INAUGURAL-DISSERTATION

zur Erlangung der Doktorwürde

der

Naturwissenschaftlich-Mathematischen Gesamtfakultät

der

Ruprecht-Karls-Universität Heidelberg

vorgelegt von Diplom-Biologin

Edilma de Jesus Andrade, MSc

aus Aracaju, Brasilien

2005

Turonian inoceramids and biostratigraphy of the Sergipe Basin, northeastern Brazil: an integrated study of the Votorantim and Nassau quarries

Edilma de Jesus Andrade

Gutachter:

Prof. Dr. Peter Bengtson

Priv.-Doz. Dr. Eduardo A. M. Koutsoukos

Promotionsdatum: 15.07.2005

This manuscript is produced only for the examination as a doctoral dissertation and is not intended as a permanent scientific record. It is therefore not a publication in the sense of the International Code of Zoological Nomenclature.

„Gedruckt mit Unterstützung des Deutschen Akademischen Austauschdienstes“

Erklärungen

Hiermit erkläre ich,

a) dass ich die vorgelegte Dissertation selbst verfasst und mich keiner anderen als der von mir ausdrücklich bezeichneten Quellen und Hilfen bedient habe.

b) dass ich an keiner anderen Stelle ein Prüfungsverfahren beantragt bzw. die Dissertation in dieser oder anderer Form bereits anderweitig als Prüfungsarbeit verwendet oder einer anderen Fakultät als Dissertation vorgelegt habe.

Heidelberg, den 2. Juni 2005

Edilma de Jesus Andrade

“Enjoy what you can, endure what you must”

Goethe

To my parents Andrelina and Manoel Pereira de Andrade, my sister Cristina and my brother Milton I dedicate this work.

Abstract

A detailed biostratigraphical survey was carried out in the Turonian (Upper Cretaceous) of the Sergipe Basin, northeastern Brazil, on the basis of bed-by-bed collecting of inoceramids, ammonites and other macrofossil groups from the Votorantim (locality Retiro 26) and Nassau (locality Mata 11) quarries in the Laranjeiras–Nossa Senhora do Socorro area. The inoceramids are described systematically with the aim of providing a reliable basis for correlation with the international biostratigraphic "standard" zonation. Additional localities were investigated in order to obtain additional material for a re-evaluation of the genera *Rhyssomytiloides* Hessel, 1988, *Sergipia* Maury, 1925 and *Didymotis* Gerhardt, 1897 and to locate the Turonian–Coniacian boundary on the basis of inoceramids. The palaeobiogeography and palaeoecology of the inoceramids are briefly discussed.

The carbonate successions exposed in the two quarries contain a relatively abundant and diversified bivalve and ammonite fauna, with inoceramid bivalves representing the dominant group. Twenty-nine species of the genera *Mytiloides* Brongniart, *Rhyssomytiloides* Hessel, *Inoceramus* J. Sowerby, *Didymotis* Gerhardt, and *Cremnoceramus* Cox are described and illustrated. Re-evaluation of the genus *Sergipia* Maury shows it to be a junior synonym of *Didymotis* Gerhardt, 1897. *Rhyssomytiloides* Hessel, 1988 is considered to be a justified genus; its similarity with *Cladoceramus* Heinz, 1932 is interpreted as a case of homeomorphy. Although less abundant than the inoceramids, the ammonites are represented by 28 species.

Nine successive inoceramid interval zones are recognized in the two quarry sections and calibrated with the local ammonite zonation. The lower Turonian is subdivided into the *Mytiloides puebloensis*, *M. kossmati*–*M. mytiloides* and *M. labiatus* zones, the middle Turonian into the *M. subhercynicus* and *M. hercynicus* zones, and the upper Turonian into the *M. striatoconcentricus*, *M. incertus*, *M. scupini* and *Cremnoceramus waltersdorfensis waltersdorfensis* zones. The Turonian–Coniacian boundary is not present in the quarry sections but exposed in the Nossa Senhora do Socorro area, east of the Nassau (Mata 11) quarry. The stage boundary is marked by the first occurrence of *C. deformis erectus* (Meek), which is firmly correlated with the corresponding level in the proposed candidate Global boundary Stratotype Section and Point (GSSP), in the Salzgitter-Salder quarry, Lower Saxony, Germany.

On the basis of a large number of common elements, the Turonian inoceramid zonation of Sergipe is reliably correlated with the European and U.S. Western Interior zonation. However, at least three inoceramid zones appear to be missing between the Retiro 26 and Mata 11 sections, corresponding to the upper middle Turonian to basal upper Turonian interval. Whether the missing zones are represented by a stratigraphical gap or concealed in the unexposed interval between the two sections is a question that cannot be resolved on the basis of available data.

Study of the ammonite fauna has allowed a refined, though as yet provisional ammonite zonation. The inoceramid and ammonite zonations are integrated with previously established zonations based on planktonic and benthic foraminifers and calcareous nannofossil.

Kurzfassung

Eine detaillierte biostratigraphische Untersuchung im Turon (Oberkreide) des Sergipe-Beckens, Nordost-Brasilien, wurde anhand von schichtweiser Probennahme von Inoceramen, Ammoniten und anderen Makrofossilien in den Steinbrüchen von Votorantim (Aufschluss Retiro 26) und Nassau (Aufschluss Mata 11), die sich in der Gegend von Laranjeiras–Nossa Senhora do Socorro befinden, durchgeführt. Um eine verlässliche Grundlage für die Korrelation mit der internationalen biostratigraphischen „Standard"-Zonierung zu erarbeiten, wurden die Inoceramen systematisch beschrieben. Weitere Aufschlüsse wurden untersucht, um zusätzliches Material für eine Neubewertung der Gattungen *Rhyssomytiloides* Hessel, 1988, *Sergipia* Maury, 1925 and *Didymotis* Gerhardt, 1897, zu erlangen und die Turon–Coniac-Grenze auf der Grundlage von Inoceramen zu erfassen. Die Paläobiogeographie und -ökologie der Inoceramen wird kurz diskutiert.

Die Karbonatabfolge, die in den beiden großen Steinbrüchen aufgeschlossen ist, beinhaltet eine relativ häufige und vielfältige Bivalven- und Ammonitenfauna, wobei Inoceramen die vorherrschende Gruppe sind. Insgesamt werden 29 Arten der Gattungen *Mytiloides* Brongniart, *Rhyssomytiloides* Hessel, *Inoceramus* J. Sowerby, *Didymotis* Gerhardt und *Cremnoceramus* Cox beschrieben und abgebildet. Die Neubewertung der Gattung *Sergipia* Maury, 1925, ergab, dass es sich hierbei um ein jüngeres Synonym der Gattung *Didymotis* Gerhardt, 1897, handelt. Dagegen wird *Rhyssomytiloides* Hessel, 1988, als gültige Gattung betrachtet und die Ähnlichkeiten mit *Cladoceramus* Heinz, 1932, als Fall von Homöomorphie interpretiert. Auch wenn sie weniger häufig auftreten als die Inoceramen, so sind die Ammoniten doch mit 28 Arten vertreten.

Auf der Grundlage des Vorkommens der Inoceramen, konnten in den beiden Steinbrüchen neun aufeinander folgende Intervallzonen unterschieden und mit der lokalen Ammoniten-Zonierung kalibriert werden. Das Unterturon wird in die *Mytiloides puebloensis*-, die *M. kossmati–M. mytiloides*- und die *M. labiatus*-Zonen, das Mittelturon in die *M. subhercynicus*- und die *M. hercynicus*-Zonen und das Oberturon in die *M. striatoconcentricus*-, die *M. incertus*-, die *M. scupini*- und die *Cremnoceramus waltersdorfensis waltersdorfensis*-Zonen gegliedert. Die Turon–Coniac-Grenze lässt sich in den Profilen der beiden Steinbrüche nicht nachweisen, ist jedoch in der Region von Nossa Senhora do Socorro, östlich von Nassau (Mata 11), aufgeschlossen. Die Stufengrenze ist durch das erste Auftreten von *C. deformis erectus* (Meek) gekennzeichnet und kann dadurch mit der entsprechenden Schicht im Aufschluss von Salzgitter-Salder in Niedersachsen, der als Grenzstratotyp [Global boundary Stratotype Section and Point (GSSP)] für diese Grenze vorgeschlagen wurde, korreliert werden.

Auf der Grundlage einer Vielzahl gemeinsamer Taxa kann die Inoceramen-Zonierung des Turons von Sergipe verlässlich mit den entsprechenden Zonierungen in Europa und dem U.S. Western Interior korreliert werden. Zwischen den beiden Profilen Retiro 26 und Mata 11 scheinen jedoch mindestens drei Inoceramen-Zonen zu fehlen, im Intervall vom oberen Mittelturon bis zum basalen Oberturon übereinstimmen. Ob das Fehlen dieser Zonen auf eine Schichtlücke zurückgeht oder ob sie in dem Gebiet zwischen den beiden Profilen, das nicht aufgeschlossen ist, verborgen sind, kann auf Grundlage der vorhandenen Daten nicht beantwortet werden.

Die Untersuchung der Ammonitenfauna erlaubt eine verfeinerte, wenn auch bis jetzt noch vorläufige Ammoniten-Zonierung. Die Inoceramen- und die Ammoniten-Zonierungen werden mit bestehenden Zonierungen, die auf der Basis von benthischen und planktonischen Foraminiferen und kalkigen Nannofossilien aufgestellt wurden, korreliert.

Resumo

Foram realizados estudos biostratigráficos detalhados no Turoniano (Cretáceo Superior) da Bacia de Sergipe, nordeste do Brasil, baseados em inoceramídeos, amonóides e outros grupos de macrofósseis, coletados camada por camada nas pedreiras Votorantim (localidade Retiro 26) e Nassau (localidade Mata 11), entre Laranjeiras e Nossa Senhora do Socorro. Os inoceramídeos são descritos sistematicamente com o objetivo de fornecer uma base confiável para correlação com o zoneamento biostratigráfico internacional "padrão". Foram investigadas localidades complementares para obter-se material adicional para uma reavaliação dos gêneros *Rhyssomytiloides* Hessel, 1988, *Sergipia* Maury, 1925 and *Didymotis* Gerhardt, 1897 e para localização do limite Turoniano–Coniaciano com base em inoceramídeos. A paleobiogeografia e paleoecologia dos inoceramídeos são brevemente discutidas.

A sucessão carbonática exposta nas duas pedreiras contém uma fauna relativamente abundante e diversificada de bivalves e amonóides, sendo o grupo dominante representado por bivalves inoceramídeos. São descritas e ilustradas 29 espécies de inoceramídeos dos gêneros *Mytiloides* Brongniart, *Rhyssomytiloides* Hessel, *Inoceramus* J. Sowerby, *Didymotis* Gerhardt, e *Cremnoceramus* Cox. A reavaliação do gênero *Sergipia* Maury indica que ele é um sinônimo júnior de *Didymotis* Gerhardt, 1897. *Rhyssomytiloides* Hessel, 1988 é considerado um gênero justificado e sua similaridade com *Cladoceramus* Heinz, 1932 é interpretada como um caso de homeomorfismo. Os amonóides, embora menos abundantes que os inoceramídeos, são representados por 28 espécies.

Nove zonas de intervalo de inoceramídeos consecutivas foram reconhecidas nas seções das duas pedreiras e calibradas com o zoneamento local de amonóides. O Turoniano inferior é subdividido nas zonas *Mytiloides puebloensis*, *M. kossmati*–*M. mytiloides* e *M. labiatus*, o Turoniano médio nas zonas *M. subhercynicus* e *M. hercynicus*, e o Turoniano superior nas zonas *M. striatoconcentricus*, *M. incertus*, *M. scupini* e *Cremnoceramus waltersdorfensis waltersdorfensis*. O limite Turoniano–Coniaciano não está presente nas seções estudadas, mas está exposto na área de Nossa Senhora do Socorro, a leste da pedreira Nassau (Mata 11). O limite é marcado pela primeira ocorrência de *C. deformis erectus* (Meek), a qual está firmemente correlacionada com o nível correspondente ao do candidato proposto para o Global boundary Stratotype Section and Point (GSSP), exposto na pedreira Salzgitter-Salder, Baixa Saxônia, Alemanha.

O zoneamento de Sergipe é confiavelmente correlacionável com o da Europa e do "U.S. Western Interior", com base no grande número de elementos em comum. Entretanto, pelo menos três zonas de inoceramídeos parecem estar ausentes entre as seções de Retiro 26 e Mata 11, correspondendo ao intervalo do Turoniano médio superior ao Turoniano superior basal. Se as zonas ausentes estão representadas por uma lacuna estratigráfica ou estão presentes no intervalo não exposto entre as duas seções é uma questão que não pode ser resolvida com base nos dados disponíveis.

O estudo da fauna de amonóides permitiu um refinamento do zoneamento de amonóides, embora ainda provisório. Os zoneamentos de inoceramídeos e amonóides foram integrados com aqueles previamente estabelecidos de foraminíferos planctônicos e bentônicos e nanofósseis calcários.

1. Introduction and objectives

The Cretaceous deposits exposed in the sedimentary basins along the Brazilian continental margin represent an important key to the understanding of the development and evolution of the South Atlantic Ocean. The Sergipe Basin in the northeastern region (Figure 1.1) contains an extensive succession of non-marine and marine rocks. In particular the middle Cretaceous marine carbonate succession is well exposed and yields a rich fauna of invertebrate macrofossils.

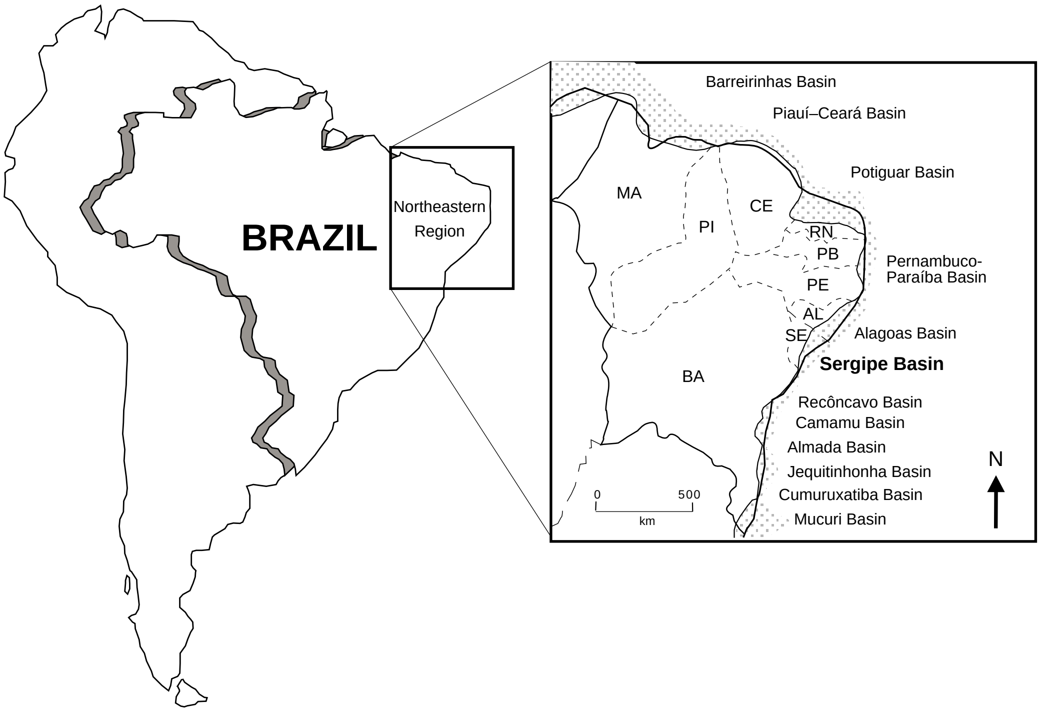


Figure 1.1: Location map of the continental margin basins (dotted) of northeastern Brazil (modified after Bengtson, 1983 and Carvalho, 2001). Abbreviations of state names: AL = Alagoas, BA = Bahia, CE = Ceará, MA = Maranhão, PB = Paraíba, PE = Pernambuco, PI = Piauí, RN = Rio Grande do Norte, SE = Sergipe.

Although the Sergipe succession is known for well over a century, biostratigraphical studies have not yet reached sufficient detail to allow accurate correlations with surrounding areas. In part, this is a consequence of the small and discontinuous outcrops in the basin, in connection with highly variable strike and dip. Establishing a composite section for the basin is thus very difficult. Until now the Sergipe succession has only been broadly correlated with the “classical” Cretaceous areas in Europe. Integrated studies comprising all biostratigraphically significant groups will provide a means of overcoming this problem.

Field work carried out by P. and S. Bengtson (University of Heidelberg, Germany) in 1971–1972 and 1977 on the Cenomanian−Coniacian sequence of the Sergipe Basin yielded a large collection of macrofossils (mainly ammonites, bivalves, gastropods and echinoids). A stratigraphical framework was presented with an eleven-fold subdivision of the Cenomanian-Coniacian based mainly on associations of ammonites (Bengtson, 1983). Inoceramid bivalves were tied to the ammonite subdivision (Kauffman & Bengtson, 1985), but were not formally described or illustrated. Owing to the initial collecting procedures, where a large number of isolated localities were sampled to provide a stratigraphical overview, a detailed biostratigraphic scheme could not be established at that time. Specimens from quarries were mainly provided by quarry workers without information on their position in sequence and may represent mixed assemblages. The first detailed biostratigraphical work on macrofossils was carried out by Hessel (1988) on inoceramids from a 35-m-thick lower Turonian limestone succession exposed in the Votorantim quarry (locality Retiro 26 of Hessel, 1988 = Retiro 15 and 16 of Bengtson, 1983), southwest of the town of Laranjeiras.

During the past decade, the Votorantim quarry was considerably expanded and today a succession of approximately 110 m is exposed. In 1998 the Nassau quarry, southeast of the Votorantim quarry, in the area of Mata 7 and 8 of Bengtson (1983), was put into operation. Today the two quarries expose over 200 m of succession, which appear to represent a major part of the Turonian Stage. This provides a unique opportunity for high-resolution biostratigraphic work in the Turonian of Sergipe. Furthermore, these two sections contain the most complete Turonian succession exposed in Brazil.

Besides macrobiostratigraphy based on inoceramids and ammonites, the Votorantim quarry has been the subject of further studies, for instance, geochemistry, cyclostratigraphy, micropalaeontology and palynology (see chapters 2 and 3).

An abundant and diverse cosmopolitan fauna of inoceramids associated with ammonites provides the basis for a detailed biostratigraphical zonation of the Turonian in the Sergipe Basin, which will serve as a standard zonation for the northwestern South Atlantic. Recent biostratigraphical work on the Turonian–Coniacian interval has shown that, in general, inoceramids are more abundant and less provincial than ammonites (Walaszczyk & Wood, 1999; Walaszczyk & Cobban, 1999, 2000a). These bivalves can therefore be seen as the principal biostratigraphic group for this part of the Cretaceous.

This study comprises a detailed biostratigraphical survey of the Turonian of Sergipe, based on bed-by-bed collecting of inoceramids, ammonites and other macrofossil groups from the Votorantim and Nassau quarries between the towns of Laranjeiras and Nossa Senhora do Socorro (Figure 1.2). The inoceramids are described systematically with the aim of providing a reliable means of correlation with the international biostratigraphic “standard” zonation. Additional localities were investigated in order to obtain additional material for a re-evaluation of the genera *Rhyssomytiloides* Hessel, 1988, *Sergipia* Maury, 1925 and *Didymotis* Gerhardt, 1897 and to locate the Turonian–Coniacian boundary on the basis of inoceramids.

In addition, the results contribute to the interpretation and reconstruction of the palaeogeographical and palaeoceanographical history of the northern South Atlantic during the mid-Cretaceous interval.

The Cenomanian–Turonian stage boundary is not exposed in the Votorantim quarry but was studied by Seeling (1999) and Walter (2000) and more recently by Teodósio & Bengtson (2003) and Gale *et al.* (in press) on the basis of other outcrops in the basin.

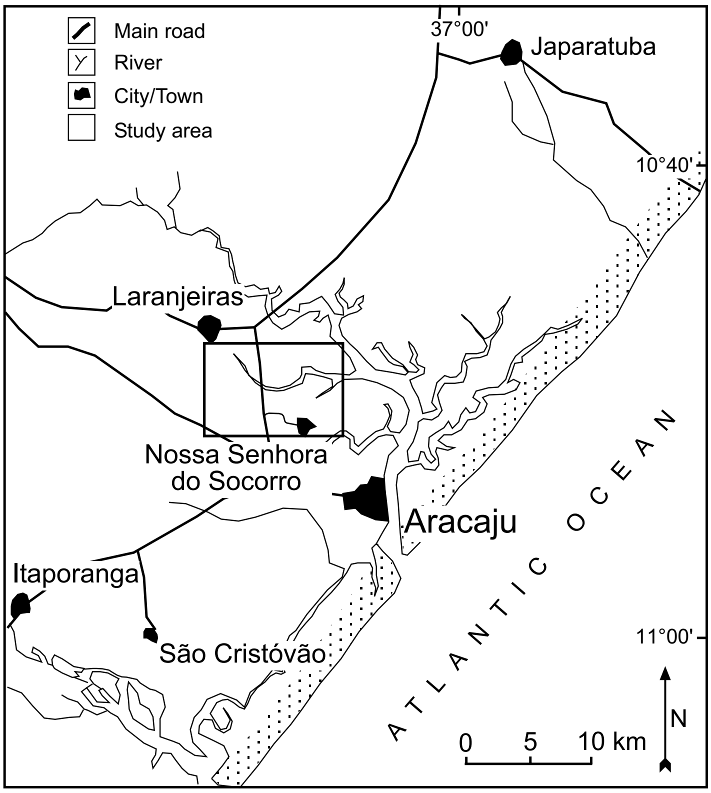


Figure 1.2: Simplified map of the onshore area of the Sergipe Basin, with location of the study area (modified after Seeling & Bengtson, 2003).

The principal objectives of this study are:

- to improve the biostratigraphical resolution for the Turonian of the Sergipe Basin on the basis of a detailed palaeontological and biostratigraphical study of the macrofossil succession in the Votorantim and Nassau quarries;
- to carry out biostratigraphical correlations with adjacent basins;
- to integrate the inoceramid–ammonite biostratigraphy with published microfossil schemes;
- to carry out biochronostratigraphical correlations with coeval successions elsewhere globally;

- to provide systematic descriptions of the inoceramid bivalves, with a re-evaluation of the genera *Rhyssomytiloides*, *Sergipia* and *Didymotis*;
- to carry out palaeobiogeographical analyses and palaeoecological interpretations of the inoceramid bivalves.

2. Geological and stratigraphical setting

2.1 Geological setting

The Sergipe Basin is one of the numerous sedimentary basins along the Brazilian coast. The onshore part of the basin is situated in the eastern part of the state of Sergipe (Figure 1.1). The basin is limited by the Japoatã-Penedo High to the north and by the Jacuípe Basin to the south. The Sergipe Basin has traditionally been considered as part of a larger Sergipe-Alagoas Basin (e.g., Lana, 1990; Pereira, 1994), but important stratigraphic and structural differences warrant a separation in two individual basins (Feijó & Vieira 1991; Feijó, 1995). On the other hand, structurally the Sergipe Basin can be regarded as one of four sub-basins (Cabo, Alagoas, Sergipe and Jacuípe) composing the Sergipe-Alagoas Basin. These four sub-basins present different tectono-sedimentary histories and sedimentary fills (Souza-Lima *et al.*, 2002). Whether the Sergipe Basin should be termed “basin” or “sub-basin” is an issue that lies outside the scope of this work; for convenience the term “Sergipe Basin” is used, which is in accordance with most recent studies.

The palaeogeographical setting of the Sergipe Basin during the late Early and Late Cretaceous is a direct consequence of the strong tectonic activity that affected the area since the beginning of rifting between South America and Africa in the Early Cretaceous. Structurally the basin consists of a series of half-grabens with a regional dip averaging 10–15º to the southeast, resulting from NE–SW-trending normal faults (Figure 2.1, 2.2). The carbonate sedimentation with associated siliciclastics was strongly controlled by differential subsidence and half-graben development along the northeast–southwest extensional faulting, the relay structures associated with hanging wall downwarps, and footwall uplifts and roll-over structures (Koutsoukos et *al*., 1993).

The onshore portion of the basin occupies a narrow coastal strip, approximately 15 to 50 km wide and 200 km long. The offshore portion extends to water depths greater than 2000 m (Koutsoukos et *al*., 1993; Koutsoukos, 1998).

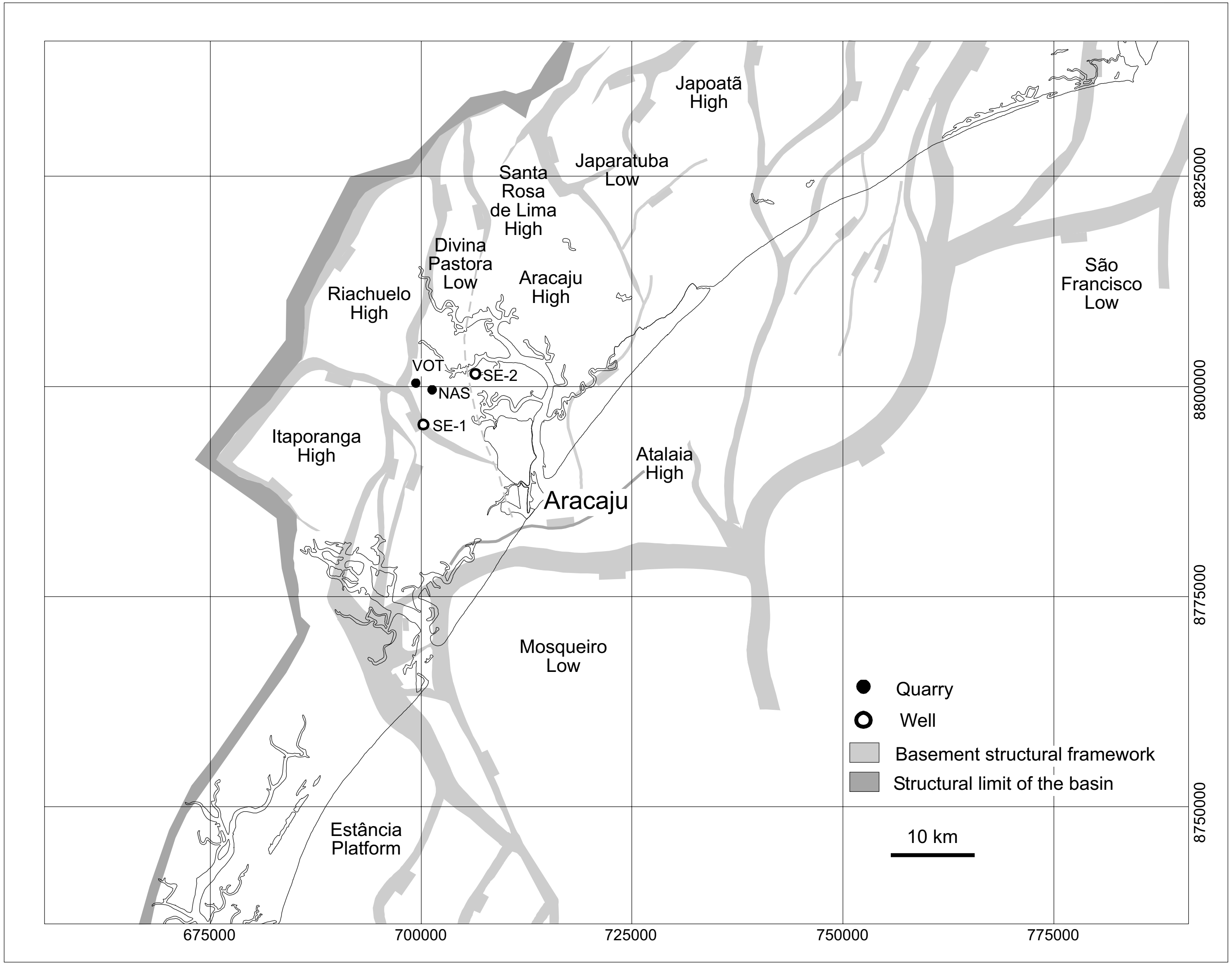


Figure 2.1: Basement structural framework of the Sergipe Basin. Thick lines are faults (modified from Falkenhein, 1986). The quarries Votorantim (VOT) and Nassau (NAS) and some previously studied wells in the area (Koutsoukos, 1989; Cunha & Koutsoukos, 2001) are plotted.

