] of the data […] were made prior to analysis. Most important was a manipulation performed to equalize the stratigraphic resolution in the data set." (J. J. Sepkoski, Jr., 1981, p. 41) This is a complete turning point in respect to Bronn's statistical analysis. As I have explained in the first chapter, Bronn identified temporal dimension with the places where fossils were collected. Essentially, he passively listed the fossils under these localities. Conversely, Sepkoski's *Compendium* decides which data can legitimately appear and under which temporal bins.

Second, he constructed the phenomena by imposing other kinds of constraints on the appearance of the constituted data. For instance, he functionally connected his data by virtue of the hierarchical framework. According to Wimsatt, this framework is "*a deep, non-arbitrary, and extremely important feature of the ontological architecture of our natural world, and almost certainly of any world that could produce, and be inhabited by or understood by, intelligent beings*

[203] See the previous chapter for the formal structure of Sepkoski's *Compendium*.

[italics in original] […] compositional levels of organization are the simplest general and large-scale structures for the organization of matter" (Wimsatt, 2007, pp. 203-204). Moreover, the spatial form of the graph was essential in order to create access to deep time. As Gould noticed about Sepkoski's previous study of the Phanerozoic, "Here we see an interesting and fruitful interaction of nomothetics and ideographics. The form of the model remains nomothetic – the 'real' pattern arises as an interaction between two general curves of the same form, but with different parameters. Ideographic factors determine the parameters and then enter as boundary conditions into a nomothetic model" (Gould, 1980, p. 115). Constituted data can appear only within a mathematical-statistical form and in turn this former has a meaning only if data have been previously constituted. This union is possible only in the space of a graphical representation. It thus allows the appearance of the paleontological phenomenon.

The subsequent models of data in figure 1 are constructed by conceptually and mathematically treating the constrained data, precisely as did Sepkoski. This case study tells us something more about the paleobiological constructivist approach. As Arnold I. Miller put it, the consensus paper changed the paleobiological world, where:

> "there was an explosion of research emphasizing the macroevolutionary and paleoecological processes responsible for the major features of Phanerozoic diversification and extinction […] The assumption implicit in all of this research was that the patterns that researchers were trying so hard to explain were, after all, *real*, and it was the Consensus Paper that validated this view." (D. Sepkoski & Ruse, 2009, p. 380)

Millier's quotation gives us important insights into the paleobiological constitution of the deep past. First, the explosion of research into the causes of the pattern that followed the publication of Sepkoski's et al. paper was the consequence of the construction of a new plausible *explanandum*. Independently from the correctness of that pattern, Sepkoski et al were able to produce a working version of the past overcoming the dark abyss of deep time. This construction was essential for drawing out a common terrain on which paleontologists could work. Indeed, this working version of the past was assumed as a reliable *explanandum* which generations of research tried subsequently to explain. As I have noticed in the previous chapter, the representation constructs an epistemic space for further researches; it creates perceptive evidence of the phenomenon.

Second, Millier highlights that the main task of the paleobiological enterprise is to set the conditions for etiological [204] assertions about phenomena in deep past. This task can be accomplished only by constructing unbiased patterns. Third, if the produced pattern is not biased, it

[204] As I will show in the next pages, the stress on etiological reasoning is one of the turning points in the making of the paleobiological phenomenon.

is then real. Although it is real, it is not independent from the system used to produce it. That would be a return to a realist stance impossible to support with the paleobiological categorial framework. The pattern is only real according to the system which has been chosen to construct it: its reality is confined within it exactly as Gertrude Stein's face obtained a new and real determination only through Picasso's representation and although this new determination has its own life, it is completely dependent upon Picasso's conceptual and material means. Fourth, the previous point entails an important epistemic question: how can the paleontologists decide that the constructed pattern represents something that really happened on the heart surface? Or to put it differently, how can paleontology know whether the constructed pattern is genuine and true? Millier's quotation indicates a possible answer. It indicates that questions about truth value are internal to the conceptual system chosen: "'Truth' […] is some sort of (idealized) rational acceptability — some sort of ideal coherence of our beliefs with each other and with our experiences *as those experiences are themselves represented in our belief system* — and not correspondence with mind-independent or discourse-independent 'states of affairs'." (Putnam, 1981, p. 50) The truth of the construction is therefore a matter of idealized rational acceptability that depends in turn on the principles used to constrain the data. It is so to speak a matter of coherence among the constraints selected. The patterns that researchers were trying so hard to explain were, after all, *real* because the *Consensus Paper* validated them. This operation was based on the principles used to constitute the data and on the consequent rational acceptability Sepkoski and colleagues were able to obtain in publishing that paper.

Hence, the notion of construction that I am proposing is a particular kind of constitution and the difference between the former and the latter concerns the weight of the perceptual stimuli[205]. A construction supplies the perceptual gaps with theoretical contents; a constitution imposes, on the contrary, formal structures on the perceptual stimuli, changing thus their logical meaning. One of the conclusions of the last chapter concerned the kind of mind-dependence involved in the paleontological practice. I am not arguing for an ontological notion of dependence of data to the paleontological mind. What there is does not depend on, or is not literally constructed by, the paleontological self. This would be Williams' mistake. On the contrary, the mind-dependence relation between data and paleontological self has a semantic meaning. It means that the possibility

[205] It is important to stress the weight of the external inputs otherwise the paleobiological movement would be entirely inscribed within Williams' epistemic practice. The perspective I am arguing for "does not deny that there are experiential *inputs* to knowledge; knowledge is not a story with no constraints except *internal* coherence; but it does deny that there are any inputs *which are not themselves to some extent shaped by our concepts*, by the vocabulary we use to report and describe them, or any inputs *which admit of only one description*, *independent of all conceptual choices*." (Putnam, 1981, p. 54)

of having a particular kind of empirical knowledge depends on the categorial framework used to read and shape the perceptual stimuli. This mind-dependence can be delineated in different ways. Quine, Hanson, Wittgenstein and Kuhn have all underlined the nature of dependence between language and world. In the last chapter, I have however pointed out that their reflections, albeit important, catch only partially the assumptions and grounds behind this relation. The mind-dependence relation I am endorsing is thus responsible for a space of empirical knowledge and thus it can be named differently as the space of open knowledge. In other words, if it aims to open a space of knowledge for the data, it can be named as a constitution; whereas, if it is directed towards the paleontological explananda, it is a construction. The difference between these mind-dependent relations is only a matter of epistemic degree of abstraction.

Therefore, this chapter begins in recalling the famous data-phenomena distinction proposed by Bogen and Woodward. After having modified this in the light of the paleontological notion of data, I will concentrate on the difference between construction and constitution. Successively, I will characterize the notion of paleobiological phenomena and its line of continuity with and rupture from with the paleontological one. I will analyze under which circumstances the layers of meaning examined in the first chapters have influenced the paleobiological notion of data. I will look at the context of applicability of Zittel and Oppel's data and connections with the paleobiological revolution of the 1970s. The results of this analysis will help me in explaining why the paleobiologists need to construct their phenomena. To achieve this aim, I will step backwards from the historicized *Faktum* of the paleontological phenomena to its conditions of possibility. I will specifically follow the changes in the notion of the fossil record and phenomenon by looking and studying three material, concrete, and layered objects: I will study three of the most important textbooks[206] between the beginning of the 20th century and 1978.

Bringing some epistemic Order

Before dealing with the construction of the paleobiological phenomena, it is necessary to bring some epistemic order to the terms I have used so far. As I have pointed out, both the paleontologists and the paleobiologists actively constitute their data and we can retroactively trace the steps of this constitution. Moreover, I have claimed that paleobiologists construct their explananda. Within the philosophical literature, Bogen and Woodward famously distinguish between data and phenomena. By sharply distinguishing data from phenomena, they defend a sophisticated realism. They claim that science aims to explain phenomena and not data. In their original paper in 1989, Bogen and

[206] Those textbooks are Lull's *Organic Evolution* (1917), Moore's *Historical Geology* (1933), and Raup and Stanley's *Principles of Paleontology* (1971, 1978).

Woodward argued that the "widely shared view of science", according to which science aims to explain and predict facts about the 'observable', is "fundamentally incorrect". For the most part, science does not aim to explain observable features of the world, but unobservable facts. To support this claim, Bogen and Woodward introduce a sharp distinction between data and phenomena. Data is usually observable and constitutes the evidence for inferring a phenomenon. Generally, data "cannot be predicted or systematically explained by theory". Data is "public records (bubble chamber photographs in the case of neutral currents, photographs of stellar positions in the case of Eddington's expedition) produced by measurement and experiment, that serve as evidence for the existence of phenomena or for their possession of certain features." (Woodward, 1998, p. 163) On the contrary, scientific theories predict and explain phenomena. These "need not to be observable" and they "are detected through the use of data, but in most cases are not observable in any interesting sense of that term" (James Bogen & Woodward, 1988, p. 306).

By differentiating data from phenomena, Bogen and Woodard characterize the former as mind-dependent and the latter as ready-made entities. Scientists thus strive to explain and predict facts about generally unobserved phenomena not about perceptual data. This claim cannot be applied to paleobiology; whereas it finds a place in Zittel's practice. Paleobiological phenomena are not ready-made: the paleobiologists actively construct them to obtain epistemic access to the events in deep time. On the contrary, Zittel considers paleontological explananda as the material fossils ready made out there. In this sense, Bogen and Woodward's analysis seems to fit with Zittel's practice.