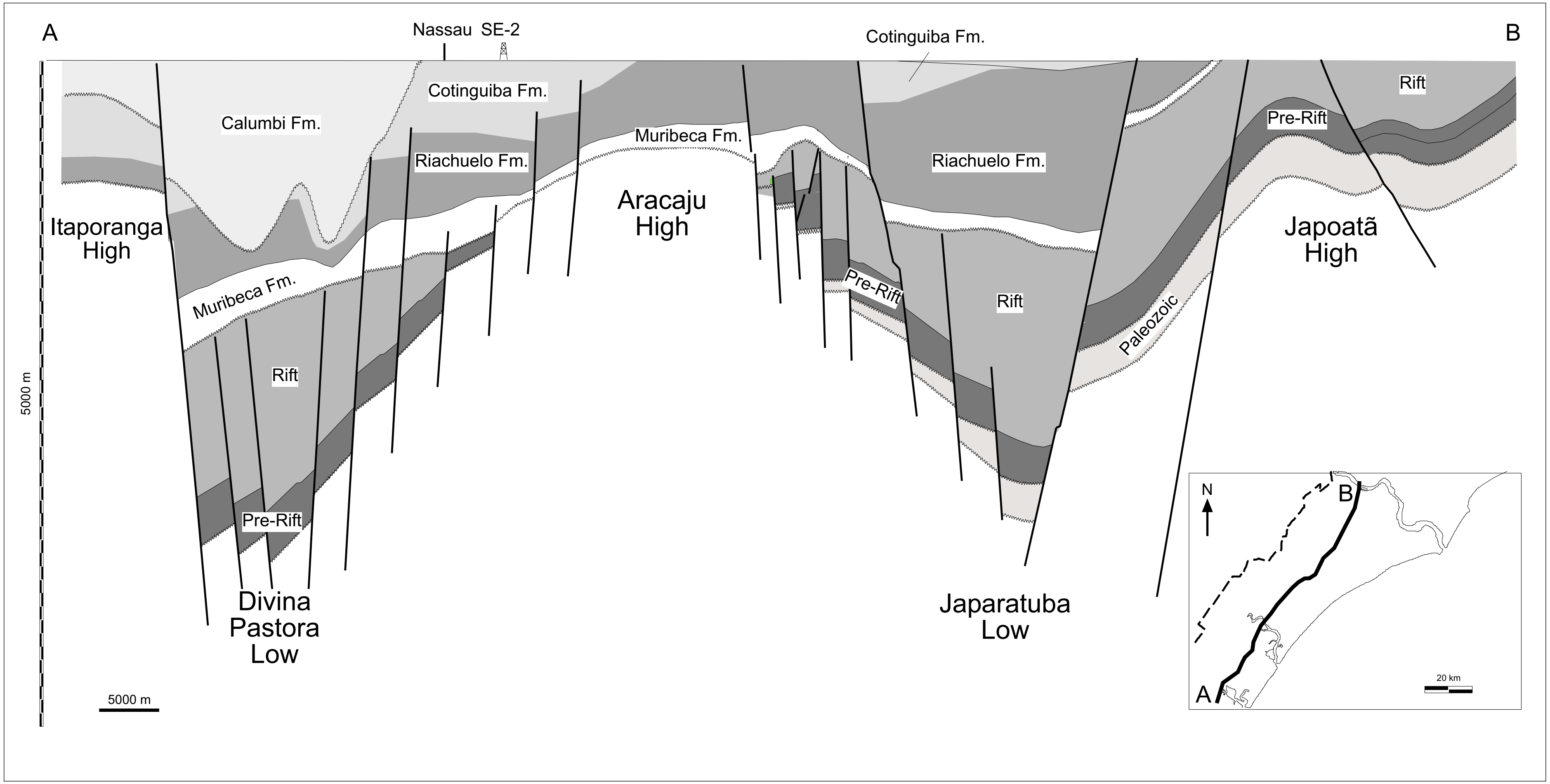


Figure 2.2: Schematic composite strike-oriented southwest–northeast geological cross section A–B (Souza-Lima *et al*., in progress).

2.2 Tectonic-sedimentary evolution and lithostratigraphy

The tectonic-sedimentary evolution of the east Brazilian marginal basins has been discussed by several authors (Ojeda & Fugita, 1976; Ojeda, 1982; Chang *et al.*, 1988, 1992; Lana, 1990). The formation of these basins is directly related to the rupture of the African-South American plate. The separation of the two continents took place along a typical divergent Atlantic-type continental margin extending nearly 8,000 km. The sedimentary basins on both sides of the present South Atlantic thus have a common evolutionary history, which encompasses four main tectonic-sedimentary phases: pre-rift, rift, transitional (evaporitic) and drift (Ojeda & Fugita, 1976; Asmus, 1981; Ojeda, 1982). The nomenclature used for these phases varies between authors (Figure 2.3).

These tectonic-sedimentary phases are mirrored by the sedimentary fill of the east Brazilian marginal basins, where five megasequences are recognised (Chang *et al.*, 1988, 1990): continental, transitional, shallow carbonate platform, marine transgressive and marine regressive (Figure 2.3).

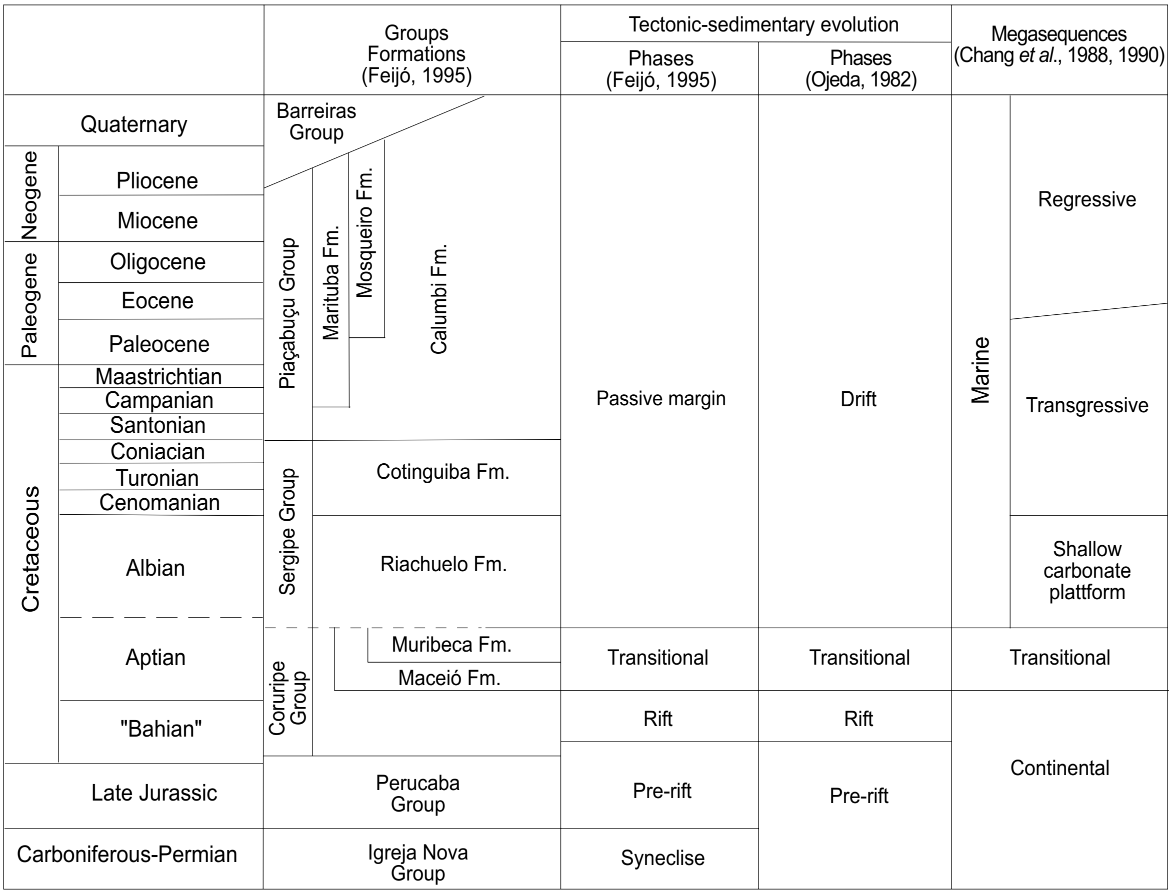


Figure 2.3: Lithostratigraphical units of the Sergipe Basin and tectonic-sedimentary evolution of the east Brazilian marginal basins.

The sedimentological and lithostratigraphical development of the Sergipe Basin with respect to the tectonic-sedimentary phases can be summarized as follows (Figure 2.3):

- **Syneclise phase** (Carboniferous–Permian), represented by siliciclastic deposits (Batinga Formation) and aeolian sandstones, shales and silicified carbonates (Aracaré Formation) of the Igreja Nova Group.
- **Pre-rift phase** (Late Jurassic to Early Cretaceous), represented by fluvial and lacustrine sediments deposited in the "Afro-Brazilian depression" (Candeeiro, Bananeiras and Serraria formations) of the Perucaba Group.
- **Rift phase** (Early Cretaceous to early Aptian), represented by alluvial, fluvial, deltaic deposits (Rio Pitanga, Penedo, Barra de Itiúba and Coqueiro Seco formations) of the Coruripe Group.
- **Transitional phase** (Aptian), represented by siliciclastic, carbonate and evaporitic deposits (Maceió and Muribeca formations) of the Coruripe Group.
- **Drift phase (passive margin)** (late Aptian to Recent), represented by marine carbonate and siliciclastic deposits (Riachuelo, Cotinguiba, Calumbi, Mosqueiro and Marituba formations) of the Sergipe and Piaçabuçu groups.

2.3 The marine Cretaceous

The Sergipe Basin contains one of the most extensive middle Cretaceous marine successions among the northern South Atlantic basins. The upper Aptian to lower Coniacian interval is represented by a carbonate succession, which can be subdivided into two main depositional systems (Koutsoukos & Bengtson, 1993; Koutsoukos *et al.*, 1993):

1. a mixed carbonate-siliciclastic platform system (late Aptian to Albian), which corresponds to the Riachuelo Formation (Figures 2.4 and 2.5), composed of three members with an average thickness of 500 m, locally reaching 1,700 m.
2. a carbonate ramp system (Cenomanian–early Coniacian), represented by the Cotinguiba Formation (Figures 2.4 and 2.5), chiefly developed as a massive succession of fine-grained, deeper-water limestones, with an average thickness of 200 m, locally up to 1,000 m.

The Cotinguiba Formation was deposited in the neritic (0–200 m) to upper bathyal (200–500 m) environments of a carbonate ramp (Koustoukos, 1989; Koustoukos *et al.*, 1993). The succession is far from complete, and in particular the Cenomanian is poorly represented (Bengtson, 1983). The Turonian and Coniacian seem to be more complete, with thicknesses up to 600 m, although there are a large number of discontinuity surfaces suggesting stratigraphical gaps (Bengtson, 1983). Petrobras well QM-1 (= SE-1 of Cunha & Koutsoukos, 2001), 5 km south of the Votorantim quarry (Figure 2.1), which was studied by Bandeira

Júnior (1978) and Cunha & Koutsoukos (2001) shows a total thickness of 750 m for the Cotinguiba Formation.

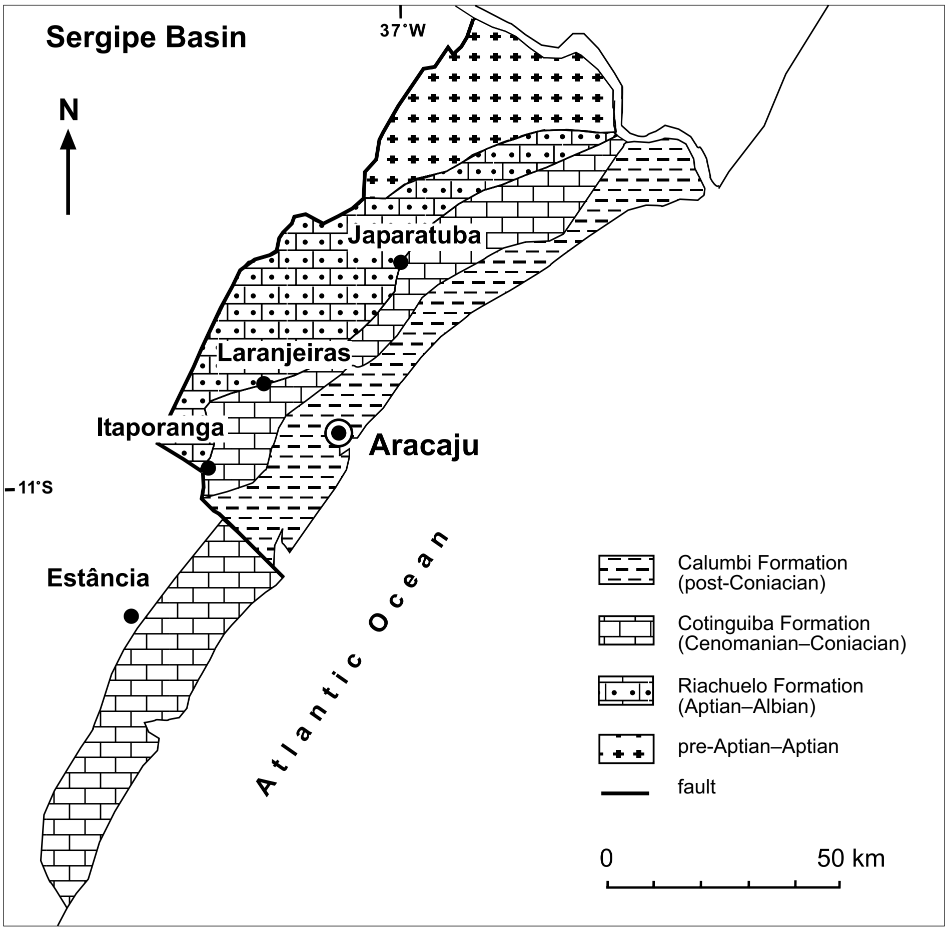


Figure 2.4: Simplified geological map of onshore area of the Sergipe Basin, including the Estância area south of the basin proper; continental Cenozoic cover removed (modified after Bengtson, 1983).

The Cotinguiba Formation consists of two members, Sapucari and Aracaju (Figure 2.5). The Sapucari Member is composed of cyclic alternations of massive and well-stratified greenish-gray carbonate mudstones and marlstones (maximum thickness of 800 m). The Aracaju Member consists of laminated, organic-rich calcareous shales with intercalations of thin carbonate mudstones and marlstones (maximum thickness of 300 m). The Aracaju Member is interpreted as the distal facies (Koutsoukos *et al.*, 1993).

After the carbonate-dominated deposition ended, predominantly siliciclastic deposits were laid down unconformably. Olive-green shales, siltites, and sandstones constitute the Calumbi Formation (Santonian to Recent), which formed in slope and oceanic basin environments. The Calumbi Formation (Figures 2.3, 2.4 and 2.5) grades laterally and vertically into the Marituba (Campanian to Recent) and Mosqueiro (upper Paleocene to Recent) formations composed of sandstones and calcarenites, respectively, deposited in neritic environments (Feijó, 1995; Souza-Lima, 2001).

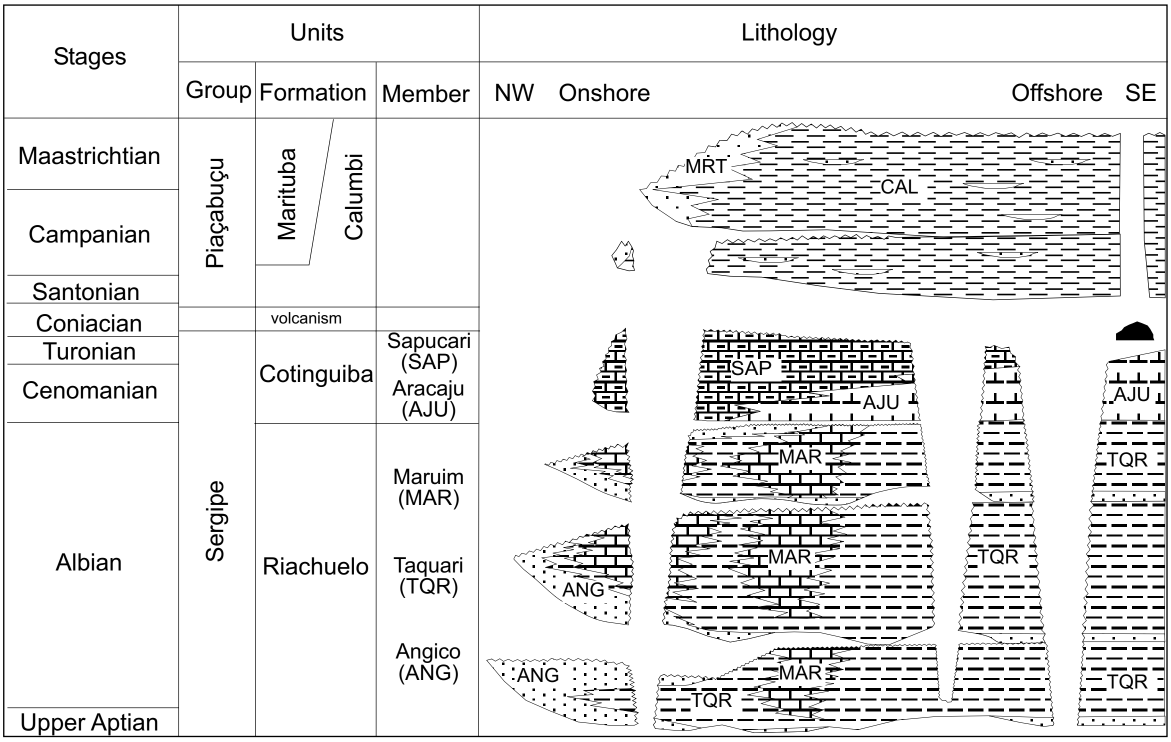


Figure 2.5: Lithostratigraphy of the marine Cretaceous of the Sergipe Basin (modified after Carvalho, 2001 and Souza-Lima *et al.*, 2002).

2.4 Sequence stratigraphy and cyclostratigraphy

Sequence stratigraphical studies carried out to date in the Sergipe Basin included only a small part of the marine succession. Mendes (1994) studied the uppermost Aptian to lowermost Cenomanian and recognised three third-order depositional sequences, informally named I (lower), II and III (upper), corresponding to the Riachuelo Formation. It is unclear why the lowermost Cenomanian was ascribed to the Riachuelo Formation, which is contrary to common practice (e.g., Feijó, 1995; Souza-Lima *et al.*, 2002; see also discussion by Bengtson, 1983, pp. 38–41).

A more detailed work was carried out by Pereira (1994) who presented a stratigraphical framework for five of the Brazilian marginal basins. He established nine depositional sequences for the Albian–Maastrichtian of the Sergipe Basin and discussed the seven sequences that are significant for regional and global correlations (Figure 2.6).

In his stratigraphical revision of the Sergipe Basin, Feijó (1995) presented a framework for the tectonic-sedimentary phases of the basin: Permian–Carboniferous syneclise, Jurassic–early Cretaceous pre-rift, rift, transitional and passive margin sequences (cf. Figure 2.3).

Sequences	Interpretation
upper Campanian/lower Maastrichtian – uppermost Maastrichtian	HST(?)
	TST
	LST
lower Campanian – upper Campanian/lower Maastrichtian	HST(?)
	TST
	LST
upper Turonian/lower Coniacian – lower Campanian	HST(?)
	LSF or LST/TST
	LSF
middle Cenomanian – upper Turonian/lower Coniacian	HST
	TST
upper Albian/lower Cenomanian – middle Cenomanian	HST
	TST
middle Albian – upper Albian/lower Cenomanian	LST
	HST
	TST(?)
upper Aptian/lower Albian – middle Albian	HST
	LST/TST

Figure 2.6: Depositional sequences for the marine Cretaceous of Sergipe proposed by Pereira (1994). Abbreviations are as follows: LST = lowstand systems tract; HST = highstand systems tract; TST = transgressive systems tract; LSF = lowstand fan.

Hamsi Júnior *et al*. (1999) presented a stratigraphical analysis of the Aptian–Coniacian carbonate succession, corresponding to the Marine Carbonate Megasequence of Chang *et al.* (1990). They subdivided this megasequence into two second-order sequences (approximately 10 Ma), K60 and K70 (Figure 2.7). K60 is interpreted as a tectono-sequence, developed during the late Aptian to late Albian, related to the late rift phase of the basin. K70 represents a tectono-eustatically controlled sequence developed during the late Albian to Coniacian. In their discussion, Hamsi Júnior *et al*. (1999) erroneously referred the K70 sequence to the upper Albian to upper Turonian, whereas their figure 2 (Figure 2.7 herein) correctly shows its extension into the Coniacian (Hamsi Júnior, personal communication, Aracaju, 2004).

Stages	Sequences		Units	Interpretation
Coniacian	Marine Carbonate Megasequence	K70	KM4	HST
Turonian			KM3	TST
Cenomanian				
Albian		K60	KM2	HST
upper Aptian			KM1	TST

Figure 2.7: Interpretation of the Marine Carbonate Megasequence of the Cretaceous of the Sergipe Basin proposed by Hamsi Junior *et al*. (1999).

The sequence stratigraphic analyses of Hamsi Júnior *et al*. (1999) were based on geophysical gamma-ray (GR), Total Organic Carbon (TOC) and biostratigraphical data of Petrobras exploratory wells. The sequences were divided into four units: KM1, KM1, KM3 and KM4 (Figure 2.7), and correlated with the foraminiferal biozones of Koutsoukos (1989). According to Hamsi Júnior *et al*. (1999), unit KM1 is interpreted as a transgressive systems tract (TST) and includes the Taquari Member and the lower part of the Angico Member, whereas KM2, a highstand systems tract (HST), corresponds to the Maruim Member and the upper part of the Taquari and Angico members of the Riachuelo Formation. Unit KM3, interpreted as a transgressive systems tract (TST), includes the Aracaju Member of the Cotinguiba Formation. Unit KM4, which represents a highstand systems tract (HST), corresponds to the Sapucari Member. It should be noted that their interpretation of the Aracaju and Sapucari members is contrary to current usage, according to which the two members represent different depositional facies.

A new sequence stratigraphic framework for the upper Aptian–Albian was presented by Carvalho (2001). He integrated palynofacies units, lithofacies and gamma ray logs of two Petrobras wells and combined these data with the frameworks of Mendes (1994), Feijó, (1995) and Hamsi Júnior *et al*. (1999).

The Turonian succession of Sergipe has been studied from a cyclostratigraphic point of view by Cunha (2001) and Cunha & Koutsoukos (2001). Analyses of two Petrobras exploratory wells (SE-1 and SE-2) and the exposed succession in the Votorantim and Rita Cacete (locality Rita Cacete 4 of Bengtson, 1983) quarries, demonstrated a well-defined cyclicity. Spectral analysis using gamma-ray and sonic log data were interpreted. The existence of orbital-climatically driven cycles was observed in two facies, defined by thinly laminated (mm-scale) and coarser limestone–marlstone (cm-scale) couplets. These facies were interpreted as Milankovitch cycles, reflecting changes in primary productivity in response to run-off variations driven by climatic changes. Retrogradational-progradational cycles were identified.

Tupinambá *et al.* (2002) presented a stratigraphical analysis of the Cenomanian–Turonian boundary in the Laranjeiras area. Based on the correlation of three small quarries, they subdivided this interval into two fourth-order sequences.

Johnson *et al.* (2003) discussed briefly the record of orbital forcing of climate, reflected in 333 limestone–marlstone couplets in the Votorantim quarry, which occur with half-precessional cycles suggested by spectral powers at 12.1 ka in the limestone and 12.6 ka in the marlstones. Further high-resolution stratigraphical, geochemical and chronological analyses of the middle-Cretaceous of Sergipe have been carried out, but remain unpublished.

3. Previous palaeontological studies

In this chapter, the most important palaeontological and biostratigraphical research on the Cenomanian–Coniacian of Sergipe (Cotinguiba Formation) is summarized. Research on the inoceramids, the principal topic of this study, is treated separately (Section 3.2). For additional information on the history of palaeontological research, see Bengtson (1983).

3.1. General palaeontology and biostratigraphy

The first geological and palaeontological study of the marine Cretaceous of Brazil was carried out by Hartt (1870) and published in his classical "Geology and Physical Geography of Brazil". In this work, Hyatt (1870) gave the first descriptions of ammonites from Sergipe. National research in Brazil was initiated with the creation of the "Commissão Geologica do Imperio do Brazil" (1875–1877), which was initially directed by Hartt.

In the first comprehensive treatment of the Cretaceous faunas of Brazil, White (1887) described ammonites, bivalves, gastropods and echinoids from Sergipe. In a monograph on the Cretaceous of Paraíba, Maury (1930) included a stratigraphic correlation chart for the Cretaceous of Sergipe. A subsequent monograph (Maury, 1937) was exclusively dedicated to the Cretaceous of Sergipe and included taxonomic revisions of the material studied by White (1887).

In the following decades, palaeontological and stratigraphical studies were carried out by numerous workers (e.g., Magalhães, 1952, 1953; Oliveira, 1958; Bender, 1959; K. Beurlen, 1961a, 1961b), in part as a result of the establishment of the Conselho Nacional do Petróleo (CNP) in 1938, for the prospection and exploration of oil.

On the basis of material collected by different workers, between 1941 and 1962, Oliveira & Brito (1969) described new species of Turonian ammonites from Sergipe. G. Beurlen (1970) discussed the ammonite zonation of the upper Cenomanian–Coniacian and described new genera and species from Sergipe. Reyment & Tait (1972) presented a subdivision of the lower Turonian and assigned the Itaporanga beds (localities Itaporanga 1–4 of Bengtson, 1983) to the lower Cenomanian (previously referred to the upper Cenomanian by G. Beurlen, 1970) on the basis of ammonites. Reyment *et al.* (1976) reported new Cenomanian–Coniacian ammonite genera from Sergipe and compared the transgressive and regressive cycles of Nigeria and the Sergipe-Alagoas Basin. Bengtson (1979) presented an informal zonation of the Cenomanian−Coniacian based on ammonite genera, which he compared with the current planktonic foraminifer, nannofossil and palynomorph zonations.

Bengtson (1983) presented a comprehensive study of the Cenomanian–Coniacian of Sergipe and subdivided the succession into eight units based on ammonite assemblages. Moreover, he presented an annotated list of taxa described or reported from the Sergipe Basin. Subsequently, Smith & Bengtson (1991) discussed the Cretaceous echinoids from northeastern Brazil with palaeobiogeographical interpretations and provided a revised ammonite zonation. Systematic descriptions of echinoids from the Albian–Coniacian of Sergipe and re-descriptions of older collections were presented by Smith (1991).

Koutsoukos & Bengtson (1993) presented an integrated biostratigraphical scheme for the upper Aptian−Maastrichtian of Sergipe based on intercalibration of ammonite and foraminifer data. Bengtson (1995, 1996a, and 1999) further discussed the occurrences of Cretaceous ammonites in Brazil and reviewed the history of research on this group.

Systematic and/or biostratigraphical work on Cenomanian–Coniacian micro- and nannofossils has been carried out for several groups, e.g., foraminifers by Petri (1962), Koutsoukos (1989), Koutsoukos & Bengtson (1993); ostracods by Krömmelbein (1964, 1966), Viviers *et al.* (2000); nannofossils by Troelsen & Quadros (1971), Freitas (1984), Cunha (2001), Cunha & Koutsoukos (2001); palynomorphs by Müller (1966) and Regali *et al.* (1974); roveacrinids (Ferré *et al.*, in press).

Microfacies analyses with paleoenvironmental interpretations were carried out by Bandeira Júnior (1978), who also proposed a depositional model for the Riachuelo and Cotinguiba formations. Berthou & Bengtson (1988) attempted intrabsinal stratigraphical correlations of the Cenomanian–Coniacian succession based on microfacies analyses. Walter & Bengtson (1998), Walter (2000) and Walter *et al.* (in press) analyzed microfacies and the microfauna for biostratigraphical and palaeoenvironmental interpretations of the Cenomanian–Turonian transition.

Further studies of the Cenomanian–Coniacian macrofaunas of Sergipe were carried out by Holmer & Bengtson (1996), who discussed the rare occurrences of brachiopods in the Sergipe Basin. Non-inoceramid bivalves were studied by Seeling and co-authors (Seeling, 1999; Seeling & Bengtson, 1999; 2003a; Andrade & Seeling, 2000; Andrade *et al.*, 2004). In addition, the palaeobiogeography of the upper Cenomanian–lower Turonian macroinvertebrates was discussed by Seeling & Bengtson (2002).

3.2 Inoceramids

Besides the Sergipe Basin, unambiguous Turonian–Coniacian inoceramids have been described or reported from the Pernambuco-Paraíba and Potiguar basins in northeastern Brazil.

The term "Sapucari limestone" cited below corresponds to the current Cotinguiba Formation (defined by Schaller, 1970), previously also referred to as "Sapucari and Laranjeiras limestones" or "Sapucari-Laranjeiras Formation" (Bengtson, 1983, Figs 5, 14).

3.2.1 Sergipe Basin

The first record of inoceramids from Sergipe was by Hartt (1870), who reported *Inoceramus* from the laminated limestones of the "Sapucahy" quarry (locality Sapucari 1 of Bengtson, 1983).

In her monograph on the Tertiary faunas of Brazil, Maury (1925) also described new Cretaceous species, including inoceramids. Based on Hartt's (1870) specimens from Sapucari, she described *Inoceramus* (*Sergipia*) *posidonomyaformis*, sp. nov., which had been previously referred to by White (1887) as "undeterminable species of *Posidonomya*".

Subsequently, Maury (1937) described *Inoceramus labiatus* Schlotheim from Cedro (Bumburum area of Bengtson, 1983), with the two new subspecies *I. labiatus cedroensis* and *I. labiatus sergipensis*. In addition, she redescribed *I.* (*S.*) *posidonomyaformis*.

The occurrence of *I. labiatus* in the Sapucari limestone was reported by Duarte (1938), K. Beurlen (1961a, b) and Schaller (1970). K. Beurlen (1961b) also reported *I. sergipensis*, probably referring to Maury's (1937) subspecies *I. labiatus sergipensis* .

Santos (1963) described the new species *Inoceramus wanderleyi* and *I. remoratus* on the basis of specimens from near Nossa Senhora do Socorro (= locality Socorro 14 of Bengtson, 1983).

Bengtson (1983) listed the following inoceramids from his Turonian–Coniacian assemblages, determined by E.G. Kauffman:

Turonian 1 – *M.* ex gr. *submytiloides* (Seitz), *M. mytiloides* (Mantell)

Turonian 2 – *M. labiatus* (Schlotheim), *M. opalenis* (Böse), *M. mytiloides* (Mantell), *M.* aff. *hercynicus* (Petrascheck), *M. subhercynicus* Seitz, *Sergipia* spp., *I. (I.) cuvieri* Sowerby, *"Sphenoceramus"* spp.

Turonian 3 – *I.* (*I.*) *apicalis* Woods, *I. perplexus* Whitfield, *M. striatoconcentricus* (Gümbel), *Sergipia* spp.

Coniacian 1 – *M. striatoconcentricus* (Gümbel), *M. dresdensis* (Tröger), *M. fiegei* (Tröger), *M. lusatiae* (Andert), *Cremnoceramus*? *waltersdorfensis* (Andert), *C.*? *rotundatus* (Fiege), *I. winkholdioides* Andert, *Didymotis* aff. *variabilis* (Gerhardt).

Hessel (1984) and Kauffman & Bengtson (1985) discussed the abundant and diverse assemblage of inoceramids in Sergipe and the biostratigraphical importance of the group. The latter authors suggested that at least 25 Turonian and 29 lower Coniacian species and subspecies occur in the basin.

Hessel (1986) described two new species of divergently ornamented inoceramids, *Sphenoceramus mauryae* and *S. alatus* from the lower Turonian, subsequently referred by her to the new genus *Rhyssomytiloides* (Hessel, 1988).

The most detailed work on inoceramids to date is by Hessel (1988), who studied the lower Turonian succession exposed in the Votorantim quarry (= locality Retiro 26). She erected the new genus *Rhyssomytiloides* with three new species in addition to the previously described *R. mauryae* and *R. alatus* (Hessel, 1986). She also described the new species *Sergipia hartti* and redescribed some previously known species.

Seeling (1999) described six inoceramid species from the Cenomanian–Turonian boundary interval of Sergipe. More recently, Andrade *et al.* (2003a) presented a tentative inoceramid biozonation for the Cenomanian–Coniacian interval, Seeling & Bengtson (2003b) discussed the genus *Didymotis* from Sergipe, and Andrade *et al.* (2003b) interpreted the genus *Sergipia* as an early form of *Didymotis*.

3.2.2 Other basins

From the Jandaíra Formation of the Potiguar Basin (Rio Grande do Norte) Maury (1925) described *I. baixaverdensis*, and assigned it to the Turonian. The locality from where the specimens had been collected was later reassigned to the Campanian–Maastrichtian by K. Beurlen (1964, 1967a). Today the Jandaíra Formation is assigned a Turonian–Campanian age (Cassab, 2003).

K. Beurlen (1961b), in a study of the Turonian of northeastern Brazil, reported *I. labiatus* from the Beberibe and Sebastianópolis formations in the Pernambuco-Paraíba and Potiguar basins, respectively. Subsequently (K. Beurlen, 1967b), he reassigned the Beberibe Formation to the Santonian–Campanian, which remains the current dating. The Beberibe specimen (no. 1117 [*err. typ.* 117 in Seeling & Bengtson, 2002], Universidade Federal de Pernambuco) was examined by P. Bengtson, who concluded that the determination as *I. labiatus* must be considered as doubtful.

K. Beurlen (1964), in his publication on the Jandaíra limestone of the Potiguar Basin, described *I. labiatus*. One specimen (DG-CTG 717) was revised by Cassab (2003) and assigned to *Mytiloides submytiloides*.

Klein & Ferreira (1979) reported *Inoceramus* from the Itapecuru Formation (Albian–Cenomanian) of the São Luís Basin (Maranhão), based on two poorly preserved external moulds. However, Hessel (1984) interpreted these specimens as non-inoceramid bivalves.

Cassab (2003) described *M. submytiloides*, Inoceramidae sp. a and Inoceramidae sp. b from the "Turonian" of the Jandaíra Formation, Potiguar Basin.

3.3 Isotopic and geochemical studies

General geochemical analyses have been carried out by some workers (Mello *et al.*, 1989; Koutsoukos *et al.*, 1991). The hemipelagic limestone–marlstone couplets in the Turonian of Sergipe are inferred to have resulted from variations in organic carbon, mud content and carbonate productivity linked to dry–wet climatic oscillations (Koutsoukos, 1989; Koutsoukos *et al.*, 1993; Carmo, 1997; Carmo & Pratt, 1999).

Isotopic and geochemical studies based on data from the Votorantim quarry (Retiro 26) were carried out by Carmo (1997), Carmo & Pratt (1999) and Johnson *et al.* (2003). Carmo (1997) and Carmo & Pratt (1999) investigated more than 300 hemipelagic limestone–marlstone couplets (approximately 70 m) in the Votorantim quarry, using elemental and stable isotopic compositions of the carbonates. The nature of the couplets was explained by alternations of dry and wet climates, with high carbonate input during the dry intervals.

Dias *et al.* (2003) presented an isotopic analysis of the Cenomanian–Turonian boundary beds exposed in the Laranjeiras area and confirmed that the periodicity of sedimentary cycles is related to Milankovitch precessional cycles as suggested by Tupinambá *et al.* (2002).

4. Biostratigraphical background

The historical development of age assignments and biostratigraphical framework of the Cenomanian to Coniacian of Sergipe was presented by Bengtson (1983, Fig. 5). Here, the most recent integrated biostratigraphical framework for the upper Cenomanian–lower Coniacian succession (Figure 4.1), based on inoceramid assemblages and ammonite, foraminifer, nannofossil and ostracod zones, is summarized.

No continuous inoceramid zonation exists for the Cenomanian–Coniacian of Sergipe (Figure 4.1). Besides the succession of assemblages of Kauffman & Bengtson (1985) and the two lower Turonian associations of Hessel (1988), three zones were established for the uppermost Cenomanian–basal Turonian by Seeling (1999). He also discussed the difficulties in recognizing the Cenomanian–Turonian boundary on the basis of inoceramids because of their scarcity in this part of the succession. This is in sharp contrast to the higher parts of the Turonian. His zones were positioned tentatively, because at least the top of the *Inoceramus* aff. *pictus* ssp. Zone remains uncertain.

Seeling & Bengtson (2003b) discussed the occurrence of the inoceramid genus *Didymotis* in Sergipe within the global biostratigraphical framework and its correlation with the *Didymotis* event II, which is recognized in North America and Europe. They also presented a tentative correlation of the upper Turonian–lower Coniacian of Sergipe (Figure 4.1) with the sections at Pueblo (Colorado, USA) and Salzgitter-Salder (Germany). *D. costatus* (Frič) was described from the upper Turonian–lower Coniacian and the associated inoceramid assemblages were listed. Their work was based on material collected by Bengtson from several small outcrops mostly lacking precise stratigraphical positioning. The inoceramid and ammonite faunas thus, at least in part, represent mixed assemblages of varying extent.

The integrated ammonite and foraminiferal zonation of Koutsoukos & Bengtson (1993) (Figure 4.1) has been used for correlation with other fossils groups. Recent field work has allowed a refinement of this zonation. Thus, Walter *et al.* (in press) propose a subdivision of the *Vascoceras harttii*–*Pseudaspidoceras footeanum* Zone into a lower *Vascoceras harttii*–*Pseudaspidoceras footeanum* Zone and an upper *Pseudotissotia* spp. Zone (reported by Walter & Bengtson, 1998). Thus, the base of the Turonian Stage in Sergipe is currently, at least in a broad sense, indicated by the first occurrence of the ammonite *Pseudotissotia* spp. (Figure 4.1). Recently, Gale *et al.* (in press) attempted the correlation with the GSSP for the base of the Turonian at Pueblo, Colorado, integrating stable isotope measurements and ammonite data.

The nannofossil zonation of Cunha (2001) was based on the work of Burnett (1998) and was correlated with the ammonite and planktonic foramineral zones of Koutsoukos & Bengtson (1983). Ostracods and palynomorphs have not allowed a refined zonation. For the upper Cenomanian–Coniacian two ostracod zones (Figure 4.1) were proposed by Viviers *et al.* (2000), whereas only one palynomorph zone (*Gnetaceaepollenites diversus*) could be established for the Cenomanian of Sergipe (Regali *et al.*, 1974).

Stage	Substage	Inoceramid assemblages (Kauffman & Bengtson, 1985; Hessel, 1988)	Inoceramid zonation (Seeling, 1999; Seeling & Bengtson, 2003b)	Ammonite zonation (Smith & Bengtson, 1991; Koutsoukos & Bengtson, 1993)	Ammonite zonation (Walter & Bengtson, 1998; Seeling & Bengtson, 2003b)	Foraminiferal zonation (Koutsoukos & Bengtson, 1993)		Nannofossil zonation (Cunha, 2001; Cunha & Koutsoukos, 2001)	Ostracod zonation (Viviers *et al*., 2000)
						Planktonic	Benthic		
Coniacian	lower	*Didymotis* sp. *I. rotundatus* *C.? waltersdorfensis* *I. winkholdioides* *I. vancouverensis* *M. lusatiae* *M. fiegei* *M. dresdensis* *M. striatoconcentricus*	*Cremnoceramus waltersdorfensis hannovrensis*	*Solgerites armatus–Prionocycloceras lenti*	*Solgerites armatus–Prionocycloceras lenti*	*Archaeoglobigerina cretacea–Dicarinella primitiva*	*Gavelinella* sp. A–*Valvulinella* sp. A	UC-9	*Brachycythere sapucariensis*
			C. deformis erectus						
				Barroisiceras (*B.*) *onilahyense–Forresteria*					
Turonian	upper	*Sergipia* spp. *M. striatoconcentricus* *I. vancouverensis* *I. perplexus* *I. apicalis*	? ? ? *Didymotis* Event II *C. waltersdorfensis*	*Subprionocyclus–Reesidites*	? ? ? *Barroisiceras* (*B.*) *onilahyense–Forresteria*				
			Interval not studied						
					Subprionocyclus–Reesidites	*Dicarinella primitiva*	*Valvulinella* sp. B–*Gavelinella bertheleni–plummerae–reussi plexus*		
								UC-8	
	middle					*Hedbergella* (*W.*) *aprica–Hedbergella* (*W.*) *baltica*	*Gabonita levis–Nodosaria* ex gr. *obscura*		
		M. cuvieri *M. hercynicus*		*Mammites nodosoides–Kamerunoceras turoniense*	*Mammites nodosoides–Kamerunoceras turoniense*				
								UC-7	
	lower	*Sergipia* spp. *M. hercynicus* *M. latus* *M. mytiloides*							
			M. kossmati *M. mytiloides*	*Watinoceras amudariense–Kamerunoceras seitzi*	*Watinoceras amudariense–Kamerunoceras seitzi*				
			M. kossmati ? ? ?	*Vascoceras harttii–P. footeanum*	*Pseudotissotia* spp.	*Hedbergella* (*W.*) *archaeocretacea–Heterohelix reussi*	*Gabonita obesa–Gabonita levis*	UC-6–UC-5c–b?	
Cenomanian	upper	*Inoceramus pictus* *I. tenuistriatus*	*I.* aff. *pictus* ssp. ? ? ?		*Vascoceras harttii–P. footeanum*				*Rehacythereis* aff. *dentonensis*
				Euomphaloceras septemseriatum	*Euomphaloceras septemseriatum*	*Hedbergella* (*Whiteinella*) *aprica–Globigerinoides bentonensis*	*Gabonita levis–Discammina* sp. A	UC-4	

Fig. 4.1: Biostratigraphical scheme based on inoceramid assemblages and ammonite, foraminiferal, nannofossil and ostracod zones.

4.1 Stage and substage definitions

4.1.1 The Turonian Stage

According to informal but well-established usage, the Turonian Stage is best subdivided into three substages (Bengtson, 1996b). At the Second International Symposium on Cretaceous Stage–Boundaries, held in Brussels in 1995, the Turonian Working Group of the Subcommission on Cretaceous Stratigraphy proposed the Global boundary Stratotype Section and Point (GSSP) for the base of the Turonian Stage at the base of Bed 86 in the Rock Canyon Anticline section, west of Pueblo, Colorado, USA, coincident with the first occurrence (FO) of the ammonite *Watinoceras devonense* Wright & Kennedy, 1981. The GSSP for the base of the Turonian was ratified in 2003 by the International Commission on Stratigraphy (ICS) (Gradstein *et al*., 2005). For the base of the middle Turonian substage, the base of Bed 120 in the same section, coincident with the FO of the ammonite *Collignoniceras woollgari* (Mantell, 1822), was proposed as a potential GSSP (Kennedy *et al*., 2000), but has not been ratified yet.

For the base of the upper Turonian, the Lengerich section in the Münster Basin in northern Germany is a potential candidate GSSP (Wiese & Kaplan, 2001). However, because of remaining problems with the ammonite and inoceramid biostratigraphy, the authors emphasized the need for additional research. The FO of *Inoceramus perplexus* is a potencial marker for the base of the upper Turonian (Walaszczyk & Cobban, 2000a).

4.1.2 The Turonian–Coniacian boundary

At the Second International Symposium on Cretaceous Stage Boundaries, Brussels, 1995, The Coniacian Working Group of the Subcommission on Cretaceous Stratigraphy proposed the FO of *Cremnoceramus rotundatus* (*sensu* Tröger, 1967 *non* Fiege, 1930) as the criterion for the base of the Coniacian (Kauffman *et al*., 1996). This species was discussed by Walaszczyk & Cobban (2000a) and considered a junior synonym of *Cremnoceramus deformis erectus* (Meek, 1877). The candidate GSSP for the base of the Coniacian is the base of Bed MK47 in the Salzgitter-Salder Quarry, southwest of Hannover, Lower Saxony, northern Germany, which coincides with the FO of *C. deformis erectus* (Kauffman *et al*., 1996; Walaszczyk & Wood, 1999).

5. Material and methods

5.1 Study area and maps

This work comprises a detailed study of the Turonian succession exposed in the Votorantim (locality Retiro 26) and Nassau (locality Mata 11) quarries in the Laranjeiras and Nossa Senhora do Socorro areas, Sergipe (Figures 1.2 and 6.1). In addition, the localities Muçuca 5, Sapucari 1, Cajaíba 8 and Socorro 11 of Bengtson (1983) were sampled for reference purposes.

For the field work 1:25,000 topographical maps were used: Mapa topográfico, Serviços Aerofotogramétricos Cruzeiro do Sul S.A.: Bacia de Sergipe-Alagoas (unpublished, used with permission of Petrobras S.A., Rio de Janeiro), sheets 722-1-2 and 635-4-3 (1966). The 1:100,000 topographical map published by SUDENE (1974), sheet SC.24-Z-B-IV Aracaju was also used. Additional localities mentioned herein were described and plotted on a 1:100,000 map by Bengtson (1983, Appendices 1 and 3). The geological map sheets cited in the locality descriptions below are 1:50,000 (Richter & Simões, 1975).

5.2 Field work

The field work was carried out during eight months, from October 2001 to January 2002, December 2002 to March 2003 and in May 2004. These three field seasons made it possible to follow the progressive expansion of the quarries, to expand the collection of fossils and to allow a more comprehensive view of the stratigraphical evolution of the sedimentary succession.

During the first field season the two sections, Retiro 26 (Votorantim quarry) and Mata 11 (Nassau quarry), were measured and sampled biostratigraphically. The second and third field seasons provided opportunities to refine the measurements of the sections with sedimentological and structural observations and to carry out complementary biostratigraphical sampling. Selected localities of Bengtson (1983) were also investigated during the three field seasons. During the third field season the type locality of "*Inoceramus* (*Sergipia*) *posidonomyaformis*", Sapucari 1, was sampled in order to obtain additional material for a re-evaluation of the genus *Sergipia*.

In the Votorantim and Nassau quarries, weathering, at least in the upper part of the sections, was considerably more intensive in the last field season than in the previous ones. In general, weathering changes the original colour of the limestone from grey to cream-yellowish colour.

Biostratigraphical sampling of macrofossils was carried out bed-by-bed. In general, macrofossils are scarce, demanding persistent work. The field work concentrated on the larger

Votorantim quarry, mainly owing to facility of access. This resulted in a more extensive and diverse collection. The relative abundance, mode of occurrence and preservation of the macrofossils were recorded. Most specimens are preserved as internal moulds, and many of them are incomplete and poorly preserved. Inoceramids are mainly preserved as single valves.

Lithologic samples were taken for microfacies analyses to recognise previously established microfacies types for the Turonian interval (Berthou & Bengtson, 1988; Walter, 2000). In addition, selected horizons of the Retiro 26 section were sampled for palynofacies analyses (Jäger & Andrade, 2005) in order to study palaeoenvironmental conditions during the short-lived occurrence of the inoceramid genus *Rhyssomytiloides*.

5.3 Fossil material and methods of study

1070 macrofossil specimens were colleted for palaeontological and biostratigraphical purposes, among which 595 inoceramid bivalves, 160 ammonites, 122 other (non-inoceramid) bivalves, 29 gastropods, 98 echinoids and 66 specimens of other associated fossil groups (including fish remains, crustaceans, bryozoans and plant remains) were identified. The fossil material was shipped to the University of Heidelberg for study with authorization of the Departamento Nacional da Produção Mineral (DNPM), Rio de Janeiro, and will be deposited in a Brazilian institution, according to current legislation.

Preparation of the macrofossils was done using conventional mechanical methods, with hammers, chisels and needles. The inoceramids and other fossils with thin shells and/or delicate ornamentation required particularly careful and time-consuming preparation.

The macrofossils were identified as closely as possible and the inoceramids described taxonomically to provide a basis for a detailed biostratigraphic zonation of the succession. Taxonomic procedures are described in Chapter 8 “Systematic palaeontology”. The inoceramids previously studied by Hessel (1988) were revised on the basis of the original material loaned from the Palaeontological Museum of Uppsala University.

The systematic study of the inoceramids also included comparisons with the material collected by P. and S. Bengtson and studied by Kauffman & Bengtson (1985) from several localities, e.g., Cajaíba, Estiva, Mata, Muçuca, Retiro, Ribeira, São Roque, Oiteiro, Socorro and Sapucari of Bengtson (1983). Furthermore, specimens described by Maury (1925), Hessel (only types, 1986, 1988) and Santos (1969), housed at the Departamento Nacional da Produção Mineral (DNPM), Rio de Janeiro, Brazil, were studied on the basis of plaster casts and photographs.

The Sergipe inoceramids were compared with material housed in European museums, primarily the collections of K.-A. Tröger, in the TU Bergakademie Freiberg, of H. B. Geinitz, in the Staatliches Museum für Mineralogie und Geologie Dresden, and of F. A. Roemer, in the Paläontologisches Institut of Bonn University.

6. Sections studied

The sections studied in the Votorantim (Retiro 26) and Nassau (Mata 11) quarries are shown in Figure 6.1. The locality Retiro 26 was described by Hessel (1988) and today includes nine localities of Bengtson (1983) and one of Hessel (1988), as discussed below. Mata 11 was recently described by Seeling (2004) and includes two localities of Bengtson.

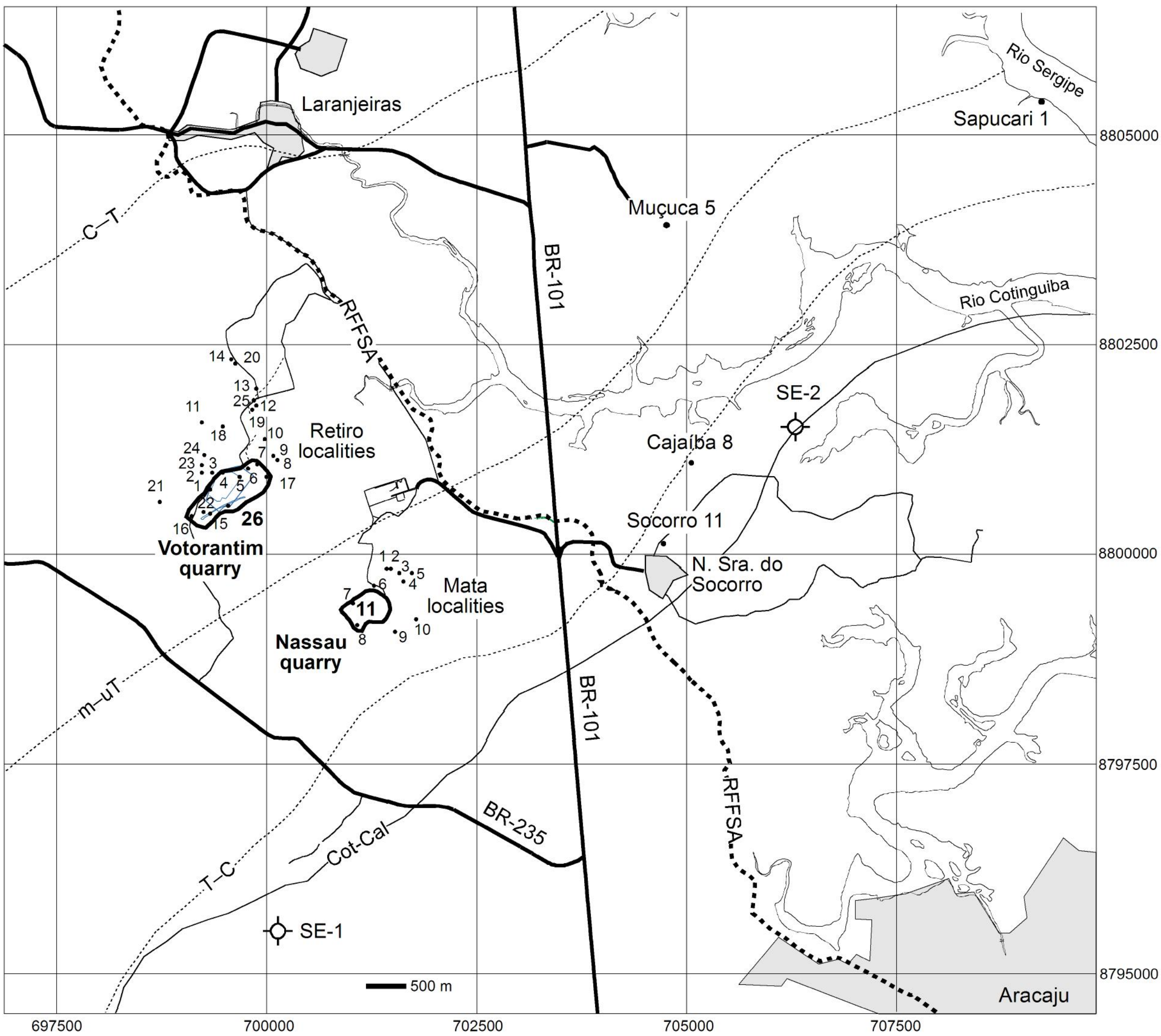


Figure 6.1: Location of the Votorantim (Retiro 26) and Nassau (Mata 11) quarries with adjacent localities of Bengtson (1983) and Hessel (1988). Additional localities sampled in the Muçuca, Sapucari, Cajaíba and N. Sra. do Socorro areas and the two wells SE-1 and SE-2 in the area are indicated. Abreviations: C–T = Cenomanian–Turonian boundary; m–uT = middle–upper Turonian boundary; T–C = inferred Turonian–Coniacian boundary; Cot-Cal = boundary between the Cotinguiba and Calumbi formations.

Geographical coordinates are given according to the international Universal Transverse Mercator (UTM) system. Starting points are 10 Mm S of the Equator, and 0.5 Mm W of meridian 39° of Greenwich, respectively. The localities are described using the system introduced by Bengtson (1983). The rocks exposed are assigned to the Sapucari Member of the Cotinguiba Formation.

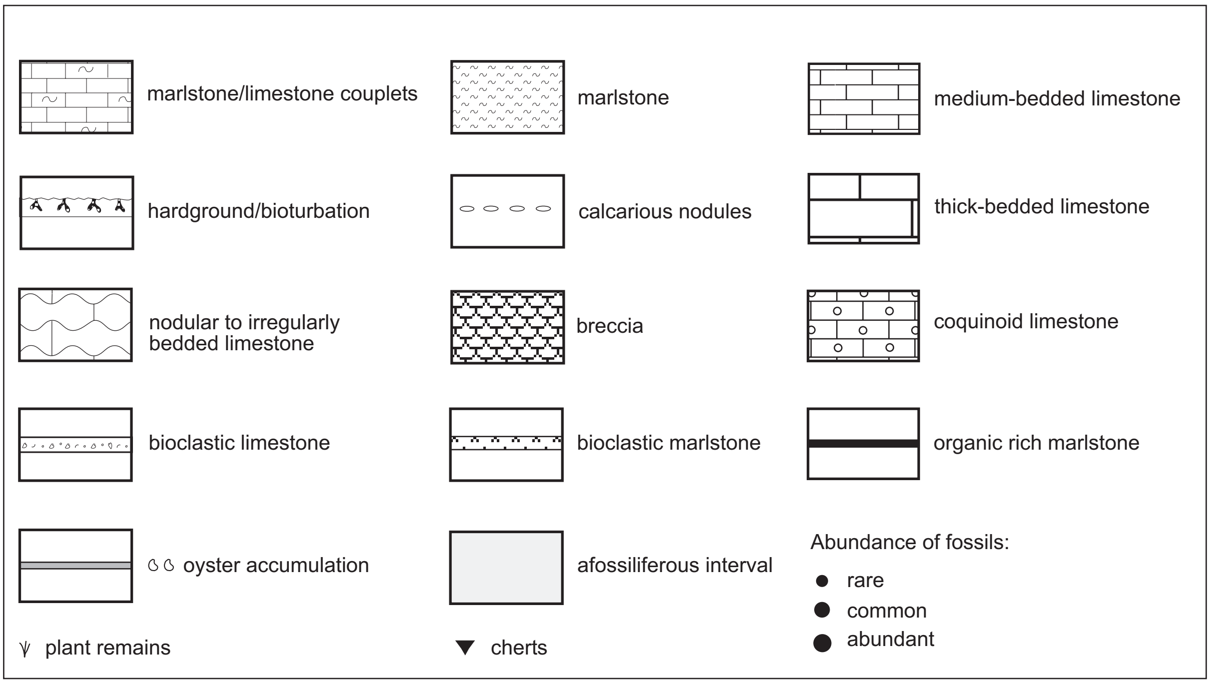


Figure 6.2: Legend to the signatures and different lithologies used in the section descriptions.