The interesting question is whether and to what extent Bogen and Woodward's data-phenomena distinction tells us something about the paleobiological epistemic practice. Initially, the only feature that seems to work from Bogen and Woodward's difference is that the scientists explain phenomena and not every single piece of data. This point leads us to a hierarchical distinction within the epistemic enterprise. For instance, Immanuel Kant had stressed in the preface of the second edition of his *Critique of pure Reason* (1787) that science does not aim at explaining every single perceptual feature. On the contrary, "a new light broke upon the first person […] who demonstrated the isosceles triangle (whether he was called 'Thales' or had some other name)" when he "found that what he had to do was not to trace what he saw in this figure" (B XII). Scientists are not thus not interested in explaining what they saw: the *explanandum* is not, mostly, a perceptual feature. Kant also points out that "although all our cognition commences with experience, yet it does not on that account all arise from experience" (B1). Scientific cognition begins with experience, i.e. perceptual sense data. Nevertheless it is not limited to this field. It aims rather at explaining what cannot be found in perceptual contents: unobservable phenomena. The neo-Kantian philosopher Ernst Cassirer followed Kant in distinguishing a perceptual and non-perceptual level of science. He asserts that "The fundamental theoretical laws of physics throughout speak of cases that are never given in experience nor can be given in it" (Cassirer, 1923, p. 174). There are therefore two levels within the structure of sciences and the fundamental laws of physics are *without exception* not about perceptual contents.

This distinction of levels is not only a characteristic trait of Kant and neo-Kantian philosophers. For example, Ernest Nagel, who came from the neo-positivistic tradition, emphasizes the same discrepancy—as Bogen and Woodward notice too. He asserts: "Why did a smaller percentage of Catholics commit suicide than did Protestants in European countries during the last quarter of nineteenth century? […] The explicandum in this case is a historical phenomenon that is statistically described […] and the proposed explanation does not […] attempt to account for any individual suicide in the period under discussion" (Nagel, 1961, p. 17). The same can be said for the father of phenomenology, Edmund Husserl. His last and polemical book, *The Crisis of European Sciences and Transcendental Phenomenology* (1936), is a critical argument about the same point. Although science is born in the life-world, it seeks to explain not the perceptual phenomena, but unobservable quantities. Therefore, Husserl argues, the phenomenologist should bridge the gap between perceptual qualities and mathematical forms. Hence, Kant, Cassirer, Nagel, and Husserl conceive a hierarchy of layers in the scientific enterprise. At the bottom is data given as the epistemic starting points for investigations, the so-called *sensate esperienze*; whereas the phenomena are at the top of this hierarchy. Starting from different point of views, all of them emphasize that science aims to explain phenomena and not every single piece of data.

Scientist aims at explaining phenomena, i.e. a higher layer of the epistemic hierarchy, and not every single piece of data. They are seen only as convenient staring points, which can be abandoned as soon as the epistemic explanation begins. Bogen and Woodward radicalize this hierarchical structure: science does not aim to explain data *at all*. Its goal is, rather, to explain the stable and ready-made features of the world called phenomenon, which appears behind the data. This radicalized claim does not fit properly either into paleontology or into paleobiology. Unlike physicists, for instance, paleontologists need to explain their data before dealing with the phenomenon. Data are therefore both the required stating points and the explananda: they cannot be conceived as given. Therefore, the peculiarity of paleontology is that it aims to explain its sources. Its starting points need to be worked and cooked before they can be used: 'data' are 'phenomena' and 'phenomena' are 'data'. For instance, Zittel and his contemporaries associated the paleontological data with facts and afterwards they became the new paleontological *explananda*.

Hence, both data and phenomena are the result of a process of constitution that can be philosophically and historically spelled out.

However, this does not mean that the data-phenomena distinction cannot be used to understand the paleontological enterprise. Two features of that distinction can be saved to understand the paleontological and paleobiological enterprise: 1) the idea that science does not attempt to explain every single point of a series of measurements, but rather the principle and the relation behind it. Neither paleontology nor paleobiology wants to explain the measured points. The former aims to depict a wider picture about the elements that compose the past world: according to Zittel, paleontology is the realization of a natural systematics of morphological and phylogenetic observations. The letter aims to discover macroevolutionary mechanisms. The principles, i.e. the categorial framework, behind Zittel's data and phenomena are different from those behind Williams or Sepkoski's investigations. As Cassirer asserts "it is not clocks and physical measuring-rods but principles and postulates that are the real instruments of measurement." (Cassirer, 1923, p. 365) Duhem emphasizes the same point, he asserts that "if an experiment in physics [or in paleobiology] were merely the observation of a fact, it would be absurd to bring in correction, for it would be ridiculous to tell an observer who had looked attentively, carefully, and minutely: 'What you have seen is not what you should have seen; permit me to make some calculations which will tell you what you should have observed'." (Duhem, 1991) The philosophical and historical task is therefore to bring out the varieties and validity of these principles. Within this particular framework, a data-phenomena distinction has validity.

2) Since the epistemic border between data and explananda is extremely labile in paleontology, Bogen and Woodward's analysis can be taken as a good methodological distinction for dividing and marking the layers of the paleontological enterprise. To put it in other words, it helps us in fixing the distinction between data sets and the possible patterns derived from them. Furthermore, it calls attention to the variety of paleobiological phenomena. Indeed, the paleobiologist is interested in explaining relations between data and not data themselves. These relations take the form of a pattern and it is dubbed a phenomenon. Within both the paleontological and paleobiological enterprise, data can be seen as a set of relations in exactly the way that phenomena are. The entries in Sepkoski's *Compendium* are sets of relations and many paleobiologists will work to explain these features. It follows that what a paleobiologist recognizes as a phenomenon might not be recognized as such by another. In fact, the second paleobiologist may focus only on the explanation of his data, thus not reaching the higher level of the hierarchical dimension of science as previously exposed. The same can be said for paleontological data: Zittel's entries are sets of morphological relations and many generations of paleontologists will attempt to

explain them. Hence, the philosophical conclusion is that “the given is now divided into wider and narrower circles of objectivity, which are distinctly separated and arranged according to a definite point of view.” (Cassirer, 1923, p. 291) Although the data-phenomena distinction is thus only about the degree of abstraction, it is still useful to bring some order to the paleontological practice both descriptively and normatively. Hence, the essential question is how can we distinguish the paleontological phenomena from the paleobiological? The modality whereby these phenomena are founded and the scientists claim their objectivity marks the difference between the two approaches.

The entries of Zittel’s textbook can be defined as pure paleontological data. Zittel’s *explanandum* is the fossil record which has been previously identified with a set of facts. A historical entity as Zittel’s *Psiloceras planorbis* has indeed a complex structure, which unifies the gathered material objects in the field. It can be dubbed as a paleontological phenomenon because it has all the features listed by Bogen and Woodward: it is a “stable, [and] repeatable” object presented in a textbook (James Bogen & Woodward, 1988, p. 317). Nevertheless, it depends *in toto* on the features of the material objects exhibited during its initial baptism. Hence, the paleontological *explanandum* oscillates between a constituted fact printed in a textbook and certain perceptive objects baptized during a lecture. These two levels are indeed fundamental: the former receives its epistemic status through the ready-made features of the latter. The initial baptism founded lays this particular circle of objectivity.

Bronn, Oppel, Waagen and Williams identified paleontological data with events that ontologically require narration. Regarding these, the paleontological *explanandum* has a historical and narrative form: it is the result of a possible narration. Giving the starting points as historical records written in a table, the paleontologist is able to follow them to narrate the path of these points through time. Bronn, for instance, narrates the path of a species to discover biological conclusions; whereas Oppel traced the path of the fossils to explain the geological conformation of Jurassic in Europe. Both these explananda are patterns derived from data sets previously understood as events. They have their own structure and the paleontologists aim to explain it. Nevertheless, Bronn reminds us that given a particular historical data set, we can produce many different patterns in accordance with it. Or as McAllister put it, “there is no limit to the number and variety of patterns that are exhibited in a data set.” (McAllister, 2011, p. 74) A question arises accordingly: which pattern does *really* represent an event and which one should be explained? Waagen answered by seeking refuge in a correspondence theory of truth. The patterns that the paleontologists seek to explain are those that correspond with what can be seen in rock layers. This entails that in virtue of the incomplete and imperfect data only a small number of phenomena can be *de facto* studied. On the contrary, Williams constructed [207] his data and therefore reduced the possibility of overdetermining it: real patterns are only those that derive from constructed data. Again, the modality in which the phenomena are saved distinguishes and characterizes the various paleontological approaches.

The paleobiological movement, as I will argue historically in the next section, does not seek to say which pattern *really* does represent something that happened on the earth surface. This would be a question about what an object really is, rather than about the value it has within a particular system. As I have argued in the previous chapter, one of the results of the paleobiological revolution was to avoid this kind of question. Namely, there is neither attempt to fix the referential conditions to obtain *real* patterns nor to delineate the referential condition of ready-made entities. On the contrary, paleontologists try to fix the domain in which justified assertions about the past can be made. The truth value of these sentences depend on what we know about the past (Young, 1995): it is the idealized acceptability internal to the chosen system. First and foremost though, the leaders of the paleobiological movement realized that in order to know the past, they have to impose formal limitations on their data so that these can be constituted. As a consequence, they defined new conditions to use and constrain the fossil record: “nature to be commanded must be obeyed” (Bacon, 2000). In other words, the question about the reality of paleontological patterns, i.e. the paleontological phenomena, is a question about 1) the nature and modality of the givenness of the fossil record and 2) how it can be legitimately constrained by paleobiologists. Hence, it is a question about the kinds of principles whereby we *de facto* read and observe past events and *de jure* make statements about them. In this regard therefore, there is a difference only in the degree of abstraction between the epistemic mind-dependence relation between data and phenomena.