6.1 Retiro 26 section (Votorantim quarry)

6.1.1 Retiro 26: UTM 8 800 900N/699 550E; UTM 8 800 450N/699 200E; UTM 8 800 450N/699 300E; UTM 8 800 820N/700 050E; UTM 8 801 060N/700 100E.

Topographical map sheet: SC.24-Z-B-IV Aracaju. Geological map sheet: SC.24-Z-B-IV-4 Aracaju. Altitude ca. 10–40 m.

The Votorantim quarry, located 17 km northwest of Aracaju (Figure 6.1), is operated by the Cimento Sergipe S.A. (Votorantim Group). It was named Retiro 26 by Hessel (1988). The quarry (Figure 6.3) has an extension of 800 m in SW–NE direction and measures 150 to 350 m across. It has been much expanded in recent years and now includes localities Retiro 1, 4, 5, 6, 7, 15, 16 and 17 of Bengtson and Retiro 22 of Hessel (Figure 6.1). The section studied by Hessel is still exposed in the quarry.

The quarry exposes a ca. 110 m thick section. The dip of the beds varies from 12 to 18° SE/S. The lithological succession, biozonations and distribution of the macrofossils are presented in Figure 6.4. The section contains the most complete succession of lower–middle Turonian rocks exposed in Sergipe, with a highly diverse fauna of inoceramids and ammonites. In general, the fauna is dominated by inoceramids.

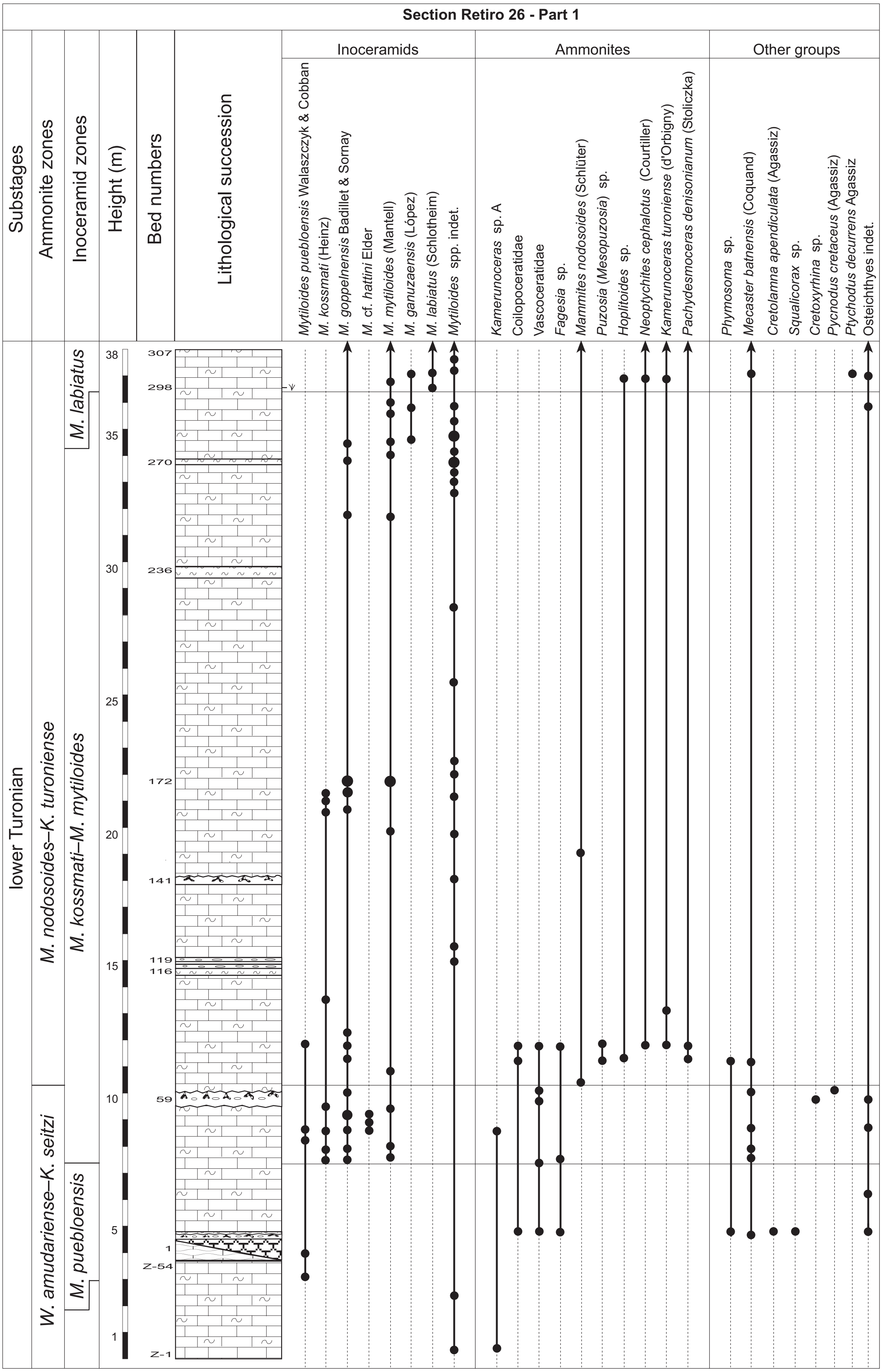
Figure 6.3: Panoramic view of part of the Votorantim (Retiro 26) quarry (counter clockwise: A–D).

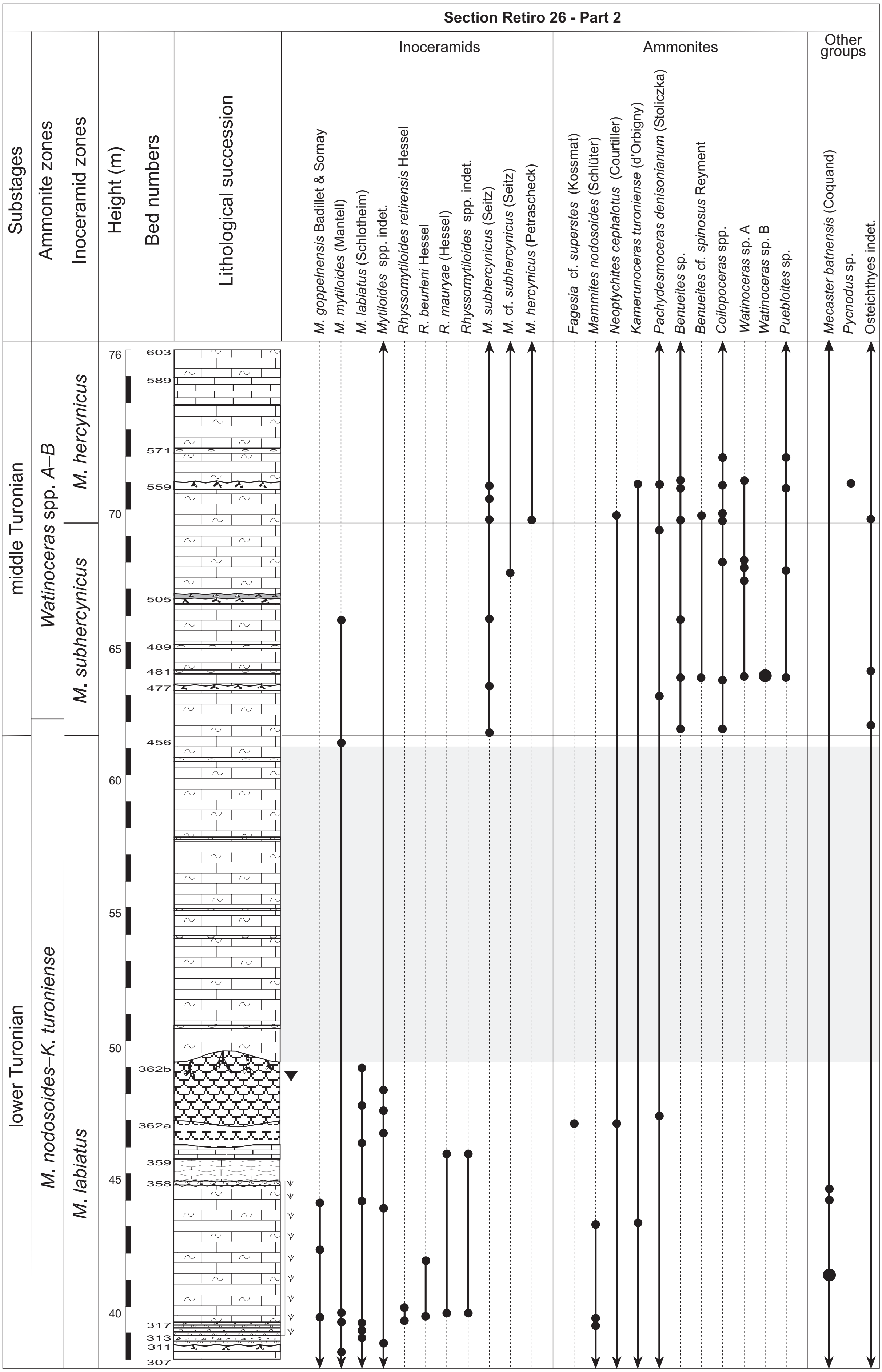
Lithologically, the section is characterized mainly by alternations of marlstones and lime mudstones, with subordinate carbonate breccias. These rhythmic deposits were referred to by Carmo (1997) as hemipelagic marlstone–limestone couplets. Fresh limestones are light grey, and the marlstones dark grey. Weathered beds vary from cream to yellow. Sedimentological analyses of these couplets, carried out by Carmo (1997), showed that the marlstones and limestones are fine-grained, with the siliciclastic fraction of the marlstones composed dominantly of clay-size material, but trace amounts of angular silt-sized quartz and feldspar can also be recognised. The principal non-carbonate constituents are organic matter (including plant remains), quartz, feldspar, clay and framboidal pyrite. However, no quantitative component analysis of the marlstone has been carried out; therefore, the term marlstone is used here *sensu lato*. The thickness of the beds is highly variable, from 3 to 40 cm (10 cm average). Normally, the limestone beds are thicker than the marlstones.

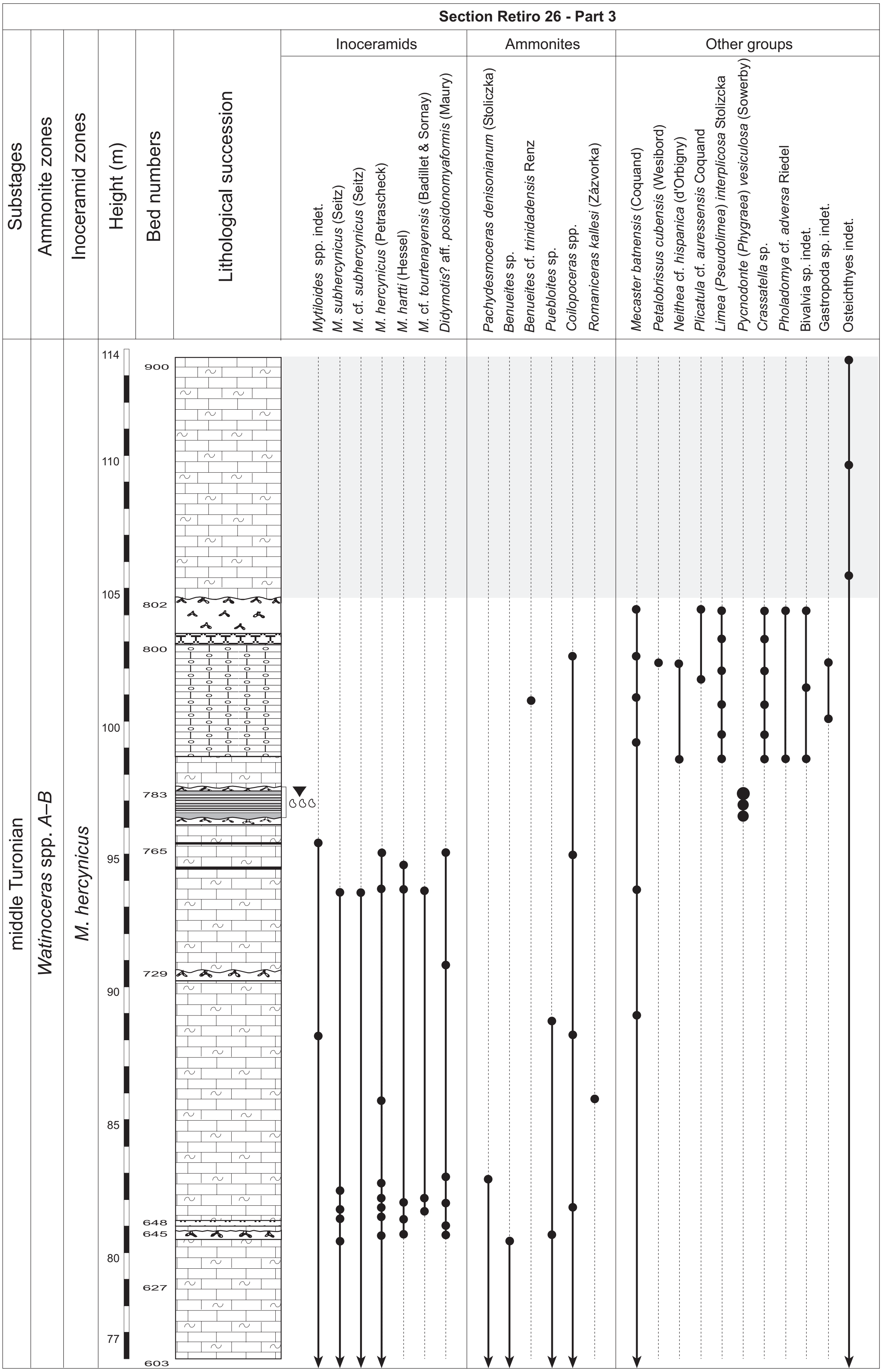
The section (Figure 6.4a) starts with a succession of marlstone and limestone beds (beds Z1–Z54 = 3.7 m) followed by a nodular bed that becomes gradually brecciated (bed 1). The top of bed 1 (Figures 6.4a, 6.5a, b) is marked by an intensely bioturbated erosional surface, with phosphate nodules, and a marlstone bed rich in fossils (ammonites, crustacean fragments and fish remains). Bed 1 is followed by a marlstone–limestone succession with hardgrounds, for example beds 59 and 141, which are bioturbated with ichnofossils of *Thallassinoides* type. Between beds 36 and 80 (7.5 and 12.0 m) the macrofossils are more abundant and diversified.

Above bed 250 (ca. 32 m) in the section, inoceramids become abundant. There are accumulations of inoceramid shell fragments and an increase in inoceramid abundance and diversity, followed by occurrences of ammonites, fish remains and crustaceans. The inoceramids are more concentrated in some marlstone beds, which also contain abundant shell fragments.

Figure 6.4 (a–c) (following pages): Lithological sucession in the Retiro 26 section (Votorantim quarry), with biozonation and stratigraphical distribution of the macrofossils.


Section Retiro 26 - Part 1
Substages
Ammonite zones
Inoceramid zones
Height (m)
Bed numbers
Lithological succession
Inoceramids
Mytiloides puebloensis Walaszczyk & Cobban
M. kossmati (Heinz)
M. goppelnensis Badillet & Sornay
M. cf. hattini Elder
M. mytiloides (Mantell)
M. ganuzaensis (López)
M. labiatus (Schlotheim)
Mytiloides spp. indet.
Ammonites
Kamerunoceras sp. A
Coilopoceratidae
Vascoceratidae
Fagesia sp.
Mammites nodosoides (Schlüter)
Puzosia (Mesopuzosia) sp.
Hoplitoides sp.
Neoptychites cephalotus (Courtiller)
Kamerunoceras turoniense (d'Orbigny)
Pachydesmoceras denisonianum (Stoliczka)
Other groups
Phymosoma sp.
Mecaster batnensis (Coquand)
Cretolamna apendiculata (Agassiz)
Squalicorax sp.
Cretoxyrhina sp.
Pycnodus cretaceus (Agassiz)
Ptychodus decurrens Agassiz
Osteichthyes indet.
lower Turonian
W. amudariense–K. seitzi
M. nodosoides–K. turoniense
M. puebloensis
M. kossmati–M. mytiloides
M. labiatus
1
5
10
15
20
25
30
35
38
Z-1
Z-54
1
59
116
119
141
172
236
270
298
307


Section Retiro 26 - Part 2
Substages
Ammonite zones
Inoceramid zones
Height (m)
Bed numbers
Lithological succession
Inoceramids
Ammonites
Other groups
M. goppelnensis Badillet & Sornay
M. mytiloides (Mantell)
M. labiatus (Schlotheim)
Mytiloides spp. indet.
Rhyssomytiloides retirensis Hessel
R. beurleni Hessel
R. mauryae (Hessel)
Rhyssomytiloides spp. indet.
M. subhercynicus (Seitz)
M. cf. subhercynicus (Seitz)
M. hercynicus (Petrascheck)
Fagesia cf. superstes (Kossmat)
Mammites nodosoides (Schlüter)
Neoptychites cephalotus (Courtiller)
Kamerunoceras turoniense (d'Orbigny)
Pachydesmoceras denisonianum (Stoliczka)
Benueites sp.
Benueites cf. spinosus Reyment
Coilopoceras spp.
Watinoceras sp. A
Watinoceras sp. B
Puebloites sp.
Mecaster batnensis (Coquand)
Pycnodus sp.
Osteichthyes indet.
middle Turonian
lower Turonian
Watinoceras spp. A–B
M. nodosoides–K. turoniense
M. hercynicus
M. subhercynicus
M. labiatus
76
70
65
60
55
50
45
40
603
589
571
559
505
489
481
477
456
362b
362a
359
358
317
313
311
307


Section Retiro 26 - Part 3
Substages
Ammonite zones
Inoceramid zones
Height (m)
Bed numbers
Lithological succession
Inoceramids
Ammonites
Other groups
Mytiloides spp. indet.
M. subhercynicus (Seitz)
M. cf. *subhercynicus* (Seitz)
M. hercynicus (Petrascheck)
M. hartti (Hessel)
M. cf. *tourtenayensis* (Badillet & Sornay)
Didymotis? aff. *posidonomyaformis* (Maury)
Pachydesmoceras denisonianum (Stoliczka)
Benueites sp.
Benueites cf. *trinidadensis* Renz
Puebloites sp.
Coilopoceras spp.
Romaniceras kallesi (Zázvorka)
Mecaster batnensis (Coquand)
Petalobrissus cubensis (Wesibord)
Neithea cf. *hispanica* (d'Orbigny)
Plicatula cf. *auressensis* Coquand
Limea (Pseudolimea) interplicosa Stolizcka
Pycnodonte (Phygraea) vesiculosa (Sowerby)
Crassatella sp.
Pholadomya cf. *adversa* Riedel
Bivalvia sp. indet.
Gastropoda sp. indet.
Osteichthyes indet.
middle Turonian
Watinoceras spp. *A–B*
M. hercynicus
114
110
105
100
95
90
85
80
77
900
802
800
783
765
729
648
645
627
603

Above an erosional surface (bed 311), a significant lithofacies change is observed (Figure 6.4b). The lime mudstones change to bioclastic limestones (wackestone) (Figure 6.5d) and are intercalated with marlstones rich in plant remains (Figure 6.5e). The bioclastic limestones occur in a short interval of three beds and grade upwards again into lime mudstones. The occurrence of plant remains in the marlstones coincides with the appearance of the inoceramid genus *Rhyssomytiloides*. The macrofauna in this part of the section (beds 313 to 359) is dominated by inoceramids, which are abundant and diversified. Ammonites are also well represented. Some limestones contain vugs partially filled with calcite crystals. A few limestone beds contain recrystallized, poorly preserved echinoids, as well as specimens of *Rhyssomytiloides*. Overlying these beds there is a nodular to massive limestone (bed 359), followed by a carbonate breccia (Figure 6.5f). This breccia varies in thickness from 1.0 to over 4.5 m and contains poorly sorted clasts (Figure 6.6a). The upper part of the breccia (bed 362) is intensively bioturbated and contains phosphate and chert nodules. The breccias are interpreted as *slumps* caused by the reactivation of small-scale faults (Koutsoukos, 1989; Koutsoukos *et al.*, 1993). Signs of tectonic activity in the form of small fractures are recognized in some limestone beds below the breccias.

Overlying the breccias there is a succession of dark grey, finely stratified marlstone–limestone couplets (ca. 10 m). Some beds contain light to dark grey chert lenses. No macrofossils were found in this interval (see shaded interval in Figure 6.4b).

Above bed 456 the marlstone–limestone couplets contain inoceramids, ammonites and fish remains. In bed 479 an accumulation of abundant small ammonites is observed. Above this, the section is characterized by marlstone–limestone couplets with some intensely bioturbated hardgrounds, for example beds 505 and 559. Bed 505 shows two successive bioturbation phases (Figure 6.6b). Bed 559 is strongly bioturbated (Figures 6.6c, d) with burrows filled with bioclastic calcarenite (Figure 6.6c), which overlies the hardground. The fauna becomes more dominated by ammonites and inoceramids upward in the section up to bed 765. Between beds 645 and 765, inoceramids are more abundant and diversified than ammonites.

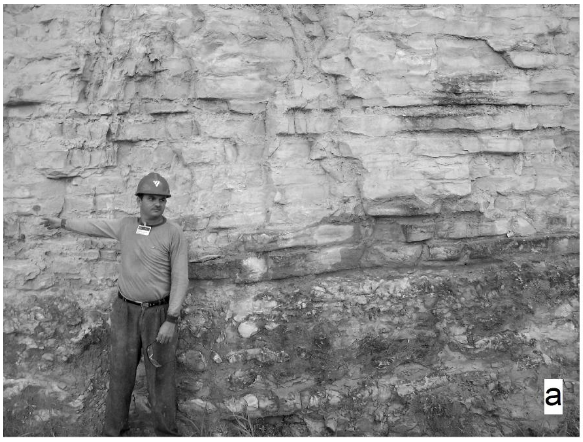
Besides hardgrounds, a number of local faults, bed truncations and erosional surfaces (Figures 6.7a, b, d) are observed in the upper part of the section. The erosional surfaces in this upper part of the section locally cut underlying beds; an example where the beds underlying an oyster bed are truncated is shown in Figure 6.7b.

A comparison of the section today with that studied by Hessel (1988) reveals that a number of beds were missing from her section, for example, an interval between her beds D and E and also the conspicuous oyster accumulations were not represented. At that time the quarry had a smaller extension, and she could not follow the vertical variations laterally, as is possible today.

Enclosing bed 765 are two dark marlstone beds rich in organic matter (Figures 6.4c, 6.7b). Overlying an erosional surface there is a succession of beds containing accumulations of the oyster *Pycnodonte* (*Phygraea*) *vesiculosa* (Sowerby) (Figures 6.4c, 6.7b). This succession varies from 1.1 to 3.5 m in thickness. Locally, near the top of the oyster beds, black chert nodules (Figure 6.7c) are recorded. Overlying a new erosional surface, there is a set of marlstone–limestone couplets, followed by a thick bed (800), consisting of cream, intensely weathered bioturbated bioclastic limestone (wackestone to packstone), with abundant non-inoceramid bivalves, ammonites, echinoids and rare gastropod fragments. *Thalassinoides* burrows are very common. This coquinoid limestone of the bed 800 grades upwards into a brecciated (bed 801) and bioturbated limestone (bed 802). The brecciated bed (Figure 6.6f) also contains bioclasts (mainly bivalves), which suggests an origin in shallower waters. Bed 800 (Figures 6.4c, 6.6e) has a variable thickness; in some parts of the section it is almost eroded away, reduced to ca. 30 cm thickness (Figure 6.7d). This bed is overlain (with an irregular contact) by nearly 9 m of weathered marlstone–limestone couplets (Figure 6.7g), devoid of macrofossils, except fish remains (see shaded interval in Figure 6.4c).

Microfacies. The Retiro 26 section includes two microfacies types proposed by Berthou & Bengtson (1988): L Tur A and L Tur B. Type L Tur B is dominant throughout the section and consists of lime mudstones, and subordinately lime wackestones, with rare macrofaunal debris. Calcispheres are common and more abundant. Foraminifera heterohelicids are less common, hedbergellids and radiolarians occur sparsely. Some samples are silicified. Type L Tur A consists of variably bioclastic lime wackestones with macrofossil remains (bivalves and echinoids). Calcispheres are common; heterohelicids, buliminids, discorbids and hedbergellids are rare. This type occurs at some levels between beds 313 and 362, and in the upper part of the section, in the coquinoid limestones (bed 800).

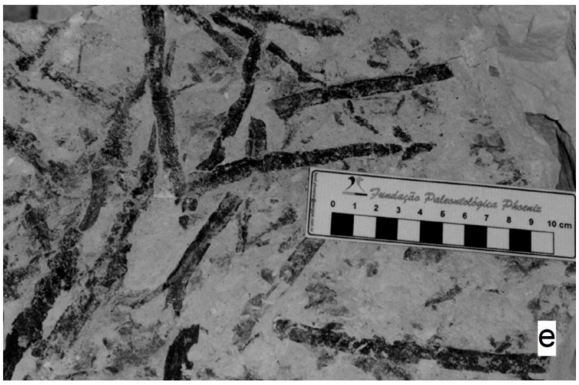
Figure 6.5 (following page): Retiro 26 section; **a**: Beds 1 to 30; **b**: Irregular contact between brecciated limestones (bed 1) and bioclastic marlstones (bed 2); **c**: Marlstone–limestone couplets above bed 185; **d**: Bioclastic limestone of bed 313; **e**: Marlstone bed with plants remains; **f**: Breccia block (bed 362) overlain by finely stratified marlstone–limestone couplets.


a


c


b


d


Fundação Paleontológica Phoenix
0 1 2 3 4 5 6 7 8 9 10 cm
e


1 m
f

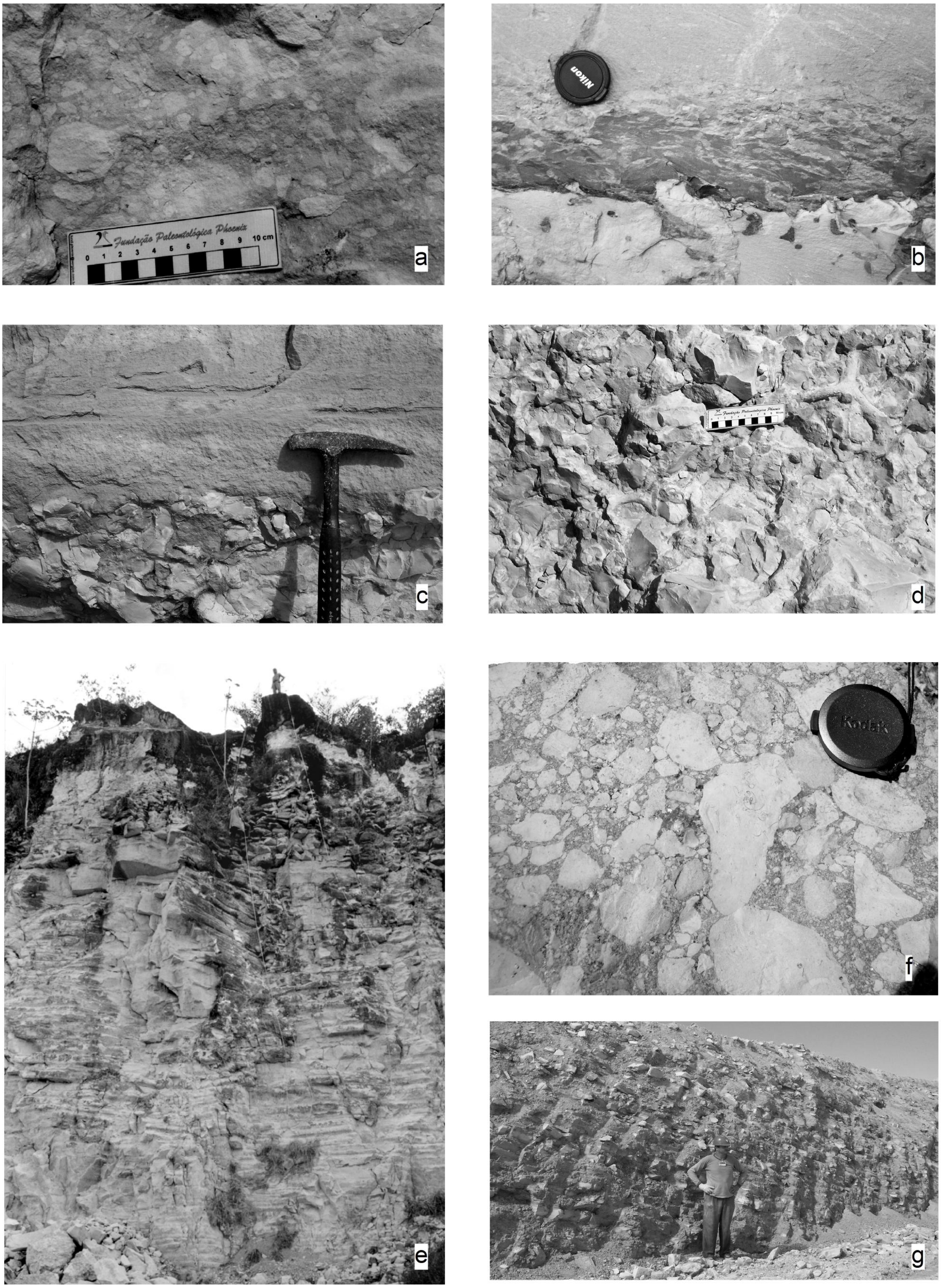


Figure 6.6: Retiro 26 section; **a**: Macroscopic detail of breccia of bed 362 with poorly sorted clasts; **b**: Hardground of bed 505; **c**: Hardground of bed 559 overlain by bioclastic calcarenite; **d**: Surface view of hardground of bed 559 with *Thalassionoides* burrows; **e**: Upper part of the section below bed 800; **f**: Brecciated limestones of bed 801; **g**: Marlstone–limestone couplets above bed 803.

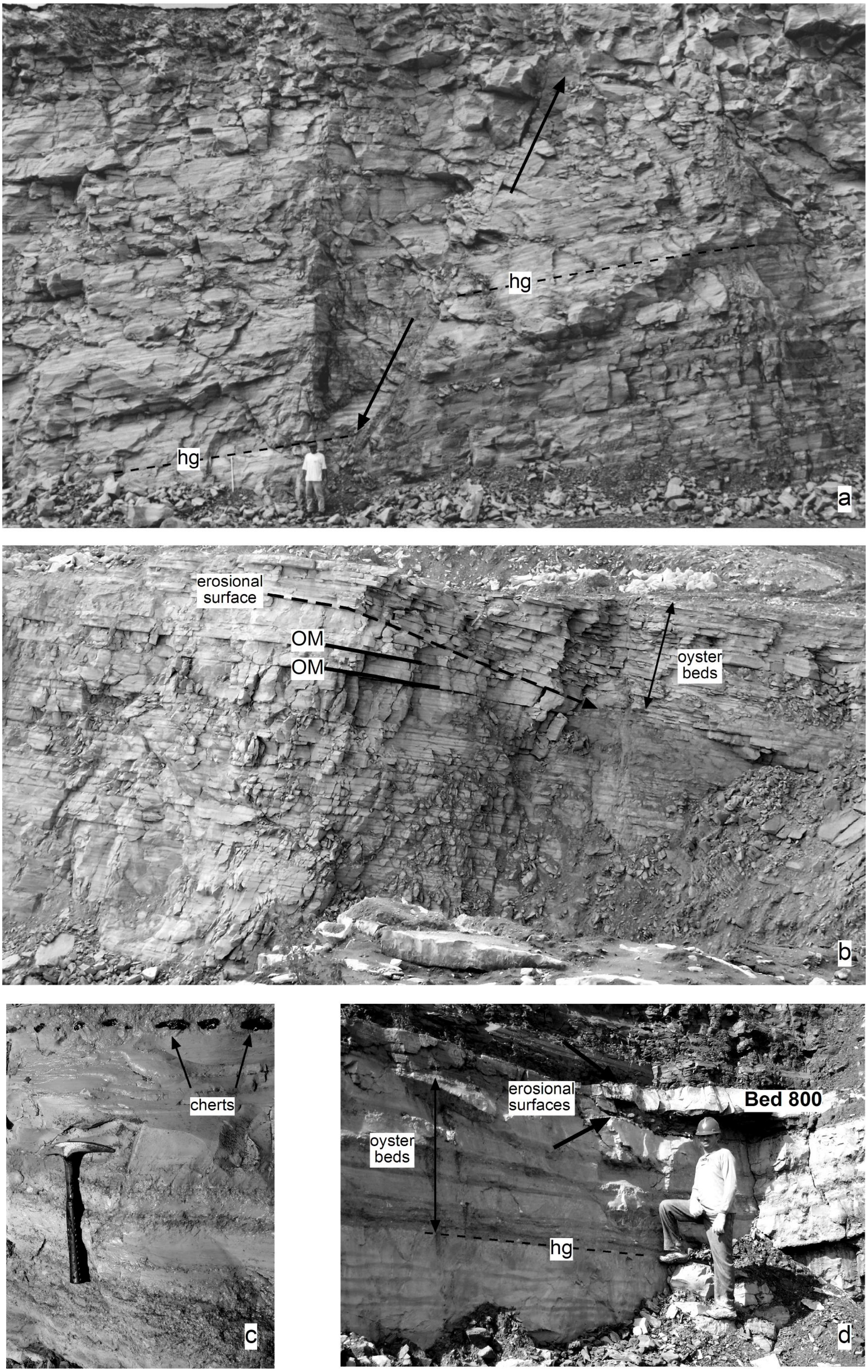


Figure 6.7: Retiro 26 section; **a**: Fault located in the upper part of the section (hg = hardground); **b**: Uppermost part of the section with marlstone beds rich in organic matter (OM), erosional surface and succession of oyster accumulation beds; **c**: chert nodules above oyster accumulation beds; **d**: erosional sufaces at the oyster accumulation beds and above bed 800.

6.2 Mata 11 section (Nassau quarry)

6.2.1. Mata 11: UTM 8.799.600N/701.300E, 8799.450N/701.350E, 8.799.350N/701.500, 8.799.400N/701.000E. Topographical map sheet: SC.24-Z-B-IV Aracaju. Geological map sheet: SC.24-Z-B-IV-4 Aracaju. Altitude ca. 25–35 m.

The quarry, located ca. 3 km southeast of the Votorantim quarry (Figure 6.1), is operated by Cimento Nassau S.A. The quarry (Figure 6.8) exposes a section with a total thickness of ca. 100 m. Its long axis SW–NE reaches ca. 400 m. The Mata 11 section today includes localities Mata 7 and 8 of Bengtson (1983).

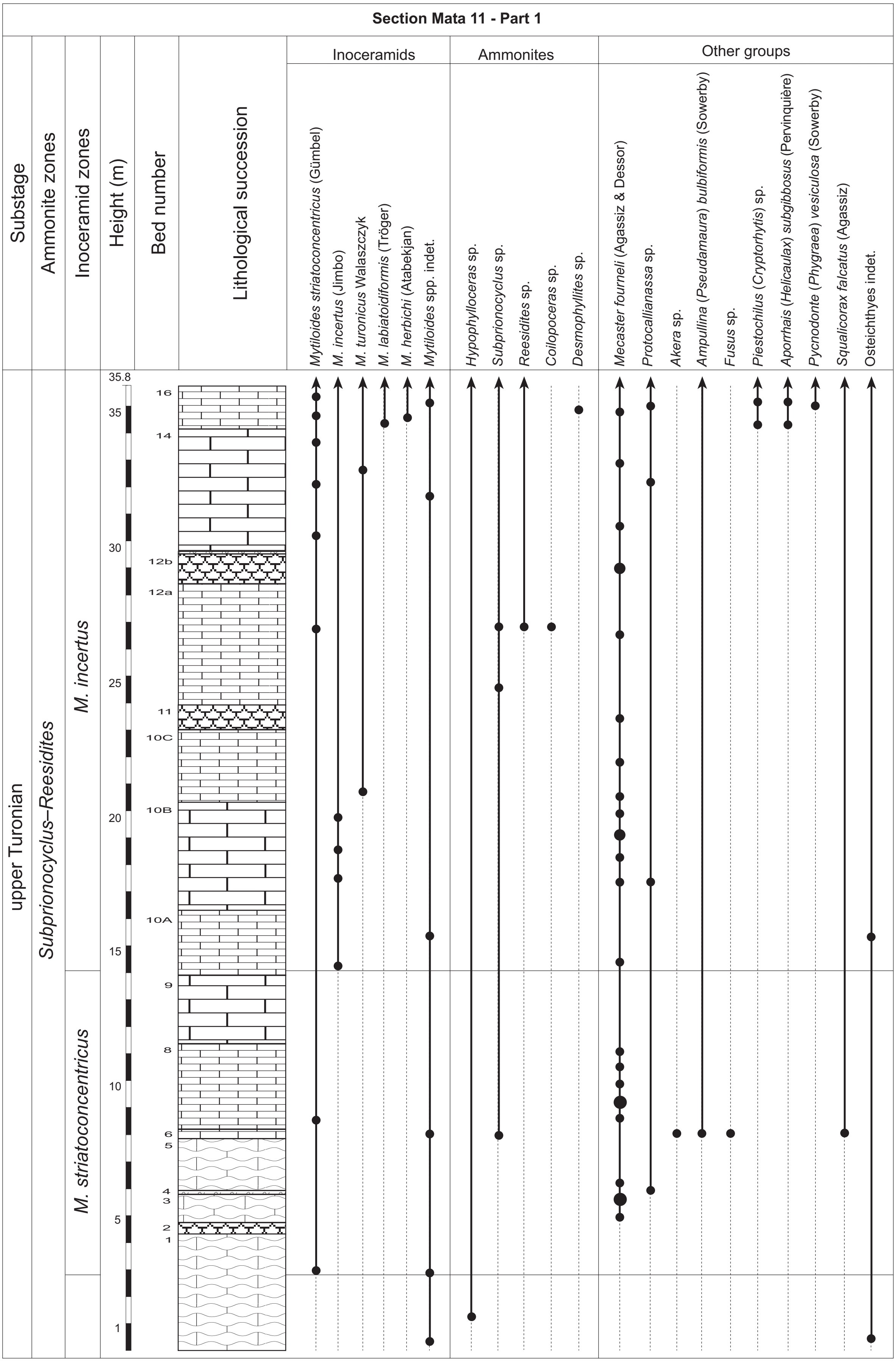
The lower and upper parts of the quarry are deeply weathered. The lithological succession consists of limestones varying from massive to stratified lime mudstones, wackestones and packstones. The dip of the beds varies between 13 and 15° SE/S.

The lithological succession, biozonations and the stratigraphical distribution of the macrofossils are presented in Figure 6.9. The section exposes an upper Turonian succession with a diverse fauna of inoceramids and other bivalves, ammonites and gastropods. Echinoids are very abundant, although monospecific. In general, the fauna is dominated by bivalves and echinoids.

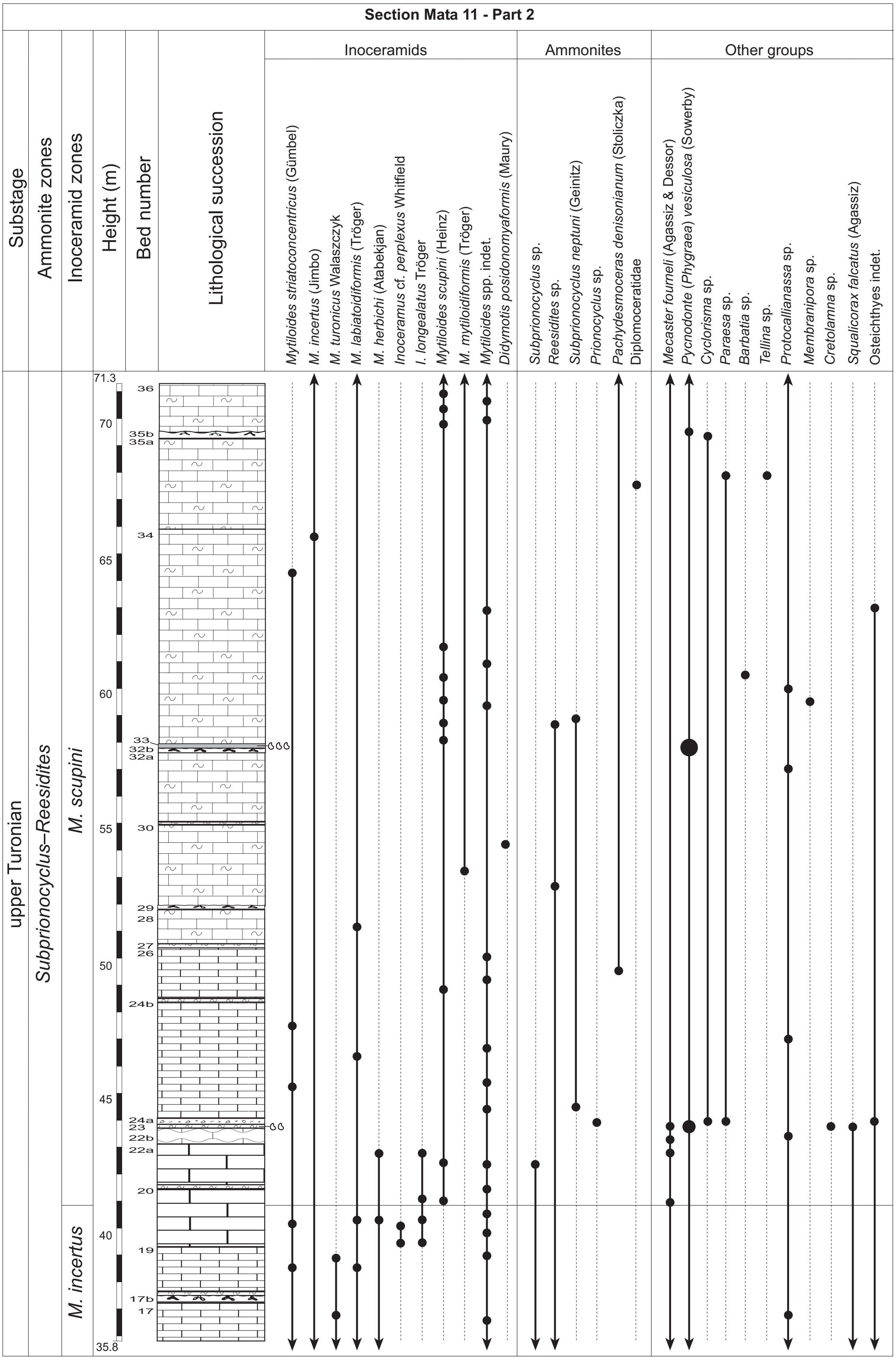
The base the section (Figure 6.9a) comprises a deeply weathered, nodular to massive limestone which grades upwards into a brecciated bed. The fossils are rare and poorly preserved, with inoceramid and ammonite fragments and fish remains. Above bed 2, the nodular limestones are strongly bioturbated, with abundant echinoids, and intercalated with a few marlstone beds. Above 8 m (between beds 6 and 12) the limestones grade into medium- (10–30 cm) to thick-bedded (30–50 cm). The fauna is more diverse with abundant echinoids, rare inoceramids and ammonites, gastropods, crustaceans and fish remains.

Beds 11 and 12b are nodular to brecciated and contain echinoids. Above these beds, follow the thickly to medium stratified beds 14 to 16. By bed 16 the inoceramid fauna becomes more diverse, associated with gastropods and rare ammonites. From bed 17 to 22 (Figure 6.9b) the limestones grade from medium- to thick-bedded. At the top of bed 22 the limestone becomes nodular (22b) and is overlain by a marlstone (bed 23). This marlstone contains abundant isolated and fragmented shells of the oyster *Pycnodonte* (*P.*) *vesiculosa*, echinoids, fish remains, inoceramid shell fragments, crustaceans and fine-grained bioclasts.

Figure 6.8: Panoramic view of part of the Nassau (Mata 11) quarry (clockwise: A–C).



Section Mata 11 - Part 1


Section Mata 11 - Part 2
Substage
Ammonite zones
Inoceramid zones
Height (m)
Bed number
Lithological succession
Inoceramids
Mytiloides striatoconcentricus (Gümbel)
M. incertus (Jimbo)
M. turonicus Walaszczyk
M. labiatoidiformis (Tröger)
M. herbichi (Atabekjan)
Inoceramus cf. perplexus Whitfield
I. longealatus Tröger
Mytiloides scupini (Heinz)
M. mytiloidiformis (Tröger)
Mytiloides spp. indet.
Didymotis posidonomyaformis (Maury)
Ammonites
Subprionocyclus sp.
Reesidites sp.
Subprionocyclus neptuni (Geinitz)
Prionocyclus sp.
Pachydesmoceras denisonianum (Stoliczka)
Diplomoceratidae
Other groups
Mecaster fourneli (Agassiz & Dessor)
Pycnodonte (Phygraea) vesiculosa (Sowerby)
Cyclorisma sp.
Paraesa sp.
Barbatia sp.
Tellina sp.
Protocallianassa sp.
Membranipora sp.
Cretolamna sp.
Squalicorax falcatus (Agassiz)
Osteichthyes indet.
upper Turonian
Subprionocyclus–Reesidites
M. scupini
M. incertus
71.3
70
65
60
55
50
45
40
35.8
36
35b
35a
34
33
32b
32a
30
29
28
27
26
24b
24a
23
22b
22a
20
19
17b
17

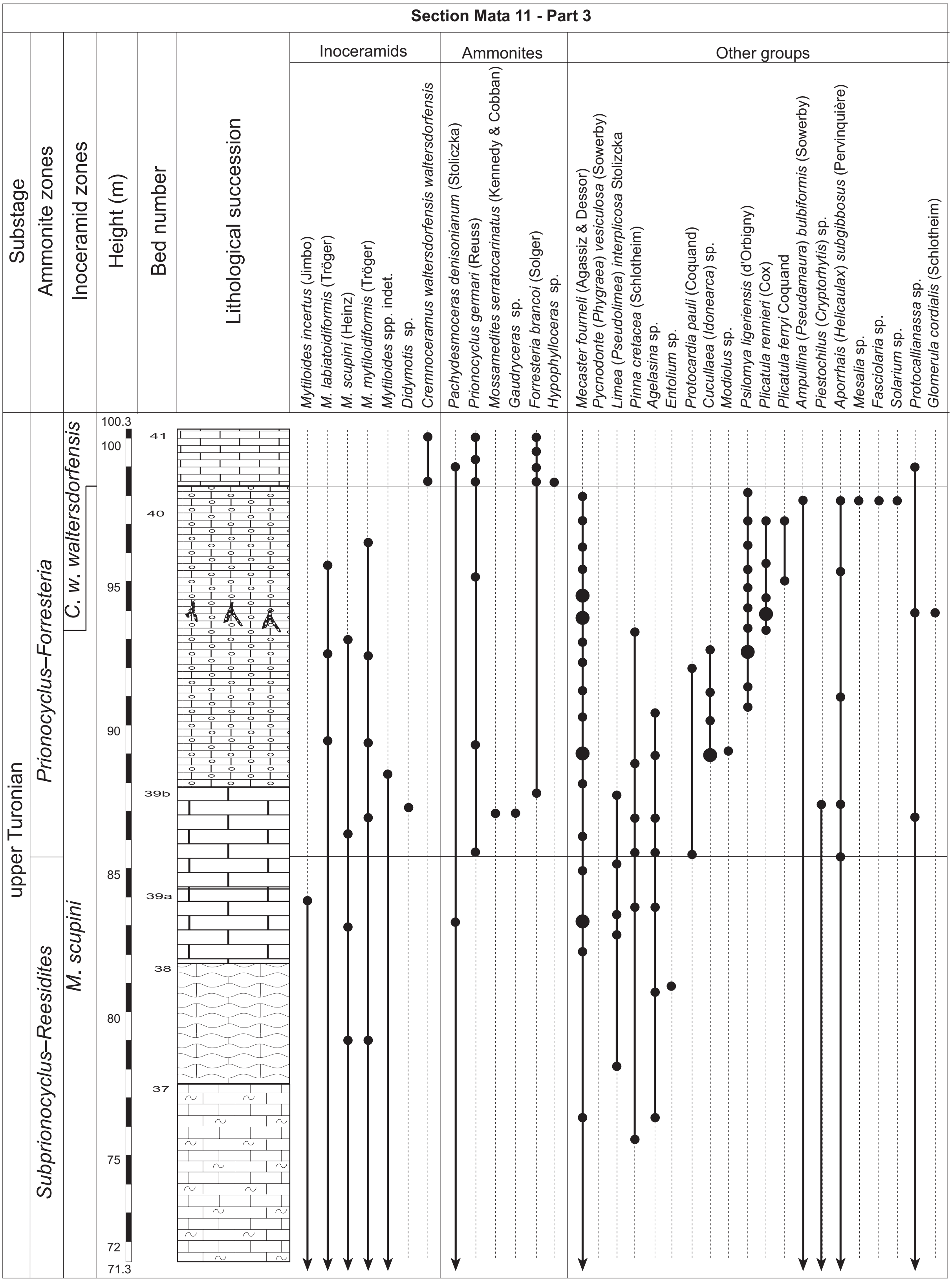


Figure 6.9 (a–c) (previous pages): Lithological sucession in the Mata 11 section (Nassau quarry), with biozonation and stratigraphical distribution of the macrofossils.

This bed is followed by a bioclastic limestone bed (24a) with small bivalves, grading into medium stratified beds (24b and 26) intercalated with marlstone beds (25 and 27). Above this there is a succession of marlstone–limestone couplets with hardgrounds (bed 29 and 32b). Resting on the latter slightly bioturbated hardground (32b) there is a marlstone (bed 33) with oyster accumulations. Bed 33 (7 cm thick) is very rich in well preserved single and double valves of *Pycnodonte* (*Phygraea*) *vesiculosa* (Sowerby) (Figures 6.10a, b). The marlstone–limestone couplets continue the succession up to bed 37 (Figure 9.9b–c). In this part of the section, two intervals of inoceramid occurrences are observed, in beds 34 and 36. Ammonites are rare, are non-inoceramid bivalves. No echinoids were found between bed 24a and the upper part of bed 37.

Bed 37 is followed by nodular limestones (bed 38) containing a fauna dominated by bivalves. This bed underlies a succession of thick-bedded to massive limestones (beds 39a–b), which are bioturbated and very fossiliferous. The fauna is diverse, with inoceramids and other bivalves, ammonites, gastropods and echinoids. Bed 40 is a deeply weathered, highly bioturbated coquinoid limestone (wackestone to packstone). This bed contains the most abundant and diverse fauna of the section. The top of the section comprises medium-bedded limestones with ammonites and rare inoceramids.

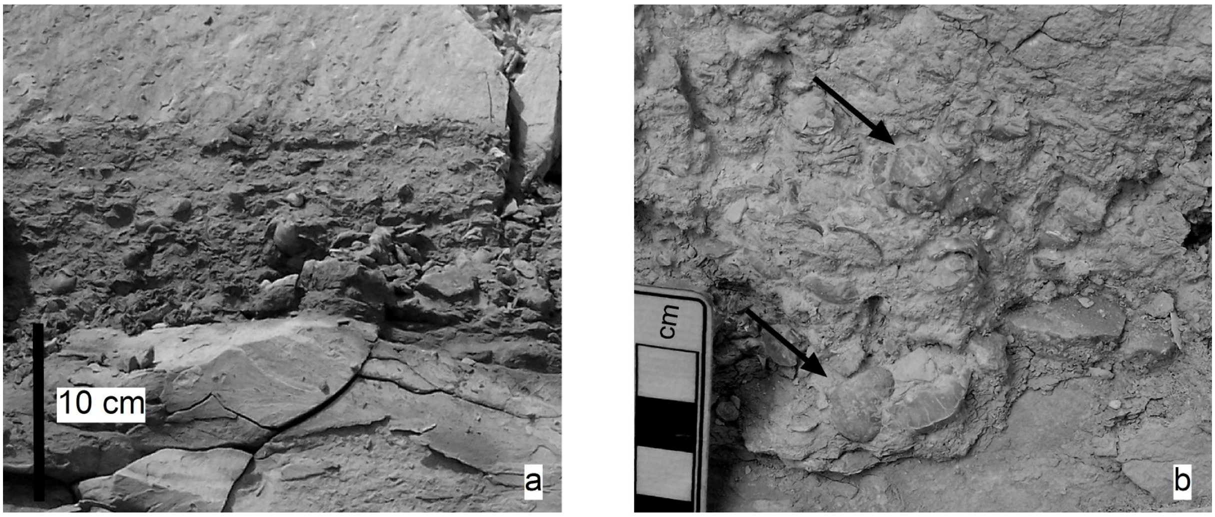


Figure 6.10: Mata 11 section. **a**: Marlstone bed 33 with oyster accumulations; **b**: Detail of oyster *Pycnodonte* (*Phygraea*) *vesiculosa* (Sowerby).

Microfacies. The Mata 11 section includes three microfacies types of Berthou & Bengtson (1988): U Tur A (1, 2), U Tur B and Con A. Type U Tur A (in the lower and upper part of the section) consists of bedded, variably bioclastic lime wackestone and is subdivided in A1 and A2. In type A1 macrofossil debris are relatively abundant, locally with large fragments that may be silicified. Echinoids dominate the macrofauna, whereas bivalves and gastropods are subordinate. In type A2 macrofossils are less common. The microfauna is composed of calcispheres, with rare heterohelicids and hedbergellids. Type U Tur B (in the middle part of the section) consists of lime mudstones nearly devoid of macrofossil remains. Where present, they consist of rare echinoids. Type Con A (in the upper part of the section) consists of lime wackestones, subordinately lime packstones, with abundant, locally silicified macrofossil remains, echinoids, bivalves (notably inoceramids and ostreids) and gastropods, rare worm tubes, and siliceous sponge spicules. Calcispheres, heterohelicids, buliminids, and hedbergellids are rare.

6.3 Discussion

The Retiro 26 and Mata 11 sections are separated by a stratigraphical interval of unknown extension. There are no outcrops in the area in between the two sections and examination of localities studied by Bengtson (1983) NE and SE of the sections did not yield any fauna that could be referred to the "missing" interval between the sections. See Chapter 9 "Biostratigraphy" for additional discussion.

A calculation of the estimated thickness of the sedimentary succession between the two sections was done, based on the topographic distance between the highest bed at Retiro 26 and the lowermost bed at Mata 11, assuming a constant dip between the sections and using average values of the measured strike and dip in the studied sections. The highest point at Retiro 26 (A) is located at UTM 8 800 400N/699 350E and an altitude of 27 m. The lowest point at Mata 11 (B) is located at UTM 8 799 600N/701 290E and an altitude of 5 m. The calculation was done using the software Geotrig (version 3.0) and showed that as much as 256 m of sedimentary thickness may be present between the two sections. A schematic section is shown in Figure 6.11.

The total thickness of the Retiro 26 (114 m) and Mata 11 (100 m) sections and the unexposed (250 m) section in between may amount to as much as 470 m. The sections studied by Cunha (2001) and Cunha & Koutsoukos (2001) in wells SE-1 and SE-2 (Figure 6.1) show thicknesses of 650 and 550 m, respectively, for the entire Turonian. The different thicknesses in the two wells can be explained by their position in relation to the structural framework of the basin: well SE-1 is located within the area of the Divina Pastora Low, whereas well SE-2 lies on the Aracaju High (see Figure 2.1). The Retiro 26 and Mata 11 sections are located between these wells.