Bogen and Woodward score thus a point by arguing that a “crucial feature of empirical data sets is the patterns that they exhibit, rather than the precise value of each data point” (McAllister, 2011, p. 74). It seems that paleontology works exactly in this way. However, this method generates a problem of underdetermination: the paleontological data are underdetermined by the possible patterns constructed upon them. The leading question therefore is about the epistemic status of paleontological patterns. This chapter focuses on the epistemic conditions that the paleobiologist requires in order to produce these patterns. To be more precise, my questions are a) how are the paleontologists able to draw out paleontological *explananda* from constituted data? b) What are the features of the system in which the paleontological epistemic thing has been inserted to produce

[207] I use the word construction in the exact same way as pointed out before. The problem related to a process of construction at this level is that the paleontologist has empirical intuitions of his explananda. Williams therefore confuses constitution with construction and tries to use a constructivist approach within the wrong epistemic field.

possible patterns? To answer these questions, I will continue the historical epistemology began in the first chapters by focusing on the paleontological textbooks as major illustrative examples for the changes in the treatment of the paleontological phenomena between 1917 and 1978. At the same time, I will reflect on the results proposed by these textbooks in order to understand on which conditions the paleobiological phenomena are based and therefore saved.

"Scientists are not born, they are made": Tracking the Changes in paleontological Phenomena through paleontological Textbooks

In the previous sections I have conceptually reframed Bogen and Woodward's distinction and I have distinguished methodologically the notion of constitution from that of construction. I have claimed that although the paleontologists constitute both their data and phenomena, there is a difference in how we can consider and define the latter. Paleobiological data are constituted; whereas paleobiological phenomena are constructed. This distinction is methodologically important if we are to acknowledge the layers of constitution in the paleobiological enterprise. I have concluded the section claiming that, according to McAllister, apparently "there is no limit to the number and variety of patterns that are exhibited in a data set." This is a common issue in data-driven sciences. The historian Hallem Stevens, for example, affirms that one of the main problems related to bioinformatics concerns the epistemic status of the patterns generated from a data set: "how do you decide when something is 'real'? How do you decide whether the computer is producing a biological result or an artifact? How do you trust the machine?" (Stevens, 2013, p. 64) I have quickly answered these questions stating that the reality of a trend can be decided only within the system chosen to construct it. It is an internal question. Hence, it is essential to investigate under which conditions (both *de facto* and *de jure)* the system is chosen and patterns are consequently produced.

The following pages characterize what paleobiological phenomena, i.e. patterns in dataset, are by means of a historical epistemology in conjunction with a meta-reflection. I will namely historicize the notion of paleontological phenomenon by looking at how this notion appears in three important textbooks. I will consequently reflect on the nature of the phenomena proposed in these textbooks. As I have pointed out in the third chapter, Zittel, Stromer, Nicholson and Romer's textbooks offer an important support for students, but they require an introduction that explains how paleontological facts can be successfully used and interpreted. The lack of a precise theoretical introduction produces a notion of the fossil record as something that fluctuates between biology and geology. On the one hand, this notion of the fossil record is meant as the correct *medium* to found paleontology as an independent and biological discipline, on the other, it paradoxically confines paleontology within geology: the paleontological sciences are not able to contribute to any theoretical aspect of biology. The fluctuation presented in these textbooks perfectly represents the main debated topics in journals and meetings during these years. Therefore, they can be used to investigate the nature of paleontological data and the characteristics of the paleontological phenomena: as I have pointed out in the third chapter, Zittel, Stromer, Nicholson and Romer conceived the paleontological phenomena as ready-made.

The following section does not deal with these morphological and classical textbooks[208]. It rather focuses on other kinds of textbooks that were essential in shaping the future notion of paleobiological data and phenomena. As David Sepkoski points out, “before the ‘revolution’ of the 1970s came an important ‘renaissance’ in the preceding decades that, in many ways, made the later events possible” (D. Sepkoski, 2012, p. 33). I will argue that the ‘renaissance’ of the 40s and 50s was possible because those generations of paleontologists received from the paleontological investigations of the first decades of the 20th century a notion of fossil record and phenomenon that paradoxically is not properly paleontological: they do not use the notion of fossil record as a fact, but as an event which requires narration. At the same time they strengthen the epistemological status of these events by associating them with Zittel’s facts. This paves the way for a change in the structures of the paleontological *explanandum*, as it will develop during the paleobiological revolution. I will track these changes and the relationships between this kind of phenomenon and the paleontological one.

As I said, I will track the changes in the notion of paleontological *explanandum* by looking at the most important paleontological textbooks used in the leading universities between 1917 and 1978. I will look at three textbooks as a concise, significant, and material epistemic object[209], exactly as I have done for the notion of paleontological representation. This survey will show 1) what paleontologists and paleobiologists meant by phenomenon; 2) how this has changed over time; and 3) to what extend the notion of paleobiological *explanandum* has its origin in German-speaking paleontology, i.e. in the identification of the fossil record with facts and events. As a result, I will be able to reflect on the condition of possibility of the paleobiological phenomena and thus to point out another layer of theory-ladenness in paleobiological enterprise.

I have noticed so far that we can recognize two distinct meanings of the fossil record. On one hand, fossils are markers for events which happened in the history of the earth. They obtain an ontological stability if they are read through the flow of deep time. Historically, this reading is

[208] I have analysed all their essential features in the second and third chapter.

[209] I agree with Marga Vicedo in asserting that “textbooks did not simply convey information or disseminate ready-made knowledge claims”, on the contrary “many textbooks played a role similar to articles of meta-analysis and literature reviews.” (Vicedo, 2012, p. 113)

understood as a stratigraphic technique to survey rock layers. Bronn, Oppel, Cleland, Williams developed it. On the other, fossils are identified as set of facts printed into textbooks and catalogues or exposed in a museum-hall. They are synchronic unities. They do not mark an event in the history of life, but a single and quite definite point. Although these are incomplete and imperfect material objects, they are not misleading and therefore the entire paleontological science can be built upon them.

As I mentioned at the end of the last section, paleontological data have been slowly transformed: diverse paleontologists treat them not by focusing on what they are, but by dealing with the kind of value they can assume within a specific system. In other words, paleontologists have recognized the continuity between an object and the modality of its representation. Particularly during the first decades of the 20th century, this change entailed a new way of looking at and defining the paleontological phenomena and it can be seen also in paleontological textbooks of that period. During the first three decades of the 20th century, some paleontologists attempted to propose a notion of the fossil record able to discern biological patterns. This notion was centered on the idea that the fossil record could be contemporaneously seen as both a means to access deep time and as a secure paleontological starting point. These paleontologists attempted to unify the qualities related to paleontological facts with the epistemic access provided by the notion of event. In other words, they tried to propose a notion of phenomenon that could be seen as the new paleontological *explanandum*, replacing thus Zittel's phenomena, and which could be used to come up with biological explanations overcoming the dark abyss of deep time.

This substitution would be finally completed during the paleobiological revolution of the 1970s, when paleontology is finally accepted at the high table of evolution. This change has a history that appears clearly in the textbooks used. Therefore, in the following section, I will analyze two important paleontological textbooks of the beginning of the 19th century, whereas I will deal with the most representative paleobiological textbook, i.e. Raup and Stanley's *Principles of paleontology*, in the second one.

Events that look like facts

In the third chapter, I have argued that the paleontological crisis of identity of the first half of the 19th century was a reaction against the biological weight given to invertebrate fossil by Zittel's works. Zittel in fact was able to equalize the vertebrate and invertebrate data: both can be used to explain and set up a natural systematics of morphological and phylogenetic observations. Despite Zittel's unification and the consequent crisis of identity, only vertebrate fossils were manifestly used as genuine biological data. In using them, however, Zittel exerted his great influence. The textbook *Organic Evolution* (1917) gives us an example of this. Its author is the paleontologist

Richard Swann Lull (1866-1957). Lull was an accomplished professor and "among the best-known students and teachers of vertebrate paleontology and organic evolution." He taught at Yale University and "it is probably as a teacher that Professor Lull is most widely remembered" (Simpson, 1958, p. 128). He wrote his *Organic Evolution* as the "outcome of twenty-three years of college teaching" (Lull, 1917, p. vii). It is indeed an exceptional example for understanding the main topics taught at Yale University at the beginning of the 20th century and consequently for discerning the features of the paleontological explananda.

Organic Evolution embodies the *Zeitgeist* already present in Zittel's textbook: paleontology takes, in main, two important directions. On the one hand, it is very close to biological sciences, and on the other it is a geological science. Lull pushes this dichotomous branching even further by stressing the accent on the biological side of paleontology. In fact, in the preface the author claims that another book on evolution "would hardly be justified in the present instance were it not for the fact that the writer is a paleontologist" (Lull, 1917, ivi). Hence, Lull's took up Zittel's insights. He conceived paleontology as a biological science and the fossil record not as a mere stratigraphical tool. Nevertheless, paleontology is not merely a taxonomical discipline that by the use of an analogical reasoning can say something about the zoology of ancient species (as Zittel did); it is also and especially an evolutionary science "whose viewpoint and evidence at disposal are materially different from those of the great majority of authors who have enriched the literature on evolutionary biology" (Lull, 1917, ivi). Paleontology can take a stance in the debate about the meaning and nature of evolution. Although according to Zittel paleontology identifies the fossils with facts, he denied that these could be used to take a position on the nature of evolutionary processes. On the contrary, Lull tried to use those morphological data to investigate biological patterns and processes: the paleontological explananda are therefore evolutionary patterns and phenomena.

The paleontologist trained at Yale[210] University with Lull's textbook could consequently learn that paleontology may be used to discover the features of organic vertebrate evolution. This has an important consequence in the map of knowledge traced by Lull. In fact, the pedagogical development of future paleontologists is based upon a strong stress on the importance of paleontology as evolutionary discipline. In *Organic Evolution*, Lull even attempts to read the geological side of paleontology in the light of the evolutionary one. He claims that

> "The distribution of animals and plants in *time* is fully as important to our understanding of evolution as their distribution in *space*, for while the biologist who

[210] I am highlighting the importance of this university, since Williams, Lull, and Simpson were all professors there.

> bases his research upon recent forms alone need concern himself with the latter distribution only, the student of documentary evidences of evolution, which are, after all, the final court of appeal, is concerned very deeply with the former." (Lull, 1917, p. 82)

Lull is asserting that the temporal geological distribution of the fossils, i.e. the temporal pattern, is fundamental for comprehending the mechanism of evolution. It furnishes rather the final court of appeal for testing those mechanisms[211]. This means that zoological classification depends in a measure upon paleontology. The Yale student can not only clearly comprehend the strong connection between evolution itself and paleontology from a classificatory point of view, but also following Lull's textbook the young paleontologist is educated to search for the ultimate evidence for the evolutionary processes in the fossil record.

The natural consequence of this approach is an epistemological training of the student's skills. He is urged to research the evidence and the causes underlying evolution. This point is extremely important, since it stresses the importance of changing the approach to the fossil record. In order to say what the fossil record is, the paleontologist should investigate what the paleontological community can do with it. Hence, students' skills have to be carefully redefined and shaped. Lull indeed undertakes an analogy between the historians and the evolutionists to better score his point. He asserts that the student of philosophy of history may:

> "gain much knowledge whereupon to erect the fabric of his theories by his own observation of contemporary events; but for final proof of his deductions he turns to musty records of the bygone countries wherein he may trace the evolution of nations and the rise and fall of empires. So it is with the student of evolution […] the final proof rests upon the evidence which in this instance Paleontology alone can furnish." (Lull, 1917, p. 420)

By means of this metaphor, Lull is attempting to accomplish a transformation in the notion of the fossil record: he is suggesting that the paleontologist should stress the positive characteristics of the fossil records in the light of evolution, going a step *deeper* than Darwin. Here, we attend to one step in the transformation of the notion of paleontological data: as I mentioned in the previous chapter, as soon as the paleontologist renounces seeing the fossil record as independent from his theoretical frame, he acquires a notion of data suitable for biological investigations. To convince his students that fossils are positive evolutionary evidence and not a mere source of embarrassment—as Darwin

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[211] This is an essential step in the formation not only of future paleontologists, but also of "average persons". Lull stresses that fossils are the "final court of appeal to test the truth of falsity of the growing belief in evolution" in a book dedicated just to satisfy, and thus to educate, "the average person." (Lull, 1931)

put[212] it in the *Origin of Species*—Lull explicitly makes use of the famous analogy between the paleontological records and the book with many missing pages and chapters. He asserts that "evidence is still imperfect in parts, the chapters were never written in others, or the record has suffered grievous mutilation by relentless hand of time. […] In spite of these vicissitudes the evidence is becoming more and more complete, and with each added link the vision of him who contemplates it grows ever clearer." (Lull, 1917, p. 420) This is a clear connection with the German historical and stratigraphical tradition. In fact, as I have stressed in the first chapter, the metaphor of the book of nature was used to associate the fossils with events in the deep time. Zittel avoided this comparison. Conversely, he treated the fossil record as material facts. Lull takes up both these traditions. He affirms that if the paleontological skills are correctly trained, the reading of the book of nature is no longer misleading: the letters of this book do not lie exactly as *Zittel's constructed material facts*. The sharp distinction between fossils as facts and events seems to find a new symbolic unity.

To summarise, Lull's *Organic Evolution* takes an important step in the formation of the paleontologist and in the theoretical foundation of paleontology itself: it teaches how the positive qualities of the fossil record can be seen as sources of evidence for evolution. Considering the paleontological data as the final court of appeal for evolutionary mechanisms entails a different weight on the epistemic tools that a paleontologist can correctly use, i.e. on the system that a paleontologist embraces to work with the fossils. Lull deemphasizes Zittel's analogical reasoning, whereas he attempts to ask for every phyla the place, time, and especially the cause of their origin. This etiological reasoning unified with the notion of a fossil as solid evolutionary evidence points towards the investigation of the tempo and mode of evolution.

George Gaylord Simpson was indeed Lull's student at Yale and his *Tempo and Mode in Evolution* (1944) is deeply influenced by Lull's textbook. Topics and sentences such as the importance of the "fresh interest in attempting to infer not only the course but also the mechanisms of evolution" (Simpson, 1944, p. xxviii) or the fact that "experimental biology in general and genetics in particular have the grave defect that they cannot reproduce the immense span of time in which population changes really occur" (Ibid.) or again that "incompleteness of the paleontological

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[212] As Darwin famously put it, "I look at the natural geological record, as history of the world imperfectly kept, and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved, and of each page, only here and there a few lines." (Darwin, 1966, p. 310).

record is an essential datum and that it, as well as the positive data, can be studied with profit"[213] (Ibid.) could have been written by Lull himself.

Therefore, Lull's *Organic Evolution* was one of the fundamental textbooks for the birth of paleobiology. It enlarges the map of paleontological knowledge and writes the first chapter of the "yet unwritten introduction" to Zittel's textbook by allowing etiological investigation in paleontology. Nevertheless, important questions are still open. Lull does not deal with the problem of the reliability of the paleontological *explanandum*. He emphasises the quality of the vertebrate fossil record, but he does not address any questions about the reliability of the *explanandum* derived from them nor does he investigate the relationship between explanandum and data. Furthermore, the book does not use tables or graphs to shape and present its data. As I have argued, these forms of representation are essential, since they offer a room for the appearance of the paleontological phenomena. These issues will be taken up not by vertebrate paleontology, but by invertebrate paleontology. This former is however meant not in the form of a morphological and evolutionary discipline, but as historical geology.

Historical Geology

In 1933 three important books were published on historical geology. They were respectively *A Textbook of Geology*, Part 2: *Historical Geology*, by Charles Schuchert and Carl O. Dunbar; *The Principles of Historical Geology form the Regional Point of View*, by Richard M. Field; and *Historical Geology*, by Raymond C. Moore. According to a later observer, "these books have a common subject: the history of the planet earth. Yet they show surprising diversity in material, emphasis and objectives, as well as in mere style and form" (Fenton, 1934, p. 625). Nevertheless, they symbolically represent the on-going interest in historical geology during the 1930s.

These textbooks are significant for my exposition, because they offer many essential details for sketching both the formation and the method of paleontologists during the 1930s. Furthermore, they deal with the problem of reliability of the paleontological *explanandum*. The solutions they proposed are deeply rooted in German stratigraphy and historical geology. At the same time, these solutions will be taken as fundamental starting points for the paleobiological revolution of the 1970s. As the reviewer of *Nature* puts it: "properly pursued, historical geology should be one of the great disciplines, as it requires accuracy of reasoning, a rigorous sifting of evidence and completeness of observation. General works on the subject should be concerned more with methods of thought than with results" (R, 1934, p. 829). This is a key statement because it supports my claim

[213] This is an essential turning point in the notion of paleobiological data. In fact, Niles Eldredge and Stephen Jay Gould use the same notion of datum to defend their paleobiological revolution. It is important to stress again that the genesis of this notion is presented in Lull's teachings and before him in German stratigraphy.

that one of the pivotal turning points in the history of paleontological concerned the methods of thought involved in dealing with the fossil record.

Moore's textbook offers the best discussion of the methods and the abilities of the historical geologists as it focuses on the "nature of the evidences concerning past history and the interpretation of these evidences rather than on the necessary new names that are employed" (Moore, 1933, p. viii) (à la Zittel or Romer). Nevertheless, quasi-paradoxically, the author asserts that "the present book treats the evolution of life on the earth in a very few chapters" (Moore, 1933). This statement sounds quite in opposition to the general disposition of Lull's *Organical Evolution*. Indeed, although the map of knowledge they present does not completely match, the epistemological assumptions they teach are complementary.