However, it should be noted that this estimated thickness of the sedimentary succession missing between the two studied sections is merely hypothetical. Strike and dip varies considerable in the sections. Moreover, the succession, at least at Retiro 26, is marked by faults and erosional surfaces. The faults indicate a reactivation of basement faults as shown in the structural framework of the basin (Figures 2.1, 2.2) or new fault generations, induced by halokinesis. The study area is located near the Aracaju High; however, the structural framework of the area between the Divina Pastora Low and the Aracaju High is complex (W. Souza-Lima, Aracaju, personal communication, 2005), which makes thickness estimates highly uncertain. Further studies are needed in order to delineate other small-scale faults besides those shown in the regional map of Falkenhein (1986).

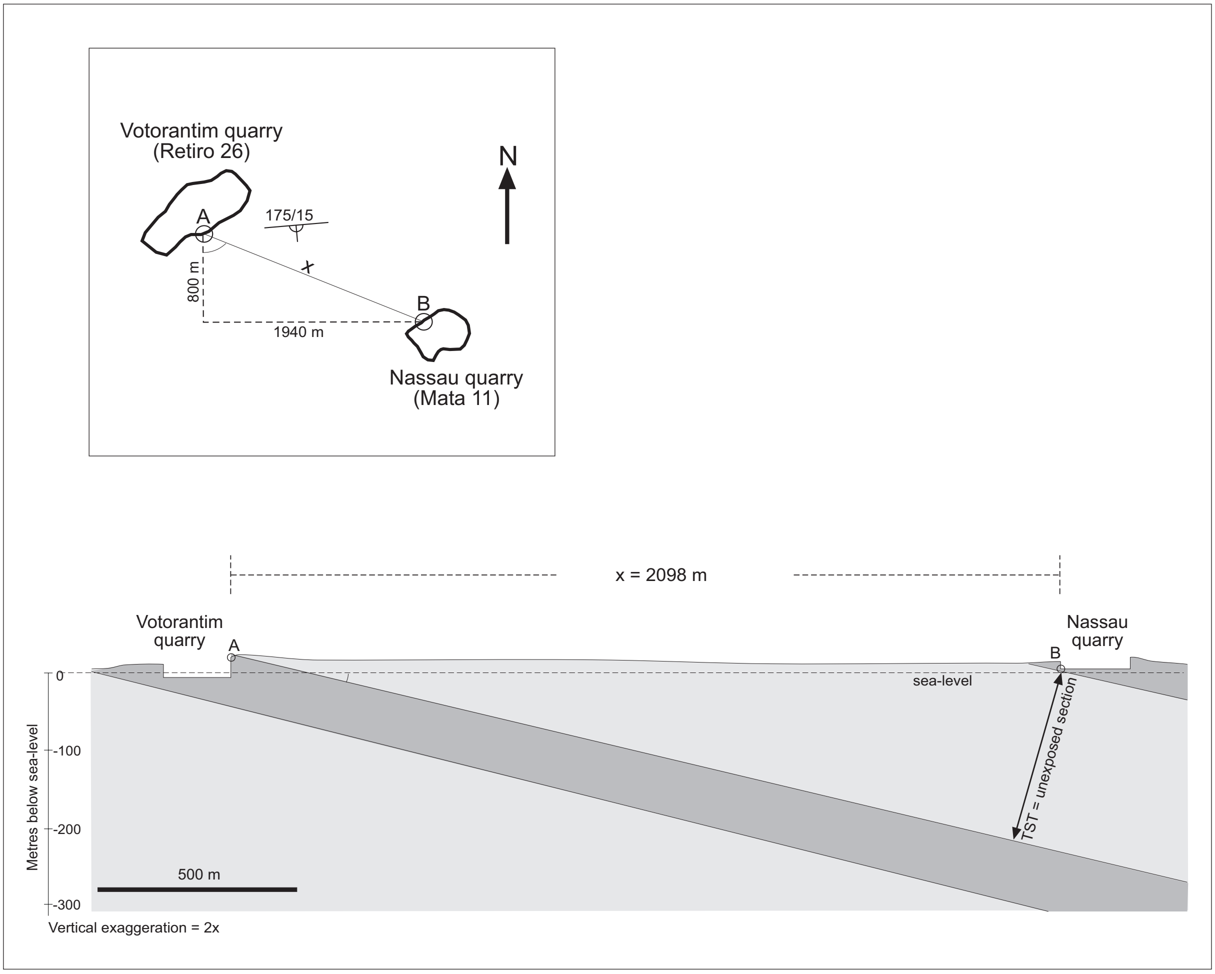


Figure 6.11: Schematic cross section of the area between the Votorantim (Retiro 26) and Nassau (Mata 11) quarries, assuming constant dip and strike of the beds.

6.4 Complementary localities

Four localities, Muçuca 5, Sapucari 1, Cajaíba 8 and Socorro 11 (Figure 6.1), described by Bengtson (1983) were sampled, primarily in order to obtain additional specimens of inoceramids. The localities Sapucari 1 and Muçuca 5 were sampled for a systematic re-evaluation of the genus *Sergipia*, whereas the localities Cajaíba 8 and Socorro 11 provided material for positioning the Turonian–Coniacian boundary on the basis of inoceramids.

6.4.1 Muçuca 5: UTM 8 803 900N/704 900E. Topographical map sheet: SC.24-Z-B-IV Aracaju. Geological map sheet: SC.24-Z-B-IV-4 Aracaju. Quarry facing SE. Altitude ca. 30 m. The quarry exposes ca. 20 m of alternating marlstones and limestones. The upper part of the quarry is strongly weathered (Figure 6.12).

Figure 6.12: View of part of the Muçuca 5 quarry.

Fossils. The abundant macrofauna is dominated by the inoceramids *Mytiloides hercynicus* (Petrascheck) and *Didymotis*? aff. *posidonomyaformis* (Maury), the ammonites *Watinoceras* spp. *Benueites* sp., *Neoptychites cephalotus* (Courtiller), *Coilopoceras* sp. *Kamerunoceras turoniense* (d'Orbigny) and the echinoid *Mecaster batnensis* (Coquand).

Chronostratigraphy: Middle Turonian

Biostratigraphy: *Mytiloides hercynicus* Zone

Microfacies type L Tur B1 (Berthou & Bengtson, 1988)

6.4.2 Sapucari 1: UTM 8 805 400N/709 350E. Topographical map sheet: SC.24-Z-B-IV Aracaju. Geological map sheet: SC.24-Z-B-IV-4 Aracaju. Altitude ca. 5–10 m. Quarry on hillside facing NW. The quarry exposes ca. 8 m of finely stratified, strongly weathered cream to grey limestones (Figures 6.13, 6.14).

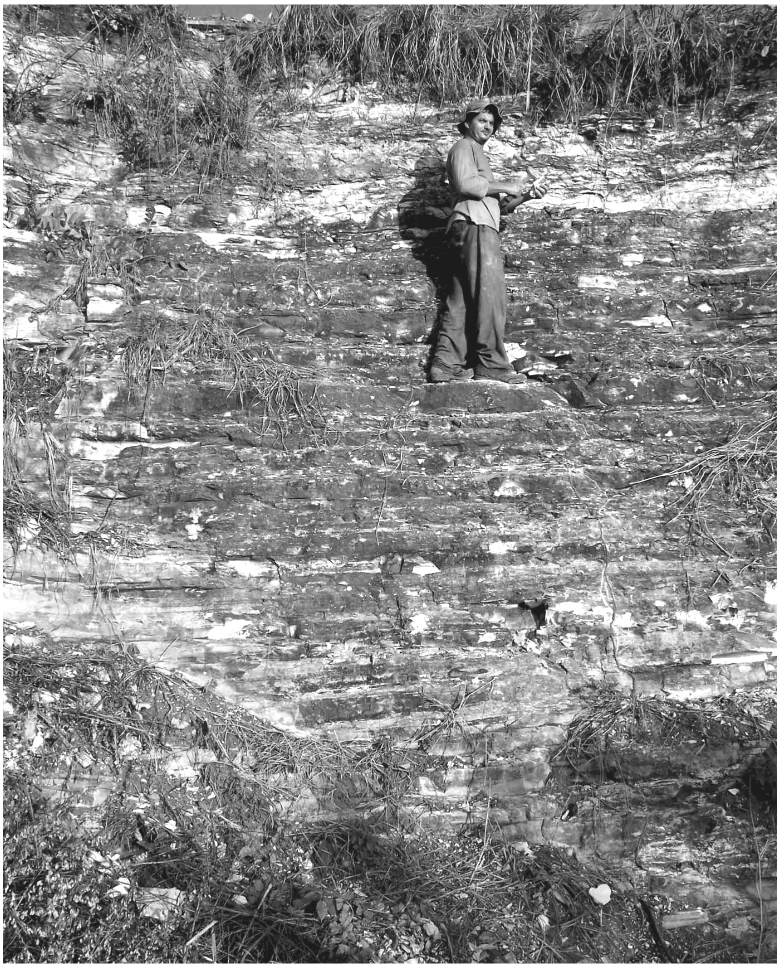


Figure 6.13: View of part of the Sapucari 1 quarry.

Fossils. The macrofauna is scarce and confined to some beds; it consists of the inoceramid bivalve *Didymotis posidonomyaformis* (Maury), the ammonite *Subprionocyclus* sp., the echinoid *Mecaster* sp. and scales and vertebrae of Osteichthyes indet.

Chronostratigraphy: Upper Turonian

Biostratigraphy: *Mytiloides scupini* Zone

Microfacies type U Tur B (Berthou & Bengtson, 1988). Lime mudstones with very scarce macrofossil remains. Where present they consist of small echinoderm fragments.

Figure 6.14: Finely stratified limestone in the Sapucari 1 quarry.

6.4.3 Cajaíba 8: UTM 8 800 850N/705 200E. Topographical map sheet: SC.24-Z-B-IV Aracaju. Geological map sheet: SC.24-Z-B-IV-4 Aracaju. Quarry facing E. Altitude ca. 10–25 m. The quarry exposes ca. 4.5 m of a cream, massive to irregularly bedded limestone, locally lightly bioturbated.

Fossils. The macrofauna consists of the inoceramids *Didymotis costatus* (Frič), *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert), *C. deformis erectus* (Meek) and rare ammonites of the genus *Hauericeras*.

Chronostratigraphy: Upper Turonian–lower Coniacian boundary interval.

Biostratigraphy: *Cremnoceramus waltersdorfensis waltersdorfensis–C. deformis erectus* zones

Microfacies type Con C1 (Berthou & Bengtson, 1988)

Figure 6.15: View of part of the Cajaíba 8 quarry.

6.4.4 Socorro 11: UTM 8 800 100N/704 850E. Topographical map sheet: SC.24-Z-B-IV Aracaju. Geological map sheet: SC.24-Z-B-IV-4 Aracaju. Quarry on hillside facing SE, immediately SE of road. Altitude ca. 15–20 m. The quarry exposes ca. 5 m of blue-grey and cream, irregularly stratified limestones.

Fossils. The macrofauna consists of the inoceramids *Didymotis costatus* (Frič), *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert), *C. deformis erectus* (Meek) and the ammonites *Hauericeras* sp. and *Forresteria* cf. *petrocoriensis* (Coquand).

Chronostratigraphy: Upper Turonian–lower Coniacian boundary interval.

Biostratigraphy: *Cremnoceramus waltersdorfensis waltersdorfensis*–*C. deformis erectus* zones

Microfacies type Con C1 (Berthou & Bengtson, 1988)

7. Macropalaeontology: general remarks

The Turonian macrofauna of Sergipe is dominated by molluscs. The fauna is characterized by a relatively abundant and diversified bivalve and ammonite assemblage, with bivalves representing the dominant group (717 specimens collected) whereas gastropods are rare. The stratigraphical distribution of macrofossils in the Retiro 26 and Mata 11 sections is shown in Figures 6.4a–c and 6.9a–c.

7.1. Ammonites

The ammonites in Retiro 26 and Mata 11 sections are preserved as internal moulds, most of them incomplete, lacking at least the inner whorls. In general they are not very well-preserved and many are therefore left in open nomenclature. The fauna collected consists of 160 specimens represented by nine families with 20 genera, including at least 28 species, as listed below:

- **Phylloceratidae:** *Hypophylloceras* (*Hypophylloceras*) sp.
- **Gaudryceratidae:** *Gaudryceras* sp.
- **Desmoceratidae:** *Puzosia* (*Mesopuzosia*) sp., *Pachydesmoceras denisonianum* (Stoliczka, 1865), *Mossamedites serratocarinatus* (Kennedy & Cobban, 1988), *Desmophyllites* sp.
- **Acanthoceratidae:** *Kamerunoceras* sp. A, *K. turoniense* (d’Orbigny, 1850), *Mammites nodosoides* (Schlüter, 1871), *Watinoceras* sp. A. *Watinoceras* sp. B, *Benueites* sp., *B.* cf. *spinosus* Reyment, 1954, *B.* cf. *trinidadensis* Renz, 1982, *Romaniceras kallesi* (Zázvorka, 1958)
- **Vascoceratidae:** *Fagesia* cf. *superstes* (Kossmat, 1897), *Fagesia* sp., *Neoptychites cephalotus* (Courtiller, 1860) and Vascoceratidae indet.
- **Collignoniceratidae:** *Reesidites* sp., *Subprionocyclus* sp., *S. neptuni* (Geinitz, 1849), *Prionocyclus germari* (Reuss, 1845), *Forresteria brancoi* (Solger, 1904).
- **Coilopoceratidae:** *Coilopoceras* spp., *Hoplitoides* sp.
- **Hamitidae:** *Puebloites* sp.
- **Diplomoceratidae:** Diplomoceratidae indet.

In the lower to middle Turonian the fauna is dominated by acanthoceratids and coilopoceratids, whereas collignoniceratids dominate in the upper Turonian. Selected, biostratigraphically significant or common species are illustrated in Plates 11 and 12.

The ammonites are the second most important macrofossil group in the Turonian of Sergipe after the inoceramids. Although the ammonite faunas of Sergipe show a low endemism (Bengtson, 1983), they are less cosmopolitan than the inoceramids. In general, the Turonian ammonite fauna of Sergipe has a Tethyan affinity.

7.2 Bivalves

The bivalves in the sections studied are represented by a diverse fauna. However, because most of them are poorly preserved, as incomplete internal moulds lacking internal features, specific identification is difficult, mainly for the heterodonts. In general, the bivalves at least at the generic level, show no endemism, except for the inoceramid *Rhyssomytiloides* which has a more restricted biogeographical distribution. The bivalves are dominated by inoceramids (591 specimens). Most inoceramids have a cosmopolitan distribution, which in connection with their rapid species turnover, make them biostratigraphically the most important group. The inoceramids are described systematically in Chapter 8. Palaeobiogeographical and palaeoecological interpretations are given in Chapters 10 and 11, respectively.

Besides inoceramids, other bivalves are well represented in the study area, most of them in the upper Turonian. They include species of pteriomorphs (10 families), heterodonts (5 families) and anomalodesmatids (2 families). The bivalve families and species recorded in the lower to upper Turonian of Sergipe are:

- **Gryphaeidae**: *Pycnodonte* (*Phygraea*) *vesiculosa* (Sowerby, 1923)
- **Arcidae**: *Barbatia* sp.
- **Cucullaeidae**: *Cucullaea* (*Idonearca*) sp.
- **Mytilidae**: *Modiolus* sp.
- **Pinnidae**: *Pinna cretacea* (Schlotheim, 1813)
- **Inoceramidae**: *Mytiloides puebloensis* Walaszczyk & Cobban, 2000, *M.* cf. *hattini* Elder, 1991, *M. kossmati* (Heinz, 1933), *M. goppelnensis* (Badillet & Sornay, 1980), *M. mytiloides* (Mantell, 1822), *M. ganuzaensis* (López, 1992), *M. labiatus* (Schlotheim, 1813), *M. subhercynicus* (Seitz, 1935), *M.* cf. *subhercynicus* (Seitz, 1935), *M. hercynicus* (Petrascheck, 1903), *M. hartti* (Hessel, 1988), *M.* cf. *tourtenayensis* (Badillet & Sornay, 1980), *M. striatoconcentricus* (Gümbel, 1868), *M. incertus* (Jimbo, 1894), *M. turonicus* Walaszczyk, 1992, *M. labiatoidiformis* (Tröger, 1967), *M. herbichi* (Atabekjan, 1969), *M. scupini* (Heinz, 1930), *M. mytiloidiformis* (Tröger, 1967), *Rhyssomytiloides mauryae* (Hessel, 1986), *R. beurleni* Hessel, 1988, *R. retirensis* Hessel, 1988, *Inoceramus longealatus* Tröger, 1967, *I.* cf. *perplexus* Whitfield, 1877, *Didymotis posidonomyaformis* (Maury, 1925), *Didymotis*? aff.

posidonomyaformis (Maury, 1925), *Didymotis* sp., *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert, 1911)

- **Entoliidae**: *Entolium* sp.
- **Pectinidae**: *Neithea* cf. *hispanica* (d'Orbigny, 1850) and *Neithea* sp.
- **Plicatulidae**: *Plicatula rennieri* (Cox), *P. ferryi* Coquand, 1862, and *P.* cf. *auressensis* Coquand, 1862
- **Limidae**: *Limea* (*Pseudolimea*) *interplicosa* (Stolizcka, 1871)
- **Crassateliidae**: *Crassatella* sp.
- **Cardiidae**: *Protocardia pauli* (Coquand, 1862)
- **Tellinidae**: *Tellina* sp.
- **Dicerocardiidae**: *Agelasina* sp.
- **Veneridae**: *Cyclorisma* sp., *Paraesa* sp.
- **Pholadomyidae**: *Pholadomya* cf. *adversa* Riedel, 1932
- **Poromyidae**: *Psilomya ligeriensis* (d'Orbigny, 1845)

In general, inoceramids are abundant throughout the Turonian, but absent or scarce wherever other bivalve groups are abundant, as shown in the upper parts of the Retiro 26 and Mata 11 sections (see Figures 6.4a–c; 6.9a–c).

Accumulation of gryphaeid oysters assigned to *Pycnodonte* (*P.*) *vesiculosa* are recorded in the middle and upper Turonian. In contrast, in the Cenomanian of Sergipe, the subfamily Pycnodontinae was rare and the oyster fauna was dominated by the subfamily Exogyrinae, represented by genera *Amphidonte*, *Exogyra*, *Ilymatogyra* and *Rhynchostreon*. Systematic descriptions and discussions of the oyster of Sergipe were carried out by Seeling and Bengtson (1999).

7.3 Gastropods

The gastropods in the sections studied are poorly preserved as incomplete internal moulds, without external ornamentation, and most of the specimens are left in open nomenclature. The gastropods are abundant in the upper part of the Mata 11 section (upper Turonian), but only eight species are present. The fauna consists of *Akera* sp., *Ampullina* (*Pseudomaura*) *bulbiformis* (Sowerby, 1831), *Aporrhais* (*Helicaulax*) *subgibbosus* Pervinquière, 1912, *Fasciolaria* sp., *Fusus* sp., *Mesalia* sp., *Piestochilus* (*Cryptorhytis*) sp. and *Solarium* sp. In the Retiro 26 section only a few specimens of indeterminable gastropods were recorded in the upper part of the section. Nearly 40 species were identified in the Cenomanian–Coniacian of the Sergipe Basin (Burrer, 2001, Dietzel, 2002, Burrer *et al.*, 2002). The Turonian genera are widely distributed and show strong affinities with faunas from Algeria, France, Gabon, Nigeria, the Palestine, Portugal and Tunisia (Dietzel, 2002).

7.4 Echinoids

The echinoid fauna in the sections studied is characterized by *Phymosoma* sp., *Petalobrissus cubensis* (Weisbord, 1934) and *Mecaster batnensis* (Coquand, 1862), in the lower and middle Turonian, and *Mecaster fourneli* (Agassiz & Dessor, 1847) in the upper Turonian. The echinoids are more abundant in section Mata 11 with a monospecific occurrence of *M. fourneli*.

Smith & Bengtson (1991) reported the spatangoid *Mecaster batnensis* from the upper Cenomanian to lower Turonian of Sergipe, which is also known from the Turonian of Texas. *Mecaster fourneli* is known from the upper Turonian to "lower Coniacian" (now upper Turonian). This species was also described by Smith & Bengtson (1991) from the Turonian to lower Campanian of the Potiguar Basin. It is a typically Mediterranean−Tethyan species, which is very abundant in North Africa. It occurs also in Nigeria, Gabon, Cameroon, Bolivia, Colombia, Ecuador, Peru, Mexico, and Texas (Néraudeau & Mathey, 2000).

The cassiduloid *Petalobrissus cubensis* was reported by Smith & Bengtson (1991) only from the Potiguar Basin. This is the first record of this species in Sergipe, which is known elsewhere from Cuba, Mexico, Texas, Tunisia and Egypt (Néraudeau & Mathey, 2000).

7.5 Other macrofossils

Decapod crustaceans are very common in the sections studied. Most of them are preserved chiefly as fragments of chelae. Bryozoans are very scarce and only one specimen of Cheilostomata (?*Membranipora* sp.) was found in the Mata 11 section. Serpulids, represented by *Glomerula gordialis* (Schlotheim, 1820), were found encrusted on *Plicatula* shells, though only in the upper part of the Mata 11.

Fish remains were recorded in two sections and mainly represented by teeth, vertebrae and scales. The fish fauna consists of chondrichthyan ptychodontids: *Ptychodus decurrens* Agassiz, 1835, *Cretolamna appendiculata* (Agassiz, 1843), *Cretoxyrhina* sp., *Squalicorax falcatus* (Agassiz, 1843) and *Squalicorax* sp. Osteichthyan pycnodonts also occur: *Pycnodus cretaceus* Agassiz, 1843 and *Pycnodus* sp.; enchodontids: *Enchodus* sp. and Osteichthyes indet.

Other macrofossil groups such as rudists, corals, brachiopods, and calcareous sponges were not found in the sections studied. The absence of these macrofossils was also noted by

Seeling & Bengtson (2002) in their study of the upper Cenomanian–lower Turonian of the Sergipe. Mathey *et al*., (1995) explained the lack of brachiopods on the Niger ramp as a result of competition with a pioneer bivalve-dominated epifauna and/or excessive turbidity of the bottom waters. These interpretations, associated with unfavourable morphological conditions (i.e. lack of shoals) on the ramp, may also explain the lack of rudists and corals during the Cenomanian–Coniacian in Sergipe. According to Holmer & Bengtson (1996), the rare occurrence of brachiopods in the Sergipe Basin could be a result of low-oxygen levels at or near the sediment–water interface, where only a few, more tolerant brachiopods are found (e.g. lingulids, discinids).

8. Systematic Palaeontology

The taxonomy of lower Turonian inoceramids is complicated by their broad morphological variability. This obscures species boundaries and has led to a large number of synonymous taxa. The methodology for inoceramid taxonomy, although generally inspired by the German school of Heinz and Seitz, still varies considerably from author to author. Most descriptions, at least until the 1970's, were done without taking intraspecific variability or deformation during fossilisation into account (Dhondt, 1992). The proliferation of generic names by Heinz (1932), most of them improperly introduced according to the rules of the International Commission of Zoological Nomenclature (ICZN) and hence considered *nomina nuda* or *nomina dubia* (Cox, 1969), contributed to complicating inoceramid systematics.

The generic classification of Turonian inoceramids has been discussed by a number of authors (e.g., Kauffman & Powell, 1977; Walaszczyk, 1992; Harries *et al*., 1996), especially for the lower Turonian. However, many questions about their generic differentiation remain open. Kauffman (in Harries *et al*., 1996) announced a revision of the generic and subgeneric systematics, utilizing a combination of external shell form and ornament with internal morphological characters. However, this work is still unpublished. Walaszczyk & Cobban (2000a) remarked that the use of internal shell characters as a basis for a satisfactory classification is illusory, because available data is still insufficient for reliable use.

8.1 Descriptive nomenclature

The morphological descriptions, terminology and measurements of external features of inoceramids used herein (Figure 8.1) follow those given by Harries *et al*. (1996). The terminology for the description of surface ornamentation is in accordance with Harries *et al*. (1996) and Walaszczyk & Cobban (2000a). Concentric elements are referred to as growth lines (symmetric and asymmetric), rugae and ribs. The term rib is applied to elements subordinate to rugae. The term microrugae is applied to the narrowest rugae as introduced by Elder (1991). Radial grooves/lines, divergent radial folds and plicae are used to describe radial ornamentation. The use of open nomenclature follows that recommended by Bengtson (1988). Measurements of material published by Hessel (1988) are not repeated here.

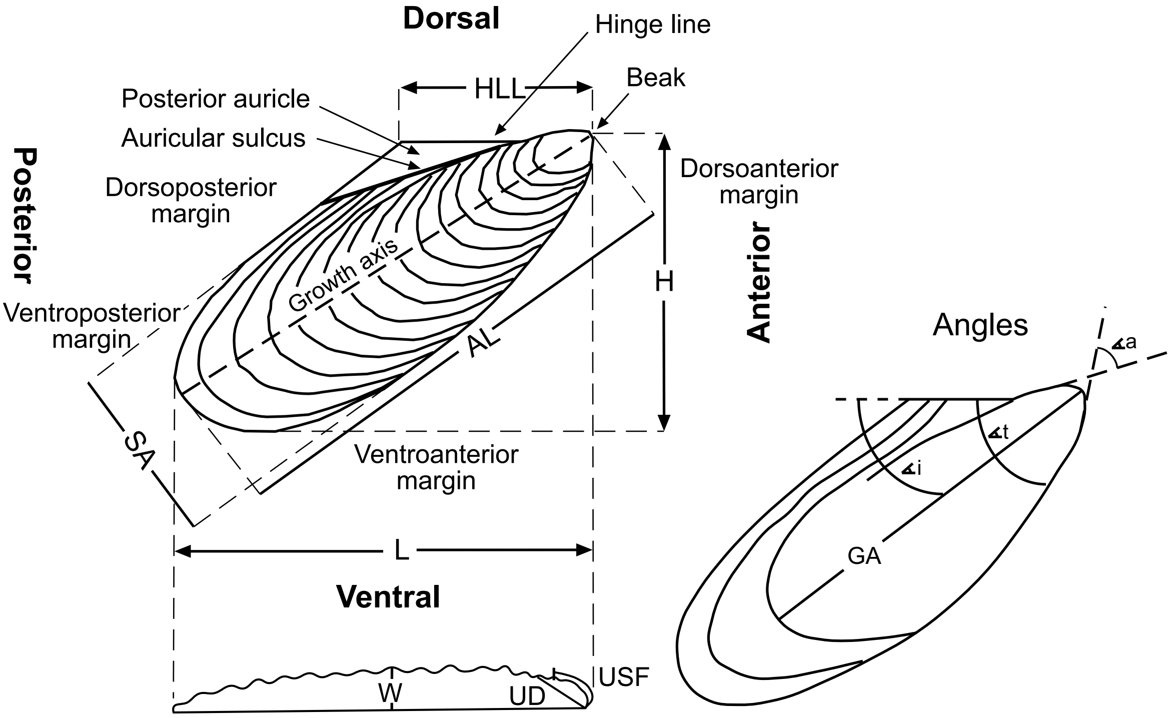


Figure 8.1: External view of right valve with terminology and measurements of external morphological features of the inoceramid shell. Abbreviations: AL = axial length, SA = secondary axis, H = height, L = length, HLL = hinge line length, UD = umbonal distance, USF = umbonal surface; W = width, GA = growth axis, a = apical angle, i = angle of inclination, t = total angle (after Harries *et al.*, 1996 and Seeling, 1999).

Terminology and abbreviations. **H**: height = maximum distance between the beak and the ventral margin of shell, measured perpendicular to the plane of the hinge line; **L**: length = distance between two lines perpendicular to the hinge line, one intersecting the anterior-,most projection of the shell and the other intersecting the posterior-most projection of the shell; **AL**: axial length = the linear dimension of a valve, approximately equivalent to the growth axis, extending from the beak to the most distal point on the ventroposterior margin (corresponding to the *Hauptachse* = Ha of Seitz); **SA**: secondary axis = the maximum dimension of the shell measured perpendicular to the axial length (*Nebenachse* = Na of Seitz); **ALmax**: the maximum axial length measured; **HLL**: hinge line length = distance from the anterior edge of the hinge line, below or anterior to the beak, to the posterior-most projection of the hinge line; **W**: valve width = the maximum distance perpendicular to the plane of commissure to the outer shell surface. Angles: **a**: apical angle = the angle between the anterior and posterior portions of the beak-umbo area to the valve; **i**: angle of inclination = the angle between the hinge line and the growth axis; **t**: total angle = the angle between the hinge line and the dorsoanterior margin of the valve. **Disc**: the entire valve, excluding the auricles; **LV** = left valve; **RV** = right valve. Measurements are given in millimeters, angle units in degrees.

8.2 Repositories and numbering of specimens

The fossil material collected for this study will be housed temporarily at the Universidade Federal da Bahia-UFBA, Salvador, Brazil, during the realization of a postdoctoral project. After that, the specimens will be deposited permanently in the Museu Nacional, Rio de Janeiro, Brazil. The number of specimens is preceded by an abbreviation of their locality as follows:

RT26 – Retiro 26
MT11 – Mata 11
SP1 – Sapucari 1
MC5 – Muçuca 5

The location of the revised inoceramid specimens (Maury, 1925; Santos, 1969; Kauffman & Bengtson, 1985; Hessel, 1988; Seeling, 1999) is indicated below under the following prefixes:

DNPM – Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil;
PMU SA – Palaeontological Museum of Uppsala University, Uppsala, Sweden;
GPIH-BR – Geologisch-Paläontologisches Institut of the University of Heidelberg, Germany.

8.3 Systematic descriptions

Class Bivalvia Linnaeus, 1758
Subclass Pteriomorphia Beurlen, 1944
Order Pterioida Newell, 1965
Suborder Pteriina Newell, 1965
Superfamily Pteriaceae Gray, 1847
Family Inoceramidae Giebel, 1852

Genus *Mytiloides* Brongniart, 1822
Type species: *Ostracites labiatus* Schlotheim, 1813, p. 93, by monotypy.

Remarks. *Mytiloides* was originally erected by Brongniart (1822) without a comprehensive diagnosis. Many authors have placed the name in synonymy with *Inoceramus* J. Sowerby, 1814 (e.g., Seitz, 1935, 1965; Tröger, 1967). Cox (1969) regarded *Mytiloides* as a subgenus of *Inoceramus*. Kauffman & Powell (1977) redescribed *Mytiloides* as a separate inoceramid genus and discussed the differences of the two genera. Further discussion is given by Harries *et al*. (1996).

Mytiloides puebloensis Walaszczyk & Cobban, 2000
Plate 1, Figures 1–4

1984 *Inoceramus* (*Mytiloides*) *hercynicus* Petraschek; Berthou, p. 53, pl. 1, fig. 3.
pars 1987 *Mytiloides columbianus* (Heinz, 1935); Kennedy *et al*., text-fig. 12a–b (*non* text-fig. 12c = *M. kossmati*).
pars 1991 *Mytiloides columbianus* (Heinz); Elder, fig. 4.9 (non fig. 4.2 = *M. kossmati*).
1996 *Mytiloides kossmati* (Heinz); Marcinowski *et al*., pl. 17, fig. 4.
pars 1999 *Mytiloides mytiloides* (Mantell, 1822); Seeling, pp. 96–98, not figured (*non* pl. 2, figs 2, 3).
2000b *Mytiloides puebloensis* sp. nov.; Walaszczyk & Cobban, pp. 321–322, pl. 6, figs 1–11; pl. 7, figs 2–3, 5–8, 12, 14; pl. 8, figs 1–11, 13; pl. 10, figs 1, 4, 6–8.

Material. 16 mainly incomplete specimens from locality Retiro 26, preserved as internal moulds of single LV or RV and/or shell fragments: RT26.02, 23, 37, 64, 66, 69, 70, 74, 86, 99, 105, 106, 115, 126, 143, 609.

Description. Medium-sized (Table 1). Outline oval to subrounded; inequivalve; equilateral; valves weakly inflated, maximum inflation in dorsocentral part of the disc. Growth axis straight to slightly convex anteriorly. Hinge line straight, relatively short to medium sized. Beak projecting slightly above hinge line. Posterior auricle small. Anterior margin convex, passing into rounded ventral margin. Posterior margin straight to slightly convex. Ornamentation consisting of almost regularly spaced, rounded rugae covered with raised growth lines or microrugae; rugae weaken towards anterior and posterior margins.

Table 1: Measurements of selected specimens of *M. puebloensis* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.02 LV	39.8	32.0	0.80	45.0	42.0	0.90	-	-	-	-	7.0	*47.0
RT26.66 RV	36.0	29.0	0.81	56.0	51.0	0.90	17.5	118	53	114	2.0	62.0
RT26.143 RV	27.2	24.0	0.88	*51.0	*44.0	0.86	17.0	102	56	100	5.0	55.0
RT26.609 LV	33.0	27.0	0.82	*46.0	41.0	0.89	*11.0	-	58	112	6.0	44.0

Discussion. The Sergipe specimens are similar to those described by Walaszczyk & Cobban (2000b) from the U.S. Western Interior, but show a variation in shell outline and ornamentation. For example, in specimen RT26.66 (Pl. 1, fig. 3) the rugae are weaker; some specimens are more rounded, e.g. RT26.02 (Pl. 1, fig. 2) and RT26.64.

The ornamentation of *Mytiloides puebloensis* shows similarities to that of *M. hattini* Elder, 1991, but differs from the latter in its juvenile part, with regularly spaced, rounded-topped rugae. However, a range of transitional forms occur, in which the rounded rugae are faint and the microrugae become very similar to those of *M. hattini*. This range of transitional forms was found in the material from Pueblo, USA, by Walaszczyk & Cobban (2000b), who interpreted their new species *M. puebloensis* as an evolutionary descendant of *M. hattini*.

Specimens RT26.02 and 64 have a more rounded to subquadrate outline resembling that of *M. wiedmanni* (López, 1992). The latter, however, lacks the regularly spaced, round-topped rugae, covered with regular raised growth lines. The two Sergipe specimens also have raised, single rugae on the juvenile part of the shell, which suggests that they may represent a transitional form to *M. goppelnensis* (Badillet & Sornay, 1980).

Specimens illustrated by Kennedy *et al.* (1987) from Texas and by Elder (1991) from the U.S. Western Interior were assigned to *M. columbianus* (Heinz, 1935). However, these specimens differ from the original of *M. columbianus* (Heinz) [= *M. kossmati* (Heinz)] in having an ornament of regular, round-topped rugae covered with growth lines, a pattern characteristic of *M. puebloensis*.

Specimens GPIH-BR RC4.I4, I7 and Sergipe3.I1 from localities Rita Cacete 4 and Sergipe 3, respectively, described by Seeling (1999) as *M. mytiloides,* show regularly spaced, round-topped rugae and fit well into *M. puebloensis*. These specimens were collected from the lower Turonian *Watinoceras amudariense–Kamerunoceras seitzi* ammonite Zone of Sergipe.

Occurrence. Lowermost Turonian of the U.S. Western Interior, Texas, Portugal, Kazakhstan and Sergipe (Brazil).

Mytiloides cf. *hattini* Elder, 1991

Plate 1, Figures 8–11

cf. 1984 *Inoceramus pictus sackensis* Keller; Berthou, p. 53, pl. 1, fig. 1.

cf. 1991 *Mytiloides hattini* n. sp.; Elder, pp. 235–240, figs 3.1–19.

cf. 2000b *Mytiloides hattini* Elder, 1991; Walaszczyk & Cobban, pp. 320–321, pl. 4, figs 7–13; pl. 5, figs 1–10.

Material. Six specimens from locality Retiro 26, preserved as internal moulds of one LV and five RV: RT26.47, 61, 72, 81, 91, 109.

Description. Small to medium-sized (Table 2). Outline subrectangular to oval; subequivalve, slightly convex; maximum inflation dorsocentrally and anteriorly of midline. Hinge line straight, relatively short or of medium length. Beak projecting slightly above hinge line. Posterior auricle small, poorly differentiated from the disc. Anterior margin long, slightly convex, passing into rounded ventral margin; posterior margin almost straight. Ornamentation consisting of concentric, regular to subregular microrugae, passing onto the posterior auricle only as growth lines; microrugae increasing in size and distance away from the beak; weakly developed rugae commonly present on the adult part of some specimens.

Table 2: Measurements of selected specimens of *M.* cf. *hattini* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.47 RV	27.5	21.5	0.78	*39.0	*34.0	0.87	*17.0	106	69	110	6.0	43.0
RT26.61 RV	29.0	22.0	0.76	*44.0	34.5	0.78	16.0	96	70	105	7.0	42.0
RT26.72 LV	41.0	31.0	0.75	51.0	39.5	0.77	17.0	110	62	102	3.0	53.5
RT26.81 RV	29.0	21.0	0.72	42.5	33.5	0.79	-	110	61	112	3.0	44.0
RT26.91 RV	31.0	22.5	0.72	*35.0	*31.0	0.88	*14.0	100	58	104	3.0	40.0

Discussion. The specimens are similar to *M. hattini* Elder, 1991, in outline and ornamentation. Specimens RT26.61 and 109 (Pl. 1, fig. 10) are slightly deformed and therefore appear more inclined. The latter specimen (RT26.109) shows a change of ornament on the adult part of the shell, where the microrugae disappear and the shell becomes almost smooth, which gives the impression of a geniculation. Specimen RT26.72 (Pl. 1, fig. 8) shows a few weak rugae on the adult part and is similar to a specimen illustrated by Elder (1991, fig. 3.18). The Sergipe specimens differ from *M. mytiloides* in being less elongate, subrectangular, less inflated and in having a shorter posterior auricle and a more erect growth axis.

M. hattini Elder is very similar to *Inoceramus pictus sackensis* Keller (1982). The similarities concerning outline and ornamentation were already discussed by Elder (1991). However, according to Elder *M. hattini* has a longer, broader posterior auricle that is poorly differentiated from the disc by a very broad shallow sulcus, whereas in *I. pictus sackensis* this sulcus is deep and prominent. Moreover, the inclination of the growth axis averages ca. 70° in the two specimens illustrated by Keller (1982), whereas in *M. hattini* this angle averages 58°. Elder (1991), in general, refers in his discussion to Keller's paratype and not to the holotype. In fact, the illustrated paratype of *I. pictus sackensis* (Keller, 1982, pl. 2, fig. 4a) differs markedly from *M. hattini*. This is not the case for the holotype of *I. pictus sackensis* (Keller, 1982, pl. 2, fig. 4b), which possesses quite the same characteristics as *M. hattini*, and according to Walaszczyk & Cobban (2000b) is actually a species of *Mytiloides*. Walaszczyk & Cobban suggest that the two specimens illustrated by Keller (1982) are thus not conspecific.

Walaszczyk & Cobban (2000b) described and discussed *M. hattini* from the Pueblo Section (Colorado, U.S. Western Interior). However, they mentioned that the systematic relationship between *M. hattini* and *I. pictus sackensis* remains unclear. They suggest that *M. hattini* might fall into synonymy with *M.*? *sackensis*, but more material from the type locality of Keller's species in northern Germany is needed to resolve this problem.

More recent discussions about these two species suggest that *M. sackensis* differs from *M. hattini* in its outline, which is more *M. mytiloides*-like whereas *M. hattini* is more subrectangular (I. Walaszczyk, Warsaw, written communication, 2004).

Occurrence. *M. hattini* is known from the topmost Cenomanian to lowermost Turonian in the U.S. Western Interior, Texas and Portugal. In Sergipe, *M.* cf. *hattini* occurs in the lower Turonian.

Mytiloides kossmati (Heinz, 1933)
Plate 1, Figures 5–7

1928b *Inoceramus plicatus* D'Orb.; Heinz, pp. 63–65, pl. 4, fig. 4.
1930 *Inoceramus naumanni* Yok. var. *kossmati* Heinz; Besairie, pp. 94 and 121 (*nomen nudum*).
1932 *Striatoceramus kossmati* Heinz; Heinz, p. 1 (*nomen nudum*).
1933 *Striatoceramus kossmati* Heinz; Heinz, p. 247, pl. 18, fig. 4.
1935 *Orpheoceramus columbianus* n. sp.; Heinz, p. 304.
1937 *Inoceramus labiatus sergipensis* subsp. nov.; Maury, pp. 113–115, pl. 8, fig. 12.
1981 *Inoceramus* (*Mytiloides*) *modeliaensis* n. sp.; Sornay, pp. 136–140, pl. 1, figs 1, 3–4; pl. 2, figs 1, 3–4.
pars 1991 *Mytiloides columbianus* (Heinz); Elder, fig. 4.2 (non fig. 4.9 = *M. puebloensis*).
1998 *Mytiloides kossmati* (Heinz); Küchler, pl. 10, fig. 4.
1998 *Mytiloides kossmati*; Villamil & Arango, figs 6b, k.
1998 *Mytiloides columbianus*; Villamil & Arango, figs 6f, g.

1999 *Mytiloides kossmati* (Heinz, 1930); Seeling, pp. 91–94, pl. 1, fig. 12.

2000b *Mytiloides kossmati* (Heinz, 1930); Walaszczyk & Cobban, pp. 322–323, pl. 9, figs 4–9.

Material. 25 mainly incomplete specimens from locality Retiro 26 preserved as internal moulds of LV or RV and shell fragments: RT26.23, 25–27, 36, 38, 39, 65, 68, 73, 75, 89, 97, 101, 118–120, 153, 155, 159–161, 180, 467, 611.

Description. Small to medium-sized (Table 3). Outline subrounded to ovate; inequilateral; valves flattened to slightly inflated. Hinge line straight, relatively short to medium-sized. Beak prosogyrous, slightly projecting above hinge line. Posterior auricle small, subtriangular, continuous with the disc. Anterior and ventral margins rounded; posterior margin weakly rounded to straight. Ornamentation consisting of closely spaced concentric rugae in the umbonal part, well-developed double-ridged rugae on the central part of the disc, which disappear gradually towards the posterior and anterior margins.

Table 3: Measurements of selected specimens of *M. kossmati* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.25 RV	30.1	25.4	0.84	*34.0	37.0	1.08	18.5	102	60	108	2.0	*40.0
RT26.26 LV	26.6	25.1	0.94	*43.0	43.1	1.00	20.5	129	61	117	3.0	*32.0
RT26.36 RV	33.0	28.0	0.84	*35.0	42.5	1.21	18.5	109	57	119	4.5	*35.1
RT26.65 RV	36.1	28.3	0.78	47.0	43.0	0.91	18.5	106	54	114	2.0	*56.0
RT26.75 RV	37.0	28.0	0.76	51.0	44.0	0.86	15.0	106	55	99	2.0	56.0
RT26.89 LV	33.4	29.4	0.88	49.5	42.0	0.84	16.0	117	60	115	2.5	50.0
RT26.118 LV	35.0	29.0	0.82	41.5	35.5	0.85	15.5	98	47	104	2.0	45.0
RT26.159 LV	42.5	34.0	0.80	*50.0	41.5	0.83	21.0	90	50	90	5.5	*47.5
RT26.161 LV	34.0	27.0	0.79	*45.0	*41.0	0.91	18.5	-	50	93	4.0	*51.5
RT26.180 RV	38.5	30.0	0.78	51.0	*36.0	0.70	15.5	-	-	-	2.0	*55.5

Discussion. The specimens of *M. kossmati* from Retiro 26 show some variation in shell outline, but most specimens are ovate. In some specimens the rugae are very closely spaced. The point of appearance of double-ridged rugae usually lies in the middle of the juvenile part but in some specimens appear earlier.

The holotype (by monotypy) of *Inoceramus labiatus sergipensis* Maury, 1937, has double-ridged concentric rugae and an ovate outline, and falls in the synonymy of *M. kossmati*.

Besairie (1930) listed *I. naumanni* Yok. var. *kossmati* Heinz from the Turonian of Madagascar without description or illustration. Heinz (1932) referred this form to *Striatoceramus kossmati*, also without description or illustration. Subsequently, Heinz, (1933) described and illustrated this taxon as a separate species and referred it to the genus *Striatoceramus*. The genus *Striatoceramus* Heinz was not erected according to nomenclatural requirements of the ICZN (ICZN, 1999, Art. 13) and is thus a *nomen nudum*. Cox (1969) included this genus and most of the other new generic names published by Heinz (1932) in *Inoceramus* Sowerby. The genus *Orpheoceramus* was placed in the genus *Mytiloides* Brongniart.

Walaszczyk (1992) synonymized all forms possessing a circular or almost circular ornamentation and lacking well-developed auricle (*M. opalensis* (Seitz, 1935, *non* Böse), *M. goppelnensis* (Badillet & Sornay, 1980), *M. modeliaensis* (Sornay, 1981)), with *Mytiloides kossmati* (Heinz). Recently Walaszczyk & Cobban (2000b) interpreted *M. goppelnensis* as a distinct species, which differs from *M. kossmati* in lacking double-ridged rugae. In the same study they included *M. columbianus* (Heinz, 1935) (= *I. plicatus* d'Orbigny of Heinz 1928b, pl. 4, fig. 4) and *M. modeliaensis* in synonymy with *M. kossmati*. This new concept is followed herein.

A re-evaluation of *Inoceramus peruanus* Brüggen, 1910, based on a revision of the holotype and other specimens from Peru and Ecuador, was recently presented by Dhondt *et al*. (2004). According to these authors, *I. peruanus* this is a species of *Mytiloides*, and its general outline and double-ridged rugae are morphologically very close to those of *M. kossmati* (which includes *M. modeliaensis* and *M. columbianus*). Thus, the two species are possibly conspecific. However, the specimens are poorly preserved and no formal taxonomic decision for the Peruvian species was given, because for such a conclusion further studies of material from the original locality would be necessary (Dhondt *et al*., 2004). The specimens of Brüggen (1910), re-illustrated by Dhondt *et al*. (2004, figs 1.4–7), differ from *M. kossmati* in having a more rounded outline, with raised concentric rugae and a more central beak. Moreover, *M. peruanus* (Brüggen) was mentioned in the literature from Peru and Colombia with ages that vary from Turonian (Steinmann, 1929) to the late Coniacian (Bürgl, 1957).

Occurrence. Lower Turonian of Colombia, U.S. Western Interior, Texas, France, Germany, Poland, Spain, Japan, Madagascar and Sergipe (Brazil).

Mytiloides goppelnensis (Badillet & Sornay, 1980)
Plate 2, Figures 1–3

1935 *Inoceramus labiatus* var. *opalensis* Böse; Seitz, p. 457, pl. 39, fig. 1.

1935 *Inoceramus labiatus* var. *opalensis* Böse n. forma *elongata*; Seitz, p. 458, pl. 38, figs 4–6; pl. 39, figs 2–4; text-figs 14–15.

pars 1935 *Inoceramus labiatus* n. var. *subhercynica*; Seitz, pp. 465–468, pl. 40, figs 2, 5, text-figs 18a–f (non pl. 40, fig. 1 = *M. subhercynicus*).

1977 *Mytiloides opalensis* (Böse); Kauffman & Powell, pp. 79–81, pl. 6, figs 3, 6.

1978 *Mytiloides opalensis elongata* (Seitz); Wiedmann & Kauffman, pl. 2, figs 5, 11.

1978 *I. hercynicus* Petraschek; Robaszynski, pl. 2, fig. 3 (only).

1980 *Inoceramus goppelnensis* nom. nov.; Badillet & Sornay, p. 324.

1982 *Mytiloides goppelnensis* (Badillet & Sornay, 1980); Keller, pp. 128–130, pl. 3, fig.1.

1982 *Inoceramus goppelnensis* Sornay; Sornay, p. 139, pl. 7, fig. 4.

1988 *Mytiloides modeliaensis* (Sornay, 1981); Hessel, pp. 19–20, fig. 30c.

1989 *Inoceramus* (*Mytiloides*) *goppelnensis goppelnensis* (Badillet & Sornay); Lamolda *et al*., fig. 4.2.

1991 *Mytiloides* sp.; Kennedy & Cobban, figs 11d–e.

1991 *Mytiloides opalensis* (*sensu* Kauffman); Elder, figs 4.3–5.

1992 *Inoceramus* (*Mytiloides*) *goppelnensis goppelnensis* Badillet & Sornay, 1980; López, pp. 496–501, pl. 1, fig. 2; pl. 2, fig. 1.

pars 1992 *Mytiloides kossmati* (Heinz, 1930); Walaszczyk, p. 10, pl. 1, figs 1–8 (non pl. 1, fig. 9 = *M. kossmati*).

1995 *Mytiloides goppelnensis* (Badillet & Sornay); Matsumoto & Nishida, figs 6a–c.

1997 *M. kossmati kossmati*; Lamolda *et al*., fig. 8c.

1999 *Mytiloides ganuzaensis* (López, 1992); Seeling, pp. 94–96, pl. 2, fig. 1.

2000b *Mytiloides goppelnensis* (Badillet & Sornay, 1980); Walaszczyk & Cobban, pp. 323–324, pl. 7, figs 9–11; pl. 8, figs 12, 14; pl. 9, figs 1–3; pl. 10, figs 2, 5, 9–10, 12; pl. 11, figs 2, 5, 7, 10; pl. 12, fig. 6; pl. 13, fig. 6.

Material. 69 mainly incomplete specimens from locality Retiro 26 preserved as internal moulds of LV and or RV and shell fragments: RT26.15–17, 20, 22, 30, 33–35, 44–46, 48, 49, 52–54, 56, 58, 59, 78, 79, 84, 85, 88, 90, 95, 98, 102–104, 110–113, 116, 129, 136, 137, 144, 145, 158, 164, 165, 171, 172, 174, 181–184, 186, 188, 198, 199, 208, 215, 221, 241, 270, 448, 455,485, 488, 490, 495, 498, 621, 623. Five specimens of Hessel (1988): PMU SA-154, 155, 176, 194, 213.

Description. Medium-sized to large (Table 4). Outline subquadrate to oval-elongate; inequilateral; equivalve. Valves slightly to moderately convex, with maximum inflation dorsocentral, more flattened towards ventral margin. Beak projecting above hinge line. Hinge line straight, short to moderately long. Posterior auricle small, subtriangular, indistinctly separated from the disc. Anterior margin convex, long, passing into rounded ventral margin; posterior margin almost straight to slightly convex. Ornamentation consisting of raised, slightly asymmetrical single rugae, variably separated; rugae of adult part covered with growth lines that weaken towards anterior and posterior margins.

Table 4: Measurements of selected specimens of *M. goppelnensis* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.20 RV	27.2	24.4	0.90	*32.2	*31.1	0.96	-	104	53	120	7.0	30.6
RT26.35 RV	41.3	36.6	0.89	*72.9	67.3	0.92	26.4	100	50	110	4.0	76.0
RT26.45 RV	25.1	25.4	1.01	*32.4	*28.6	0.88	13.3	118	59	135	4.0	*36.0
RT26.56 RV	41.0	34.0	0.83	89.0	75.0	0.84	32.0	100	56	103	11.0	95.0
RT26.58 RV	40.0	31.0	0.77	46.5	*40.0	0.86	17.0	100	67	115	-	51.0
RT26.111 RV	38.0	29.0	0.76	58.0	50.5	0.87	-	85	-	-	4.5	67.0
RT26.113 RV	29.5	24.0	0.81	38.0	31.0	0.81	23.4	106	59	111	5.0	41.7
RT26.129 RV	41.0	33.0	0.80	*65.0	61.0	0.93	16.0	96	54	100	8.0	*72.0
RT26.136 RV	39.0	31.0	0.79	*54.5	52.0	0.95	28.0	94	51	102	7.5	*50.0
RT26.144 RV	39.5	32.0	0.81	*63.0	52.5	0.83	18.0	93	55	97	-	67.0
RT26.158 LV	31.0	26.0	0.84	*46.0	*37.0	0.84	14.0	-	62	-	-	*51.0
RT26.174 LV	29.0	24.0	0.83	*42.0	*33.0	0.78	18.0	-	-	-	-	*37.2
RT26.182 LV	55.5	41.0	0.74	102.0	*89.0	0.87	29.0	-	51	80	12.0	127.0
RT26.186 RV	48.0	34.0	0.71	*62.0	*50.0	0.81	*14.6	106	50	95	12.0	*69.5
RT26.188 RV	42.0	31.0	0.74	64.0	*55.0	0.85	25.0	95	45	93	4.0	*72.0
RT26.198 LV	38.0	32.0	0.84	50.0	44.0	0.88	18.5	86	56	103	-	55.0
RT26.199 RV	40.0	31.0	0.78	*63.0	*51.0	0.81	14.0	-	53	103	4.0	70.0

Discussion. The specimens from Retiro 26 are very similar to the specimens of *M. goppelnensis* illustrated by Seitz (1935). They show some variation in outline, which includes subquadrate as well as oval to more elongate shells (Pl. 2, Figs 1–3). The spacing of the single-ridged rugae is variable. Some specimens, for example RT26.164, 172, 490, with more spaced, ridged rugae resemble *M. peruanus* Brüggen. However, they are incomplete and poorly preserved. Also the inflation of the shells varies to some extent; some specimens have more flattened shells. There are also specimens transitional to *M. ganuzaensis* (López), such as RT26.186 (Pl. 2, fig. 4), which shows rounded spaced rugae covered with growth lines on the adult part.

Specimens PMU SA-154, 155 and 213 of Hessel (1988) are incomplete and their juvenile ornamentation is very similar to that of *M. goppelnensis*, but their ornamentation also resembles that found on the earlier convex ontogenetic stage of *Rhyssomytiloides mauryae*

(Hessel, 1986). The specimens of Hessel derive from her bed A (Hessel, 1988), where species of *Rhyssomytiloides* already occur.

Badillet & Sornay (1980) revised the forms interpreted by Seitz (1935) as *I. labiatus opalensis* and *I. labiatus opalensis* forma *elongatus* and recognized the difference between these two forms and *I. opalensis* Böse (1923). Thus, they introduced the new name *M. goppelnensis* for the two taxa of Seitz.

Walaszczyk (1992) treated Seitz' species very widely, including forms with and without double-ridged rugae in a single species. He also placed *M. goppelnensis* (Badillet & Sornay, 1980) and *M. modeliaensis* (Sornay, 1981) in synonymy with *M. kossmati* (Heinz, 1933). However, in a subsequent study Walaszczyk & Cobban (2000b) recognized *M. kossmati* and *M. goppelnensis* as separated species, and stated that *M. goppelnensis* is the proper name for *M. opalensis sensu* Seitz.

Specimens described and illustrated as *M. ganuzaensis* by Seeling (1999, pl. 2, fig. 1) from localities Japaratuba 11 and Jardim 29 are typical forms of *M. goppelnensis*. These specimens have subequal single-ridged rugae and do not exhibit rounded spaced rugae covered with regular to sub-regular growth lines as in *M. ganuzaensis*.

Occurrence. Lower Turonian of the U.S. Western Interior (Pueblo, Colorado), Colombia, France, Germany, Poland, Spain, Japan and Sergipe (Brazil).

Mytiloides mytiloides (Mantell, 1822)

Plate 2, Figures 5–12; Plate 3, Figures 1–6

1822 *Inoceramus mytiloides*, Mantell, p. 215, pl. 28, fig. 2.

pars 1871 *Inoceramus labiatus* Schloth. sp.; Geinitz, pp. 46–48, pl. 12, figs 2 and 3 (only).

1899 *Inoceramus labiatus* Schloth.; Simionescu, pp. 269–260, pl. 1, fig. 9, pl. 2, fig. 2.

pars 1911 *Inoceramus labiatus* (Schlotheim), 1813; Woods, pp. 281–284, Text-fig. 37, pl. 50, figs 2 and 3 (only).

1933 *Mytiloides labiatus* (Schloth.); Heinz, pp. 248–249, pl. 17, fig. 2 (only).

1935 *Inoceramus labiatus* var. *mytiloides* Mant.; Seitz, p. 435, pl. 36, figs 1–4, pl. 37, figs 4 and 5, text-fig. 2a–f, text-fig. 3a–f.

1937 *Inoceramus labiatus cedroensis* subsp. nov.; Maury, p. 113, pl. 8, fig. 17.

1954 *Inoceramus* (*Mytiloides*) *labiatus* (Schlotheim) sensu lato; Rutsch & Salvador, pp. 419–421, pl. 40, fig. 1.

1961 *Inoceramus labiatus* (Schlotheim) 1813; Rossi Ronchetti, pp.348–349, pl. 26, figs 1–4.