As I have shown above, Lull encourages the students to attempt an etiological study of evolution by means of the fossil record; whereas Moore's textbook teaches how "training in clear thinking, in the scientific consideration of numerous complex problems, and in reasoning from evidences or effects to the causes that produced them" (Moore, 1933, p. vii). Moore poses therefore important questions about the method of thought, the kind of causality and the nature of knowledge involved in the historical reconstruction of earth. These insights are addressed to bring out the constructive status of the paleontological phenomena meant as patterns in deep time. He furthermore asks about the reliability and trustworthiness of the paleontological data, phenomena, and explanation.

The starting point is very interesting, since it can also be used in the contemporaneous debate about the nature of the paleontological knowledge. Moore asserts that "the means of arriving at conclusions concerning earth history are much more important than the conclusions themselves". Given that a) the conclusions are difficult to find in the historical disciplines and b) once they have been found further perceptual data can overturn them (as Bronn repeatedly asserts), it follows that c) the paleontologist should concentrate his efforts on the foundation of his epistemic method rather than on the conclusions themselves. He should come up with new methods to arrive at and produce conclusions. These can be obtained only by forcing the fossil record to reveal something about the evolutionary history of the earth. Thus, the data gathered should be inserted into a system that gives them a logical meaning. As the philosopher of science Carol E. Cleland[214] has pointed out, historical sciences, as paleontology, are subjected at what David Lewis called the time asymmetry of overdetermination. They are in the same condition as the investigator who is trying to reconstruct what, exactly, shattered a window starting from the traces on the floor. The present event (a broken window, or in paleobiology a mass extinction) over-determines its causes. Replaying the tape of

[214] See (Carol E. Cleland, 2002; Carol E Cleland, 2011).

time, we cannot be sure to identify the correct sequence of cause-effect, since there are many possible causal chains backwards from the local event. The important point is that mass extinction is a pattern derived from the available data and the identification of this event, according to Moore, is more important than the debate about its causes. The leading question is therefore how can this event be identified starting from the available data?

To overcome this difficulty, the paleontologist should focus on his or her ability to interpret the data in order to come up with epistemic tools able to support biological interpretations[215]. The construction of interpretative means is as important as the quality of data. In fact, by producing correct tools that are able to overcome the decay of information within deep time the paleontologist can compensate for the instability of his data. This is a clear point of contact with the notion of the fossil record as event. From Bronn onwards, paleontologists have been redefining their techniques to read and constitute the fossil record. The paleontologists Williams and Cleland, for instance, stressed that the interpretative practice is even able to modify the ontological status of the fossil record. Although this extreme solution was completely rejected in the 1930s, the key idea behind it is still present: the fossil record is an event and the paleontologists should improve their interpretative techniques to obtain from it a possible *explanandum*. Therefore, "depending only on their completeness [of the materials of earth history] and our ability to interpret them accurately, these records are no less explicit in their testimony concerning the earth's past than are the trappings in the tomb of an ancient Pharaoh concerning the past civilization of Egypt" (Moore, 1933, p. 1).

Comparing paleontological data with the trappings in the tomb of ancient Egypt implies three consequences. First, it means that these former can be posed in the same temporal level as the latter. This was exactly Zittel's conception of the fossil record: the abyss of deep time does not constitute the ontological characteristics and biases of the fossils. In fact, although the time-scale between human and geological history is not the same, the paleontologists can use similar techniques of reasoning to explain the past. This entails that the unimaginable length of time can be shortened and hence grasped only by adopting correct interpretative reasoning. The weight of this

[215] This point can be traced back to a particular "philosophical" approach to paleontology and geology diffused through Germany during the first decade of the 20th century. It found its main support in Johannes Walther (1860-1937). In his *Allgemeine Palaeontologie*, Walther asserts "wenn man aber unsere Lehr- und Handbücher nach jenen grundlegenden Fragen befragt, so begegnet man nur selten einer Diskussion derselben. Mit einer gewissen Absichtlichkeit werden diese 'philosophischen' Fragen übergangen, weil sie keinen Zusammenhang zu haben scheinen mit den 'Tatsachen', deren Festlegung die alleinige Aufgabe verkenne, daß alle unsere 'faktischen' Fesselungen von theoretischen Voraussetzungen beeingelußt werden. Man sehe sich ein einziges Profil oder ein Stuck einer geologischen Karte an und frage sich, wieviel hypothetische Annahmen in ihrer Darstellung enthalten sind?" (Walther, 1919, p. v)

interpretative reasoning is nevertheless different. The second consequence is that the fossils are not facts, but events, or rather, they look like facts, but they are events that can be narrated. To put it in other words, the paleontologist can fruitfully overcome the Buffonian dark abyss of time by virtue of a constructive and narrative thought. This should be the main result of the paleontological training. Third, the trappings in the tomb of ancient Egypt are figurative patterns. These in turn can say something about the culture and nature of the Egyptian society. The task of the archaeologist is therefore to decipher them. Almost the same can be said for the fossil record: given some kinds of interpretative and constitutive operations, the paleontologist is able to express patterns from the fossil record. These have as stable a degree of knowledge as Zittel's facts.

Hence by accurately interpreting his data, the paleontologist is able to literally express (Latin *ex-* out + *pressāre* to press, to press out) reliable information about the past. These take the form of a possible pattern exactly as do the trappings in the tomb of an ancient Pharaoh. The reliability depends *in toto* on the interpretative and constructive operation of the paleontologist. Moore then describes this backward process of investigation from the effects to the causes. It is worth quoting this description in full.

> "Like a detective who with trained eyes searches for all possible evidences bearing on a crime and from these evidences constructs answers to questions when, how, why, and by whom the crime was committed, so the geologist seeks for evidences in the rocks, undertaking to determine when, how, and by what agency certain conditions and events in earth history were brought about." (Moore, 1933, p. 32)

The forensic metaphor, already used by Lull, is again *in auge* in Moore's characterisation of the historical geologist. He tries to infer backward a possible explanation from the traces laid at the scene of the crime. Moore—and broadly speaking historical geology—gives us a first answer to one of the questions with which I opened this section: "The *trustworthiness of inferences concerning geological history depends on completeness of reasoning, thoroughness of observations, and accuracy of reasoning*. This last factor is especially important. In it lies one of the main educational values of historical geology." [italics mine] (Moore, 1932) Historical geology gives thus the limits within fix the reliability of the produced patterns: these depend on the epistemic conditions chosen by the paleontologists. Hence, the ontology of the paleontological patterns is fixed and determined by how we constitute and know them.

Thus, Moore stresses that scientific reasoning must be trained and he tries to propose which skills and practices should be improved if the historical geologist wants first to identify his explanandum and second to come up with causal explanations of the history of earth. To put it in other words, paleontological phenomena are patterns constructed upon the disposition of the fossils.

To bring out these patterns the paleontologist has to improve and strengthen his ability to constitute and define the fossil record. These patterns will then be pressed out from the constituted materials. Once this has been done, the trustworthiness of both the drawn patterns and the conclusions reached depends on completeness of reasoning, thoroughness of observations, and accuracy of reasoning: it is a matter of coherence within these layers.

We can bring Lull together with Moore's account to delineate what the paleontological data and phenomena were during 1920s and 1930s. The paleontological map of knowledge was based upon a growing conviction that A) the fossil record could be a valid source of knowledge, or rather the final court of appeal for evolutionary investigations. Following Zittel's decree, invertebrate and vertebrate paleontology are put on the same epistemic level. B) The fossil record could be a valid source of knowledge only if the ability to constrain and interpret the data is trained. Indeed, only by interpreting the evidence can we acquire a reasonable knowledge of the past: "we may say at the outset that our story will be inaccurate if the evidences that we gather are misconstrued" (Moore, 1933, p. 2). C) The paleontological phenomenon begins to be understood somewhat as the product of an active paleontological construction that does not aim to fix the referential border of what an isolated fossil is, but to fix "the epistemic conditions under which we can reasonably and justifiably (albeit fallibly) make assertions" (Massimi, 2011, p. 10). In fact, both Lull and More stress that paleontology is interested in producing "interpretative means" that are able to "reasonably and justifiably (albeit fallibly) make assertions" about the past life. D) These two textbooks sketch thus out an introduction to Zittel's works: they provide the firm paleontological hope to correctly interpret past events overcoming thus the abyss of time. This hope is the result of the education of the paleontologists based upon textbooks that do not passively embody the normal paleontological science, i.e. Zittel's notion of fossil record. On the contrary, they propose interpretative tools that cannot be found in strictly paleontological textbooks. Therefore, they prepare the 'renaissance' in the paleontological publications of 1940s and 50s. D) The techniques of constituting and reading the fossil record proposed in these textbooks are rooted in German historical geology and stratigraphy. How this hope would be transformed in reality will be shown in the next section.

An indirect, quasi-theoretical approach

In this third section, I focus only on the textbook *Principles of Paleontology*[216] by David M. Raup and Steven M. Stanley. This is due to the fact that this textbook perfectly represents the paleobiological movement born in those years. The authors, indeed, “considered as titles for our book ‘Paleobiology’ and ‘Geobiology’, but decided that textbook titles should follow, rather than precede, name changes of major disciplines” (Raup & Stanley, 1971, p. 10).

To introduce the importance of Raup and Stanley’s textbook, it is necessary to start with an anecdote of one year before its publication, as recorded by Schopf in the preface to *Models in Paleobiology* (1972). Here Schopf recounted a conversation with a student at the Atlantic City meeting of the Geological Society of America in 1969:

> “In answer to my casual inquiry about what he was working on, he stated that his professor had made a collection of brachiopods from a certain formation, that these fossils had never been described, and that this description would make a good problem. The tacit assumption was that because the description had not previously been made, it was worth doing. […] I decided that this particular student was unaware of the various alternative strategies of research available in invertebrate paleontology.” (Schopf, 1972a, p. 3)

Principles of Paleontology deals with the “various alternative strategies of research” that are at the heart of the paleobiological movement and not with a mere taxonomical description of the main phyla. The goal of the book is to present the principles of paleontology at an undergraduate level, but at the same time it “is not designed to provide the entire content of such a course; rather, it is meant to provide a conceptual background for the course and essential information and ideas that may be only partially presented in lectures and laboratories” (Raup & Stanley, 1971, p. ix).

This statement is very interesting since it seems to assert that the main aim of the textbook is to publically present the so far unwritten introduction to paleontology required by Watson in reviewing Zittel’s textbook and consequently to teach it in paleontological courses. I think that this approach was indeed what the authors had in mind: in the textbook they wanted to offer the categorical schema whereby reading the conventional descriptive morphology thus characterising the paleontological notion of data and phenomena. As it appears from many reviews, the textbook was used, appreciated and welcomed in many universities. For instance in *The Journal of Geology*, Ralph G. Johnson declares, “David Raup and Steve Stanley have written an outstanding textbook that deserves wide adoption. […] Raup and Stanley have produced a textbook that will profoundly

[216] I have decided to analyse the first and the second edition of the book in the same section because the differences between those editions are quantitative rather than qualitative. All the additions present in the second edition have their origin in the first one.

affect the quality of teaching paleontology" (Johnson, 1971, p. 751). Alfred G. Fischer in *Science* asserts that "paleontology [has] traditionally emphasized the descriptive-taxonomic side of the subject. Raup and Stanley have broken out of this mold." (Fischer, 1971, p. 1051)

Principles of Paleontology is divided into two parts: description and classification of fossils and the use of paleontological data. By reading the preface, the student can recognise the change in paleontological teaching that the two authors have in mind: paleontology should be taught not following a phylum-by-phylum narration, but an "assignment of extensive reading on principles and approaches" should be preferred (Raup & Stanley, 1971, p. ix). The principles of paleontology are tightly tied with the notion of paleontological data. Indeed, the student is *ex abrupto* thrown into the peculiarities of the data that he or she deals with: "the fossil record—far from being complete—represents only a small sample of past life. […] We must learn what can be done through the use of fossils and what cannot."(Raup & Stanley, 1971, p. 3) Also Raup and Stanley identify the fossil record with a small sample of the past life. This point is particularly important and it comes directly from the German concept of the fossil record through Beerbower's textbook. The identification of the fossil record with a sample implies that the fossil record has to be treated in a bulk and it cannot be considered as an isolated point. Fossils are rather events in the flow of deep time and paleontology can study the movement and the pattern of this flow. The future paleontologist learns thus from the first line of the book that his or her primary task is to a) recognize that paleontological data are incomplete[217]; and b) discover what can be done with fossils by identifying them as samples of the past. These two points are connected with the conclusions that I have proposed by drafting the possible introduction to paleontology in 1930s. At the same time however they overcome them: the paleontological ability to interpret data should be constantly trained and paleobiology gives the *canon* for such a training.

From a pedagogical point of view, paleobiology aims thus to train paleontological skills to perceive and obtain reliable data. This is exactly what historical geology aimed at. The first step in this path is never "to accept a fossil assemblage at face value; it probably represents? a strongly biased picture of the past" (Raup & Stanley, 1971, p. 27). The young student may therefore collect fossils, but he may not read them directly: paradoxically, the paleobiological data can never be accepted as given[218]. This is one of the key points that I have emphasized in the previous sections.

[217] This point is particularly interesting as it opposes recognition of a completeness of the fossil record. Williams in fact recognized the fossils as complete unities. The paleobiological movement on the contrary aligns itself with the classical definition of the fossil record.

[218] Michael J. Benton asserts that, "in an ideal world, the best approach to establishing the pattern of the diversification of life would be to collect data from a comprehensive fossil record and to read off the empirical pattern

The main distinguishing feature between the paleobiological data and the paleontological one consists in the fact that the paleobiological data are not used as external and ready-made sources of knowledge, but as perceptive stimuli that should be formally constituted and inserted into a system. Not only do paleobiologists use *de facto* this approach, but they were also keen on teaching it to their students.

Having stated what the paleobiological data are, we can now investigate how the paleobiologists conceived the notion of phenomena. Raup and Stanley describe remarkably the passage between a set of data and a phenomenon in their textbook:

> "There are perhaps two reasons why the rather poor overall sample of past life in the fossil record is often adequate for the types of study that characterize paleontology:
>
> In *large-scale* studies of rates, trends and patterns of evolution and evolutionary relationship within major plan and animal group, paleontologists tend to restrict themselves to a groups that have relatively good fossil records—fossil records that are adequate statistical samples.
>
> In interpreting fossil faunas and floras of *local* rock units." (Raup & Stanley, 1971, p. 27)

The incomplete sample of the past life can be adequate in two different, but not opposite, contexts: the fossil record is adequate when it is used either in *large-scale* study of rates, trends, or patterns of evolution or in the interpretation of *local* unities. As I have said, these two contexts of applications are not so distinct as it might seem at first glance. Or rather, they have the same historical origin. Oppel and German stratigraphy developed techniques to connect fossil faunas and floras with large-scale studies of rates and trends. Oppel's *Juraformation* was indeed a large-scale study of trends and rates of speciation. Nevertheless, he did not investigate these trends from a biological point of view, but only from a biostratigraphic one.

The notion of a large-scale study of data is thus also central to define the paleobiological data and it clearly descends from German investigations in historical geology [219]. The

as documented by the fossils. The world, however, is not ideal, and this approach entails many problems of interpretation not least the quality of the fossil record." (Benton, 1997, p. 490)

[219] The study of large-scale of data, Francis Bacon *docet*, drives the formation of hypotheses and big questions. Turner has pointed out that the need to ask big questions is a specific characteristic of paleobiology. This need however is already felt by most of the paleontologists investigated in this dissertation. Let us consider another example. In their famous paper on *Punctuated Equilibria* (1972), Eldredge and Gould assert polemically that the classical paleontological textbooks do not pose big biological questions. One of the aims of paleobiology is consequently to pose such questions. Johannes Walther in 1912 argued similarly that "wenn wir den Inhalt dieser systematischen Werke [in paleozoology or paleophytology] prüfen, sehen wir die Fragen allgemeiner Natur nur in kurzen einleitenden Abschnitten, Anmerkungen oder Schlußkapiteln mehr angedeutet als untersucht [...] so gebrauche ich hier den Ausdruck *Allgemeine Paläontologie* als umfassenden sinngemäßen Titel für die vielseitigen *Fragen über das Laben der Vorzeit*. Was man neuerdings unter

paleobiological revolution pushes on this field of research: Raup and Stanley complete the biological turn. Not only do they list paleontological insights into evolution in the first place, rather than concerning geology, but they also assert that "determining the rates at which speciation has taken place is a problem perhaps more suitable for the paleontologist than for the biologist.[220]" (Raup & Stanley, 1971, p. 99)

Therefore, the paleobiological explananda are "*large-scale* studies of rates, trends and patterns of evolution" and "fossil faunas and floras of *local* rock units". A further step in paleobiological training is to show how rates, trends and patterns of evolution can be fruitfully studied, being thus reliable explananda. The answer is already present in the two points listed above: fossils are adequate where they are seen as *statistical samples*. In fact, in the fourth chapter of the textbook the student learns how to treat the fossil record as a reliable sample: the reliability of the patterns depends only on the methods of investigation previously chosen. Accordingly, the paleontologist should "turn to more formal statistical techniques" instead of studying the fossils by the use of classical pictographical techniques. Multivariate and bivariate analysis officially enters into paleontological practice: curve fitting and tests of significance, rather than pictographical descriptions, are now the epistemic tools used to draw out the diversity within and among species.

Hence, "if the differences between the [plotted] lines turns out to be statistically significant, we may proceed to make a biological or geological interpretation" (Raup & Stanley, 1971, p. 90). That is the key point in the notion of paleobiological explananda. The transition from a data set to a pattern is possible if there is a statistical difference in the plotted lines. This difference is empirically traceable, but it is based, *de jure*, on the constitution of the paleontological data. Only by imposing formal constraints on the fossils, is paleobiology able to use them as reliable data. The plotted lines then are the possible *explananda* and these are constructed by using statistical techniques.

Principles of Paleontology gives us important insights into how *we position the paleobiological explananda*. It shows us how paleontologists can work with the fossil record to provide essentially biological and, as a related consequence, geological interpretations of the history of life. This is possible because the paleontologist is *educated to statically construct patterns on his constituted data*. Hence, in order to work down from general abstract phenomena or entities, such

dem Namen Paläontologie, Paläoklimatologie, Paläogeographie oder Palächtalogie zusammengefaßt hat, sind Teilgebiete". (Walther, 1919, p. 7)

[220] We can again see the roots of this claim in the paleontological investigations between the end of the 19th century and the beginning of the 20th century. For instance, the common opinion among the participants at the International Geological Congress in Bologna was "Croit qu'un Congrès de géologues a plutôt qualité pour discuter des questions de mutation qu'un Congrès de biologistes" (Anonymous, 1882).

as an event of mass extinction, to data, the paleobiologist has to come up with a series of models. He has to model the layers that divide the abstract field from the concrete and perceptive one. Patrick Suppes made exactly this point in 1962 in a famous paper in which he argues that there is a hierarchy of model[221] between the data and the theory (Suppes, 1966). According to Suppes, a hierarchy of constructed models thus mediates the epistemic gap between data and phenomena. It is important to stress that models do not aim to mimetically represent the reality (that would be simply impossible in paleobiology and paleontology). On the contrary they denote a target, i.e. a represented and interpreted version of the past. This has a full validity and a meaning only related to the chosen model[222]. This philosophical conclusion has important implications both for the paleontological map of knowledge and the notion of data itself and it would be prominently stressed in the second edition of the book.

Hence firstly, the paleontologist can legitimately inquire into the limits of the paleontological knowledge. This is grounded on an enlarged notion of data. As I have shown through a meta-reflection on the notion of representation in the last chapter too, paleobiological data are always constituted. Questions such as "To what extent do fossils actually represent life in the past? How has the composition of biologic world changed? To what extent is the fossil record biased by preferential preservation?"(Raup & Stanley, 1971, p. 12) are certainly not contemporary, but nevertheless have contemporary value; they acquire a different meaning in the present. In other words, after the paleobiological revolution these questions have no longer a mere validity in themselves, but they assume a new weight, since they can be finally answered through the study of the epistemic reconstruction of the paleontological data. Particularly, the question asking to what extent do fossils actually represent life in the past can assume a quantitative answer.

Secondly, this interrogation of the limits of paleontological knowledge leads to a deeper awareness of paleontology's role with respect to geology and biology. Geology is confined to the last chapter of the textbook conversely pointing out that biology is the main interlocutor of paleontology. The dialogue between paleontology and biology is based upon the conviction that "the paleontologist is in a much stronger position to contribute to our knowledge of how the evolutionary process has carried particular species forward." (Raup & Stanley, 1971, p. 90) This statement assumes a new sense: paleontology can contribute to our knowledge of how the evolutionary process has been carried forward because "without the fossil record, large-scale organic evolution would remain a hypothesis instead of being an accepted fact" (Raup & Stanley,

[221] This hierarchy is composed by these models: *certeri paribus* conditions, experimental design, models of data, models of experiment, linear response models.

[222] For a similar, albeit less radical, approach see (Suppe, 1977; Weisberg, 2013).

1971, p. 255). This is possible only where the paleontologist imposes a particular order on the imperfect data, and consequently transforms them. By identifying the fossil record with a sample that can be statistically investigated and plotted into a graph, the paleontologist constitutes his new raw data and creates his explanandum: the "graph[223] provides the raw material from which evolutionary rates can be calculated" (Raup & Stanley, 1971, p. 268). The graphical form therefore gives an important space for the manifestation of the paleobiological phenomena. It creates a space where the phenomenon can finally be identified. The phenomenon appearing in a graph is the target of a possible model, not the 'real past world'. This distinction is very important: the paleobiologists can in fact say something about the deep past only by constructing it. Hence, the target related to a possible model is the product of formal constraints[224]. It provides epistemic access to the past, or rather, it is, so to speak, the deep past. In fact, it is the only way whereby the paleobiologist "can reasonably and justifiably (albeit fallibly) make assertions" about the past. Even the last realist stance has thus been removed.

To summarise, through my historical epistemology, I have historicized the notion of paleobiological phenomena by looking at how it has been treated in three significant textbooks. I have argued that the paleobiological phenomena are constructed on the constituted data. This means simply that to overcome the abyss of deep time the paleobiologists decide which constraints to impose on the elaborated perceptive inputs. They dictate the space for the appearance of their phenomena. Lull, Moore, Raup and Stanley stress the importance of how we place the paleontological object, since differences in the categorial framework determines difference in the notion of paleontological data and phenomena.

Conclusion

To conclude this chapter—so paving the way for the general conclusions of my dissertation—I would like to summarise my main scored points. First, paleontology is able to investigate the trends and patterns of evolution, because a) it decides what a datum is, b) how it can be read, and c) it

[223] It is interesting also to notice that the function of the graphs changes in the paleontological textbooks: from being almost absent in Zittel's textbook, to becoming the new raw material in *Principles of Paleontology*.

[224] The debate about the K-T mass extinction provides an excellent example. Paleobiologists have been struggling to comprehend this phenomenon since the 1980s. Much of this debate is based upon a different concept of causality shared by the different scientists. This in turn generates different models and targets that provide the only epistemic access to what happened at the Cretaceous–Paleogene boundary.

constructs on them working versions[225] of the past that are able to draw out some biological characteristics. By doing so, it exchanges the material concreteness of the fossils for a statistical one, and consequently increases their reliability. The fossil record is no longer an object in a museum, but a part of the pattern that the paleobiologist seeks to explain. According to Cassirer, "to know a content means to make it an object by raising it out of the mere status of givenness and granting it a certain logical constancy and necessity." (Cassirer, 1923, p. 303)

This new role and status of the fossil record enables the independent nature of the data. The paleobiological data are arguments of possible functions imposed by paleobiologists. Therefore, they can be inserted into different functions independently from their physical nature: the physical representation of the data can be changed without modifying their logical meaning.

Second, I have precisely historicized this notion of data independence and the role it plays in making paleontological phenomena: the concept of data independence between the observable features of the data gathered and their logical structures has its place of origin in historical geology. This investigation stresses the necessity of freeing the data from their observational contents and to emphasize instead the kind of relations that can be traced to connect all the collected data. As I have revealed, Moore, among others, was very explicit about this point: the paleontological data can have a meaning only if they are thought of as possible patterns.

Third, this brief historical epistemology on the notion of paleontological phenomena has shed light on the features of the paleobiological explananda. I have in fact investigated both *de facto* and *de jure* to what extent and under which conditions the paleontologists were able to detect paleontological explananda. By *de facto* stretching the fossil record into a database and treating it statically, the paleobiologist is *de jure* able to impose formal constrains (for instance, temporal, spatial limitation, a hierarchal notion of nature, or a particular causal dimension) and to overcome the dark abyss of the deep time. This provides an answer to Buffon's enigma: "Why, Buffon had asked himself, does the human spirit seem to *lose its way* in time more than in space or in the consideration of measure, weight, and number?" (Rossi, 1984). The paleobiological movement was able not to *lose its way* in time, because it forced the perceptual inputs to become *conceptually determined appearances* (Massimi, 2008).

I have consequently historically traced the steps that have lead to the notion of paleobiological phenomena. Paleobiological phenomena are patterns detected and constructed in a specific graphical space. The graphical representation of biological patterns is not arrived at though

[225] I have used the plural since *de facto* the paleobiologist constructs many patterns based on his data. They are then figuratively synthetized in graphs and these latter become the new raw material. The consequent issue is thus how to rule out the patterns that do no correctly represent an event in the history of the earth.

a mere contingent representation. On the contrary, it is an essential form exactly as the tabular form is crucial for the constitution of the paleobiological data. It is the necessary virtual space in which reconstructed versions of the past can finally appear. To put it concisely, time for the data and space for the phenomena are two forms of the possible manifestation of the paleontological appearance. They “allow the manifold of appearance to be intuited as ordered in certain relations” (Kant, 1999).

Lastly, following Suppes, I have indicated that the hierarchical dimension, which characterizes the paleontological enterprise, is composed by a series of complex models. These represent[226] the reality creating thus epistemic access to deep time: “*models* are representations of target systems” (Weisberg, 2013, p. 171) and they represent them in different forms depending on which layer in the paleontological hierarchy they refer to. Hence, the distinction between constitution and construction, as I have proposed, is only a matter of more or less abstraction from the direct and immediate perceptive stimuli.

[226] For the meaning of this verb in paleontology see the previous chapter.

Conclusion

In my dissertation I have historicized the notion of paleobiological data to point out its origins and features. Indubitably, paleobiological data are rooted in Bronn's paleontological statics. Bronn conceived the fossil record as an event in deep time. Accordingly, he developed a mathematical method to read the fossil record and thus to illustrate biological patterns and processes. In order to carry out a mathematical treatment of data, however, the fossil record needed to be constituted. The fossil record is an imperfect and incomplete material object. Bronn therefore came up with a complex system of tables to crunch the fossil record. He imposed formal constraints and a tabular framework in order to work with it successfully. Nevertheless, his reading was imperfect and imprecise. Its results were not able, on the one hand, to overcome the abyss of deep time and, on the other, to endure against the future. This was due mainly to deep time itself. Bronn, in fact, did not study its structure, but relied on an intuitive concept of time. In other words, he passively noticed the places where the fossils were found and identified them with the temporal dimension. Therefore, his analyses relied on this intuitive and read-made temporality. This praxis was not however, enough, since deep time has a destructive role. In fact, the paleontologist was not able to intuitively understand "in wie ferne sich die den einzelnen Schichten, Formationen, Perioden entsprechenden Zeit-Abschnitte unter sich gleich verhalten" (Bronn, 1849f, p. 783).

Many paleontologists adopted Bronn's concept of the fossil record and his results. In fact, although Bronn's results were imperfect, imprecise, and incomplete, he provided a valuable *Bild der Wissenschaft*. This image of science is grounded on the identification of the fossil record with events in deep time and on the statistical framework required to narrate a biological history. Paleontologists of the next generations both positively reworked and critically refuted these two cornerstones. Karl Zittel criticized the mathematical treatment of data in light of its metaphysical results. The mathematical treatment of the fossil record generated results openly in contrast with the Darwinian model of evolution. Furthermore, the results of the statistical treatment were, as Bronn admitted, incomplete and imperfect. Therefore, the mathematical method could not be set at the center of the paleontological investigations. He conversely proposed a different concept of the fossil record. Instead of seeing it as an event in deep time, he saw it *as it appears*. He emphasized its perceptual features because these constitute secure data for further biological treatment. These are what has survived from the degenerative work of deep time and as such they offer the required foundation for paleontology. They support the paleontological work a) avoiding dangerous metaphysical drifts, b) ensuring the biological status of paleontology. We can refer to paleontology as a biological science where it collects and classifies the morphological features of the fossils. The paleontologist's role is purely to correctly classify what he sees. He is not permitted to search for evolutionary laws behind the morphological data. Hence, paleontology is a pure ideographic discipline. It is interested in showing what once lived on the earth, fixing thus the reference of natural kinds terms. Since it wants to preserve its epistemic status, it accurately avoids making statements about what can no longer be perceived. It does not deal therefore with chronological and biological laws.

Zittel's concept of both paleontology and the fossil record was extremely successful. It would constitute the dominant approach until the paleobiological revolution of the 1970s. It overpowered Bronn's method despite that method's reworking by diverse paleontologists. In fact, in the second part of the 19th century, many stratigraphic studies were published with the precise aim to refine the temporal dimension absent in Bronn. Among them, Oppel's investigation into the Jurassic marked an important turning point within the mathematical treatment of the fossil record. Although this study was not meant as a statistical investigation, it provided impetus for refining Bronn's paleontological statics. It measured and classified events and changes in deep time. Oppel's main result was a finer temporal dimension. This was no longer based on passively listing the places where fossils were found, but on "carving nature at its joints". The result was the construction of an ideal profile able to give a more precise temporal dimension. This temporal dimension was particularly sought by Bronn. Second, Oppel used the concept of zone as an assemblage of fauna to construct the temporal dimension. This particular concept would be set as the fundamental unity for further biological readings of the fossil record. To recall this concept, zone is a precise space in which an entire fauna, which characterizes a determinate period, can be found. Many paleontologists used both Oppel's new temporal dimension and concept of zones to support their mathematical investigations. For instance, Williams, Cleland, and Fuchs treated the fossil record statistically by using these new conceptual tools. Their investigations however provided results in open contrast with the Darwinian model of evolution. This was not acceptable since Darwin's theory of evolution gave the essential foundation for the biological status of paleontology.

The paleontological community accepted Zittel's secure approach and thus rejected the statistical method. Most paleontologists in fact reconsidered Oppel's insight in light of Zittel's notion of data. For instance, Neumayr and Waagen used the notion of zone to support and strengthen Darwin's theory of evolution and therefore to secure Zittel's notion of paleontology. Waagen's series of forms was in fact a natural continuation of Zittel's notion of data. This was based upon a realist foundation, securing paleontology from metaphysical and speculative drift. Hence, it completed the notion of ideographic paleontology continued until the paleobiological revolution. Conversely, this method implied a narrow degree of paleontological knowledge. The conceptual framework of Zittel's collective enterprise is based upon a realist foundation. It conceives the fossil record as a ready-made entity and therefore the empirical knowledge that can be tested against this background (Friedman, 2001) is extremely narrow. Waagen, for instance, only used and promoted statements that had a relationship with ready-made fossils. As a result, evolution is understood as a process of *gradual diversification* and organization of living organisms from a common origin.

The paleobiological movement changed this categorial framework. It unconsciously reconsidered some of Bronn's insights to indicate what could be done with the fossil record. Paleontological data are in fact not given at all. They are the final result of a complex activity in which the fossil record acquires stable and reliable characteristics. First, they stress the constitutive power of their representational tools. In fact, in order to understand what happened in deep time, paleontologists needed to represent these events: they needed to present their starting points for a second time, overcoming thus the abyss of deep time. Deep time has a destructive power: it destroys the information contained in the fossil record. Hence, paleontologists developed representational techniques to save this bulk of information. Zittel, Waagen, Gould and Sepkoski all developed representational techniques to secure paleontological data and phenomena. By studying the structures of these representations, I have shown how the categorial framework appears behind them. Zittel and Waagen founded their techniques on a realist stance; the paleobiological movement, on the contrary, comprehended the importance of constitution and construction in its epistemic practice. Paleobiologists realized and emphasized the deep connection between what there is and how we know it. The main consequence of this was a different concept of 'given', as applied to data. Data is not something given independently from the paleobiologists' conceptual schema. It is on the contrary what emerges from a series of limitations. The fossil record does not guarantee the epistemic status of general statements by the fact that it is a ready-made entity. On the contrary, it is a constituted unity to which paleobiological investigations are directed. This implies that it is at the same time the paleontological starting point and explanandum. In other words, the distinction between data and phenomena is based on different and abstractive points of view. Both phenomena and data need to be constrained and explained.

Secondly, paleobiology does not aim to explain what an object is, but to explain which relations can be traced and developed from it. It is interested in depicting what happened in the deep past and this has a space of empirical manifestation only within the conceptual limits imposed by the paleobiological community. It follows that the truth in paleontology is related to the coherence among the constraints imposed on data.

The general philosophical conclusion is that the notions of ready-made phenomena, mind-independent data, and correspondence theory of truth are misleading and erroneous in paleontology or rather that the rejection of these notions has signaled the transition from paleontology to paleobiology. Two different categorial frameworks in fact characterize these disciplines and therefore the space for their empirical knowledge is different. The paleontological framework is based upon metaphysical realism, whereas the paleobiological framework is based upon the constitutive role of scientific practice.

Moreover, the study of the structures of paleontological data has given the correct impetus for comprehending the nature of Big Data sciences. Paleontology has always been a quantitative discipline. Bronn's analyses are marked by the quantity of data used. The same can be said for Zittel's different paleontological approach: his textbooks are first and foremost characterized by a massive use of data. The quantity of data has always played a role in the paleontological sciences: the turning point within the paleontological science is not that paleobiology uses a great quantity of data. This has always been the case in paleontology. The turning point, rather, centered upon how this data was used: on how the paleontologist was able to orient himself in thinking. The history of paleontological data has indeed clearly shown that paleontology, and broadly speaking historical big data disciplines, cannot be dubbed as hypothesis-free. The conceptual framework of the investigator has a constitutive role. This point connects paleontology with other, albeit less historically oriented, big data sciences. Bioinformatics for example shares many characteristics with paleontology. In describing the notion of bioinformatic data, Stevens has recently argued that data is only the property of computers: the result of computational treatment. Although this statement is historically imprecise, as my analysis has pointed out, it has the quality of calling attention to the constraints imposed by bioinformatics on their data: data are never given independently from a constitutive space. They are the product of certain limitations fixed by the experimenter.

Another feature links paleobiological data with the bioinformatic: as a result of scientists' constitutive role, "[bioinformatic] data will be rich and reliable enough that doing a digital experiment by manipulating data will be considered the same thing as doing an experiment with cells and molecules" (Stevens, 2013, p. 219). This implies that also bioinformatics will free itself form this last realistic residual: there is no difference between experimenting with digital data and with perceptually recognizable entities. These two kinds of data have the same ontological features: they are both real. Paleobiology underwent the same epistemic change during the paleobiological revolution.

The last characteristic connects the nature of the paleobiological ideographic and nomothetic data with the future line of development in bioinformatics. According to Hallam "doing things with large amount of biological data requires thinking of them as a picture, not merely as a text […] The representation of the genome [at the Ensembl database, at European Bioinformatics Institute] is almost entirely a visual one; through it, the user-biologist ‘sees’ the genome as a set of color-coded horizontal lines.” (Stevens, 2013, p. 172) Even in bioinformatics data are *seen as*[227] something else. This practice is also accomplished in paleobiology and, as I have extensively argued, it has its origin in Bronn’s investigations. Furthermore, since the paleobiological *explanandum* emerges from and is epitomized in graphs, it means that it is a visual picture and no longer a text. This implies that, in the end, Zittel’s epistemic practice was successful. In fact, Zittel pictographic and ideographical notion of the fossil record was adopted by the paleobiological movement to the detriment of the textual metaphor. At the same time, these pictures are not static facts as are those represented in Zittel’s textbook, but dynamic events that occur in the deep time. This is the ideographic factor presented in paleontology.

To conclude, the study of the nature of paleontological data has paved the way for further investigation of the differences notions of data within big data sciences. These enquiries need to be associated with a careful study of the conceptual frameworks used to constrain them. Indeed, as Husserl noticed, *ego cogito* is inseparably connected with the data of our activities: *ego cogito - cogitata qua cogitata*. Hence, it is particularly important to investigate how conceptual frameworks change and influence the growth of new epistemic approaches and methods as, for instance, in the passage between paleontology and paleobiology.

[227] On the notion of seeing as and seeing that, see the second chapter.

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