1965 *Inoceramus paramytiloides* n.sp.; Sornay, pp. 13–14, pl. C, figs 1–4, test-figs 6–7.

1972 *Inoceramus labiatus* v. Schloth. v. *mytiloides* Mant.; Sornay, p. 32, pl. 1, fig.8.

1977 *Mytiloides mytiloides* (Mantell); Kauffman & Powell; pp. 74–78, pl. 6, figs 11–16.

1978 *Mytiloides mytiloides mytiloides* (Mantell) sensu Seitz, 1934; Kauffman, pl. 1, figs 4, 12.

1978 *Mytiloides mytiloides* (Mantell) n. subsp., late elongate form; Kauffman, pl. 1, fig. 11.

1978 *Mytiloides submytiloides* (Seitz); Kauffman, pl. 1, figs 2, 7, 8.

1981 *Inoceramus* (*Mytiloides*) aff. *paramytiloides* Sornay, 1965; Sornay, pp. 140–141, pl. 2, fig. 2.

1982 *Mytiloides mytiloides* (Mantell, 1822); Keller, pp. 121–125, pl. 3, figs 4, 6.

1982 *Mytiloides* sub*mytiloides* (Seitz, 1934); Keller, pp. 125–128, pl. 3, fig. 2.

1982 *Inoceramus mytiloides* Mantell; Sornay, p. 139, pl. 7, fig. 2.

1987 *Mytiloides mytiloides* (Mantell); Hattin, p. 243, figs 13a–b.

1988 *Mytiloides mytiloides* (Mantell, 1822); Hessel, pp. 16–18, figs 30a–b.

1988 *Mytiloides* aff. *mytiloides* (Mantell, 1822); Hessel, pp. 18–19, fig. 30e.

1988 *Mytiloides submytiloides*? (Seitz, 1935); Hessel, p. 19, fig. 30d.

1989 *Inoceramus* (*Mytiloides*) *mytiloides* (Mantell); Lamolda et *al*., fig. 3.7.

1989 *Inoceramus* (*Mytiloides*) *submytiloides*? (Seitz); Lamolda et *al*., fig. 4.1.

1991 *Mytiloides mytiloides* (Mantell, 1822); Kennedy & Cobban, p. 18, figs 11f–i.

1992 *Inoceramus* (*Mytiloides*) *mytiloides* Mantell, 1822; López, pp. 484–492, pl. 1, figs 3–4.

1992 *Inoceramus* (*Mytiloides*) *submytiloides* Seitz, 1934; López, pp. 492–494, pl. 2, fig. 3.

pars 1992 *Mytiloides labiatus* (Schlotheim, 1813); Walaszczyk, pp. 13–16, pl. 1, fig. 10; pl. 4, figs 1, 3.

1995 *Mytiloides mytiloides* (Mantell); Matsumoto & Nishida, figs 7a–g.

1997 *Mytiloides mytiloides*; Lamolda *et al*., fig. 8a.

1997 *Mytiloides submytiloides*; Lamolda *et al*., fig. 8b.

1998 *Mytiloides mytiloides*; Villamil & Arango, figs 6a, c, d.

1999 *Mytiloides mytiloides* (Mantell, 1822); Seeling, pp. 96–98, pl. 2, figs 2, 3.

2000b *Mytiloides mytiloides* (Mantell, 1822); Walaszczyk & Cobban, pp. 325–326, pl. 12, figs 4, 5, 7–12, pl. 13, fig. 7.

2001 *Mytiloides mytiloides* (Mantell); Jolet *et al.*, fig. 7.11.

2003 *Mytiloides submytiloides* (Seitz, 1935); Cassab, p. 55, fig. 29a.

Material. 54 specimens from locality Retiro 26 mainly represented by incomplete internal moulds of single LV or RV or shell fragments. Only two specimens are double-valved: RT26.18, 21, 40, 41, 43, 50, 51, 63, 100, 121, 138, 140, 142, 151, 152, 157, 167–170, 185, 187, 189–193, 200, 203, 207, 406, 409, 410, 411, 415, 418, 419, 421, 422, 426, 429, 433, 446, 452, 466, 479, 487, 491, 523–526, 560, 610, 616. Nine specimens of Hessel (1988): PMU SA-193, 195–197, 199–202, 222.

Description. Medium-sized to large (Table 5). Outline oval, disc narrow, axially elongated, strongly prosocline; inequilateral, subequivalve; weakly to moderately inflated, maximum inflation dorsocentrally. Hinge line straight, long; angle of inclination (i) small (averages 44°). Beak moderately projecting above hinge line. Posterior auricle large and well separated from disc by sulcus. Anterior margin long, slightly convex; posterior margin relatively straight; ventral margin rounded.

Ornamentation consisting of low, irregularly spaced, subequal rugae, covered with fine to slightly raised growth lines. Shell more flattened on adult part, with ornament weakening towards ventral margin.

Table 5: Measurements of selected specimens of *M. mytiloides* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.50 RV	33.5	21.5	0.64	*52.0	*45.0	0.86	26.0	-	45	82	5.0	*63.0
RT26.51 RV	40.5	28.3	0.70	*49.0	*40.0	0.82	20.5	72	45	90	11.0	*51.0
RT26.138 LV	35.0	22.0	0.63	*46.0	*33.0	0.72	14.0	70	46	84	9.0	*50.0
RT26.167 RV	37.0	26.0	0.70	*45.5	*35.0	0.77	-	-	-	-	-	*42.0
RT26.185 LV	47.0	30.0	0.64	*59.0	*44.0	0.74	22.0	78	45	96	13.0	*55.5
RT26.187 RV	42.0	31.0	0.74	*70.0	*62.0	0.88	35.0	-	40	81	9.0	*76.0
RT26.189 RV	47.5	32.0	0.67	*73.0	*66.0	0.90	29.6	-	44	87	-	*86.0
RT26.190 LV	50.0	33.0	0.66	92.5	122.0	1.31	35.0	81	36	78	29.0	128.0
RT26.406 LV	15.5	10.0	0.65	*40.0	*39.0	0.97	22.0	-	54	90	8.0	*47.0
RT26.560 LV	41.0	28.5	0.70	*52.0	*53.0	1.02	30	-	40	90	-	*58.0
RT26.610 RV	33.5	22.5	0.67	*35.0	*32.0	0.91	19.5	92	46	80	6.0	*44.0

Discussion. The specimens from Retiro 26 display a relatively wide range of variation in ornamentation, especially concerning to the development of the rugae. Some specimens, for example RT26.51 and RT26.610, are weakly ornamented, with weak rugae and fine growth lines to relatively smooth surface (Pl. 2, Figs 5 and 6). Others have regularly to irregularly spaced rugae, covered with raised growth lines, such as in RT26.187 (Pl. 3, Fig. 3); or low rugae that are irregularly covered with fine growth lines, such as in RT26.415 and RT26.560 (Pl. 3, Figs 4 and 6). The convexity of the shells also varies, which can be observed in co-occurring specimens, for example RT26.51 and RT26.50 (Pl. 2, Figs 6 and 7), which show more convex and flattened shells respectively.

Specimens RT26.190 and RT26.406 (Pl. 3, Figs 1 and 5) have an axially elongated disc, longer hinge lines and larger posterior auricles than in typical *M. mytiloides*. Moreover, they have more inflated shells, especially on the umbonal part, thus showing a morphotype transitional to *M. labiatus*.

Specimen RT26.167 (Pl. 2, Fig. 12) has a mytiloid outline and a very fine ornamentation, which shows similarities to *Inoceramus pictus sackensis* Keller, 1982. However, the specimen from Sergipe is incomplete and its auricle is damaged. Thus, to confirm the presence of that species in the Sergipe Basin more material is needed.

Before Seitz' (1935) study, *M. mytiloides* (Mantell) was commonly included in the synonymy of *M. labiatus* (Schlotheim, 1813). Based on statistical analysis, Seitz (1935) differentiated three species within the group of the typical labiatoid lower Turonian inoceramids: *M. labiatus*, *M. mytiloides* and *M. submytiloides*. According to him, *M. labiatus* differs from *M. mytiloides* in having a higher SA/AL ratio and a higher inclination. The other characters are undistinguishable in the two species. Kauffman & Powell (1977) discussed the interpretation of Seitz (1935) and accepted *M. mytiloides* and *M. labiatus* as distinct species. They differentiated the two species on the basis of ornamentation, the convexity of the beak and the umbo, and the angle of inclination. Keller (1982) also separated the two species, with *M. labiatus* having a higher hinge angle, a shorter anterior margin and a larger angle of umbonal inflation than *M. mytiloides*.

Walaszczyk (1992) remarked that the character sets used to define the two species differed widely. In his opinion, based on studied material and the lack of well-working concepts for *M. labiatus* and *M. mytiloides*, the distinction of the two species is questionable and both should represent extreme morphs of a single species, which, according to the priority rule, must be referred to *M. labiatus* (Schlotheim). However, Walaszczyk & Cobban (2000b) recognized that according to the North American record the two species are clearly distinct and probably had quite different evolutionary origins. However, they did not give a detailed description of their specimens of *M. labiatus* and also discussed the possibility of forms referred to the latter species belonging to *Inoceramus apicalis* Woods.

Following the concepts of Seitz (1935), Kauffman & Powell (1977), Walaszczyk & Cobban (2000b) and Walaszczyk (2004, Warsaw, written communication), *M. mytiloides* differs from *M. labiatus* in having a smaller beak, a more inclined and less convex shell, and lower SA/AL ratios, which average 0.67 for specimens from Sergipe, expressing an elongated axially disc. However, owing to the strong variability of *M. mytiloides* a more extensive systematic revision of this species is needed.

Inoceramus paramytiloides described by Sornay (1965) from Madagascar shows the same characters as *M. mytiloides*, e.g., an oblique outline, a long hinge line, a long anterior margin, and is only slightly convex. The same characters can be observed in *I.* (*M.*) aff. *paramytiloides* described by Sornay (1981) from Colombia. Both forms are here considered synonymous with *M. mytiloides*.

The interpretations of *M. submytiloides* (Seitz, 1935), as given by some workers, for example Hessel (1988) and López (1992), differ considerably from the original concept of Seitz (1935). These authors did not mention the presence of a distinct anterior sulcus, the character used by Seitz to differentiate this species from *M. mytiloides*. An extensive discussion about the taxonomical justification of *M. submytiloides* was presented by Walaszczyk (1992). He mentioned that besides the anterior sulcus, there is no other character that allows the distinction of *M. submytiloides* from *M. mytiloides*. According to him, the anterior sulcus is found only in specimens preserved as internal moulds, which makes it difficult to state whether or not this character represents an original element of the shell. Thus, as long as the taxonomical value of the anterior sulcus is not proved, there is no reason to consider *M. submytiloides* as a distinct species. This opinion is also followed here. Therefore, the hitherto illustrated forms of *M. submytiloides* are considered to fall within the range of variation of *M. mytiloides*.

Occurrence. Lower Turonian and lowermost middle Turonian of the U.S. Western Interior, Texas, Colombia, France, Spain, Germany, England, Poland, Czech Republic, Afghanistan, Japan, Morocco, Madagascar and Sergipe and Rio Grande do Norte (Brazil).

Mytiloides ganuzaensis (López, 1992)
Plate 2, Figure 12

1989 *Inoceramus* (*Mytiloides*) *goppelnensis* (Badillet & Sornay) n. subsp.?; Lamolda *et al.*, text-fig. 4.3.
1992 *Inoceramus* (*Mytiloides*) *goppelnensis ganuzaensis* subsp. nov; López, pp. 503–507, pl.2, fig. 2.
non 1999 *Mytiloides ganuzaensis* (López, 1992); Seeling, pp. 94–96, pl. 2 fig. 1 (= *M. goppelnensis*).
2000b *Mytiloides ganuzaensis* (López, 1992); Walaszczyk & Cobban, pp. 324–325, pl. 11, figs 1, 3, 6, 8–9; pl. 13, figs 1–5.

Material. Four specimens from locality Retiro 26, preserved as one incomplete internal mould of RV and three incomplete shells: RT26.205, 206, 424, 451.

Description. Medium-sized to large (Table 6). Outline ovate, slightly convex. Posterior auricle flattened, well developed, without auricular sulcus. Anterior margin rounded to slightly straight, ventral margin rounded; posterior margin almost straight. Ornamentation consisting of regularly spaced, rounded rugae covered with regularly to sub-regularly spaced growth lines; rugae narrow on umbonal and juvenile parts, becoming wider towards ventral margin.

Table 6: Measurements of the specimens of *M. ganuzaensis* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.205 (RV)	49.0	39.0	0.79	76.0	*61.0	0.80	20.0	-	57	108	3.0	85.0
RT26.206 (LV)	40.0	36.0	0.90	49.0	*42.0	0.85	18.0	-	52	-	2.0	58.0
RT26.424 (RV)	43.0	31.0	0.72	*54.0	*44.0	0.81	-	-	-	-	2.0	51.0
RT26.451 (RV)	31.0	24.0	0.77	*38.0	*40.0	1.05	25.0	-	48	105	4.0	48.0

Discussion. The specimens of *M. ganuzaensis* from Retiro 26 show ornamentation similar to that of the specimens of López (1992). However, the Sergipe specimens are less convex and some of them show a more elongate outline, as in RT26.205 (Pl. 2, Fig. 13). Specimen RT26.206 has a similar outline as the holotype, but the ornamentation is poorly preserved.

M. ganuzaensis differs from *M. goppelnensis* (Badillet & Sornay) in its ornamentation. The latter has slightly asymmetrical raised single rugae. With respect to its outline and ornamentation, *M. ganuzaensis* is more similar to *M. mytiloides* (Mantell), although ornamentation of the latter species is more irregular. Nevertheless, the two species seem to be closely related.

The specimens described by Seeling (1999) as *M. ganuzaensis* (López) from Japaratuba 11 and Jardim 29 show the typical ornamentation of *M. goppelnensis* and are referred to this species (see discussion of *M. goppelnensis*).

Occurrence. Lower Turonian of Spain, France, the U.S. Western Interior and Sergipe (Brazil).

Mytiloides labiatus (Schlotheim, 1813)
Plate 3, Figures 7–13

1813 *Ostracites labiatus* von Schlotheim, p. 93.
1871 *Inoceramus labiatus* Schloth. sp.; Geinitz, pp. 46–48, pl. 12, fig. 1 (only).
pars 1911 *Inoceramus labiatus* (Schlotheim), 1813, Woods, pp. 281–284, pl. 50, figs 1, ?4 5, 6 (*non* figs 2 and 3 = *M. mytiloides*).
1933 *Mytiloides labiatus* (Schloth.); Heinz, pp. 248–249, pl. 17, figs 1, 3 (*non* fig. 2 = *M. mytiloides*).
1935 *Inoceramus labiatus* v. Schloth. var. *labiata*; Seitz, pp. 448–454, pl. 38, figs 1–3, text-fig. 9.
1965 *Inoceramus labiatus* von Schloth. var. *antsaronaensis* n. var.; Sornay, pp. 12–13, pl. B, fig. 1; pl. C, fig. 5.
1978 *Mytiloides labiatus labiatus* (Schlotheim); Kauffman, pl. 3, figs 1, 6; pl. 4, fig. 9.
1978 *Mytiloides labiatus* (Schlotheim; sensu Seitz, 1935) n. subsp. (late form); Kauffman *et al*., pl. 6, fig. 14.
1982 *Mytiloides labiatus* (Schlotheim, 1813); Keller, pp. 119–121, pl. 3, fig. 3.
pars 1992 *Mytiloides labiatus* (Schlotheim, 1813); Walaszczyk, pp. 13–16, pl. 2, figs 1–3; pl. 3, figs 1–4; pl. 4, fig.4.

Material. Thirteen mainly incomplete, poorly preserved specimens from locality Retiro 26, mainly represented by internal moulds of single LV or RV, some with shell fragments. Only one double valved specimen present: RT26.242, 243, 271, 273, 274, 416, 420, 431, 434, 435, 447, 520, 521.

Description. Small to medium-sized (Table 7). Outline obliquely elongate to subovate; inequilateral; strongly inflated, maximum inflation anterodorsal. Hinge line short; beak-umbo projecting above hinge line. Posterior auricle short, not separated from disc by sulcus. Anterior margin short, slightly convex, passing into long ventral margin; posterior margin almost straight to slightly convex. Ornamentation consisting of low and irregularly spaced rugae.

Table 7: Measurements of selected specimens of *M. labiatus* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.420 LV	16.0	12.5	0.78	*36.0	*35.0	0.97	-	-	45	94	9.0	49.0
RT26.434 RV	29.0	23.0	0.79	32.0	*30.0	0.94	12.0	-	50	-	11.0	40.0
RT26.435 LV	37.5	30.0	0.80	46.0	44.0	0.95	15.0	100	50	96	18.0	50.0
RT26.447 RV	30.0	26.0	0.86	*67.0	*54.0	0.80	-	103	-	-	11.0	*68.0

Discussion. The specimens from Retiro 26 are poorly preserved and most of them are small, probably juvenile forms. The majority has a weaker ornamentation than the specimens of *M. labiatus* described by Heinz (1933) and the type of *Inoceramus labiatus antsaronaensis* described by Sornay (1965) from Madagascar. They are very similar to specimens illustrated by Keller (1982) from Germany. In some specimens, e.g., RT26.416 and 447, the rugae are stronger. These specimens are more similar to specimens described from Poland (Walaszczyk, 1992). However, in the Polish specimens the rugae are more irregularly developed.

The outline, the convexity and the concentric ornamentation of specimens RT26.420 (Pl. 3, Fig. 9) and RT26.435 (Pl. 3, Fig. 11) indicate that these might represent a precursor of *Rhyssomytiloides retirensis* Hessel, 1988. The latter specimen is poorly preserved, but has the same outline.

Seitz (1935), Kauffman & Powell (1977), Walaszczyk (1992) and Walaszczyk & Cobban (2000b) discussed the *M. labiatus* lineage. *M. labiatus* is very similar to *M. mytiloides*, but the latter has a large and axially elongated posterior auricle and a less inflated shell. Moreover, *M. labiatus* has higher SA/AL ratios (averages 0.80) than *M. mytiloides* (averages 0.67) (see also discussion under *M. mytiloides*).

Occurrence. Lower Turonian of Germany, England, Czech Republic, Poland, Madagascar, the U.S. Western Interior and Sergipe (Brazil).

Mytiloides subhercynicus (Seitz, 1935)

Plate 4, Figures 7–10

pars 1935 *Inoceramus labiatus* n. var. sub*hercynica*; Seitz, p. 465, pl. 40, fig. 1 (*non* pl. 40, figs 2 and 5; text-figs 18a–f = *M. goppelnensis*).

1935 *Inoceramus labiatus* n. var. sub*hercynica* n. forma *transiens*; Seitz, p. 468, pl. 40, fig. 3–4.

1978 *Mytiloides subhercynicus transiens* (Seitz); Kauffman, pl. 1, fig. 6.

non 1976 *Mytiloides subhercynicus* (Seitz); Offodile, p. 71, pl. 16, fig. 1.

1978 *Mytiloides subhercynicus subhercynicus* (Seitz); Kauffman *et al.*, pl. 6, figs 7, 8.

1982 *Mytiloides transiens* (Seitz, 1934); Keller, pp. 133–135, pl. 3, fig. 5.

1988 *Mytiloides transiens* (Seitz, 1935); Hessel, pp. 21–22, fig. 31a–b.

?1988 *Mytiloides* aff. *goppelnensis* (Badillet & Sornay, 1980); Hessel, pp. 20–21, fig. 31c.

pars 1988 *Mytiloides hercynicus* (Petrascheck, 1904); Hessel, p. 21, only fig. 31f (*non* 31d–e = *M. hercynicus*).

pars 1992 *Mytiloides opalensis* (Böse); Walaszczyk, pp. 19–20, pl. 6, figs 1, 4; pl. 7, figs 1–3; pl. 8, fig. 2.

1992 *Inoceramus* (*Mytiloides*) *transiens* Seitz, 1934; López, pp. 507–510, pl. 2, fig. 5.

1994 *Mytiloides subhercynicus* (Seitz, 1935); Chancellor *et al.*, pl. 27, figs 1, 2, 4.

1998 *Mytiloides subhercynicus*; Villamil & Arango, figs 6e, 7b.

2000b *Mytiloides subhercynicus* (Seitz, 1935); Walaszczyk & Cobban, pp. 327–329, pl. 15, figs 1–7.

Material. 26 mainly incomplete, poorly preserved specimens from locality Retiro 26, represented by shells and or incomplete internal moulds of single LV or RV: RT26.283, 294, 312, 316, 317, 324, 332, 333, 336, 339, 347, 352–354, 364, 394, 527, 528, 561, 567, 568, 578, 584, 585, 589, 627. Eleven specimens of Hessel (1988): PMU SA-152, 164, 166, 175, 178, 180, 181, 190, 191, 198, 226.

Description. Medium-sized (Table 8). Outline obliquely elongate to subovate; inequilateral; weakly inflated, maximum inflation dorsocentrally, growth axis oblique. SA/AL ratio low (averages 0.83); angle of inclination (i) low, between 48° and 50°. Hinge line short to moderately long; beak slightly projecting above the hinge line. Posterior auricle subtriangular, moderately to well-developed, separated from disc by a large step-like fold. Anterior and ventral margins rounded; posterior margin almost straight. Ornamentation on juvenile part consisting of fine, closely spaced rugae; adult part with widely spaced and slightly asymmetrical rugae, covered with concentric growth lines.

Table 8: Measurements of selected specimens of *M. subhercynicus* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.332 LV	19.1	16.5	0.86	*27.5	*31.5	1.10	*13.0	130	50	109	2.0	*33.5
RT26.336 LV	25.5	19.5	0.76	*42.0	*38.0	0.90	16.5	-	48	137	2.0	45.5
RT26.347 LV	31.0	26.1	0.84	*48.0	*50.0	1.04	19.6	124	48	130	4.0	*55.0
RT26.578 LV	25.5	21.0	0.82	*40.0	38.0	0.95	15.0	-	-	-	3.0	46.5
RT26.627 LV	52.5	45.5	0.86	80.0	89.0	1.11	-	-	-	-	3.0	92.5

Discussion. The Sergipe specimens show some variation with respect to the ornamentation. In some specimens the rugae in the adult part are very low and covered with slightly raised growth lines. The juvenile part is distinctly subcircular in some specimens, e.g., RT26.347 (Pl. 4, fig. 9).

Walaszczyk (1992) discussed and interpreted *M. subhercynicus* (Seitz) as a conglomerate of extreme forms belonging to different species, and which does not represent any independent taxon. However, Walaszczyk & Cobban (2000b) re-evaluated the definition of *M. subhercynicus* (Seitz) and referred some specimens illustrated by Seitz (1935, pl. 40, figs 2 and 5; text-fig 18a–f) to *M. goppelnensis*. They also discussed the differences between *M. subhercynicus* (Seitz) and *M. hercynicus* (Petrascheck) and maintained them as separate species.

According to Walaszczyk & Cobban (2000b), the form *transiens* was applied by Seitz (1935) to a particular ontogenetic stage of *M. subhercynicus*. This opinion is followed here.

M. subhercynicus is very similar to *M. hercynicus*. Both species have a characteristic step-like boundary between disc and posterior auricle in the juvenile part, but in *M. hercynicus* the disc is oval, with the long axis parallel to the hinge line, whereas *M. subhercynicus* has a more oblique form, smaller inclination angles (i), which oscillate between 48° and 50°, and lower SA/AL ratios than the latter. Nevertheless, the transition between the two species has been little discussed. Their morphological differences are not clearly defined and most published studies consist of only illustrations without adequate descriptions.

Specimen PMU SA-164, referred to *M.* aff. *goppelnensis* by Hessel (1988, fig. 31c), shows a marked distinction between the juvenile and adult parts. The ornamentation in the juvenile part and the maximum inflation in the dorso-central part of the disc resemble those of

M. goppelnensis, but the specimen differs from the latter species in possessing a large posterior auricle, which is well separated from the disc. This specimen might represent a transitional form between *M. goppelnensis* and *M. subhercynicus*. However, the other specimens, also referred to *M.* aff. *goppelnensis* (PMU SA-190 and 198) by Hessel, have the typical ornamentation and oblique form of *M. subhercynicus*.

A number of specimens referred by Walaszczyk (1992) to *M. opalenis* (Böse) are more oblique than the original specimens of Böse (1923), which are almost erect. Most of them are better referred to *M. subhercynicus* (see synonymy).

Occurrence. Lowermost middle Turonian of the Czech Republic, England, France, Germany, Poland, Spain, Tunisia, Colombia, the U.S. Western Interior and Sergipe (Brazil).

Mytiloides cf. *subhercynicus* (Seitz, 1935)

Material. Ten specimens from locality Retiro 26, represented by incomplete internal moulds of LV or RV or shell fragments: RT26.295, 301, 309, 310, 323, 329, 348, 362, 372, 601.

Discussion. All specimens are incomplete or represent juvenile forms. However, their ornamentation pattern and their oblique outline resemble *M. subhercynicus*.

Occurrence. Lowermost middle Turonian of Sergipe (Brazil).

Mytiloides hercynicus (Petrascheck, 1903)
Plate 5, Figures 1–4, 7–10

v. 1903 *Mytiloides hercynicus* n. sp.; Petrascheck, pp.156–158, pl. 8 figs 1–3, text-fig. 1.
1923 *Inoceramus Hercynicus* Petrascheck; Böse, pp. 181–183, pl. 12, figs 1–5.
1935 *Inoceramus labiatus* var. *hercynica* Petr.; Seitz, pp. 454–457.
?1960 *Inoceramus hercynicus* Petr.; Moskvin & Pavlova, pp. 135–136, pl. 2, fig. 3, pl. 3, figs 1, 2.
?1972 *Inoceramus* sp. juv. ex gr. *hercynicus* Petr.; Sornay, p. 32, pl. 1, fig. 6.
non 1976 *Mytiloides hercynicus* (Petrascheck); Offodile, p. 71, pl. 15, figs 4, 5.

1978 *Mytiloides subhercynicus subhercynicus* (Seitz); Kauffman, pl. 1, fig. 5; pl. 3, fig. 3.

1978 *Mytiloides* ? *hercynicus* (Petrascheck); Kauffman, pl. 1 fig. 10.

1978 *Mytiloides hercynicus* (Petrascheck); Kauffman, pl. 3, fig. 7.

1978 *Mytiloides* ? *hercynicus* (Petrascheck); Kauffman *et al*., pl. 6, fig. 11.

1982 *Mytiloides hercynicus* (Petrascheck, 1903); Keller, p. 131–132, pl. 4, fig. 1.

1984 *Inoceramus* (*Mytiloides*) *hercynicus* Petrascheck; Berthou, pl. 1, fig. 3.

v. pars 1988 *Mytiloides hercynicus* (Petrascheck, 1904); Hessel, p. 21, figs 31d–e (*non* 31f = *M. subhercynicus*).

v. pars 1988 *Sergipia hartti* n. sp.; Hessel, pp. 23–25, only fig. 32f.

1989 *Inoceramus* (*Mytiloides*) *hercynicus* (Petrascheck); Lamolda *et al*., fig. 4.4.

1992 *Inoceramus* (*Mytiloides*) *hercynicus* Petrascheck, 1903; López, pp. 510–514, pl.3 fig. 1.

1992 *Mytiloides hercynicus* (Petrascheck, 1903); Walaszczyk, pp. 17–19, pl. 5, figs 1–5.

pars 1992 *Mytiloides opalensis* (Böse); Walaszczyk, pp. 19–20, pl. 8, figs 1 and 3.

1997 *M. hercynicus*; Lamolda *et al*., fig. 8e.

1998 *Mytiloides hercynicus* (Petrascheck); Küchler, pl. 10, fig. 3.

2001 *Mytiloides hercynicus* (Petrascheck); Jolet *et al*., figs 8.1, 8.3.

Material. 22 mainly incomplete specimens from locality Retiro 26, represented by internal moulds or shell of LV or RV: RT26.284, 337, 338, 363, 370, 376, 377, 383, 384, 391, 393, 395, 399, 577, 582, 588, 598, 600, 603, 624, 626, 628. Fifteen specimens of Hessel (1988): PMU SA-176, 177, 179, 182, 184–186, 188, 189, 204, 207, 208, 216, 223, 224.

Description. Medium-sized (Table 9). Outline rounded to subovate; equivalve; inequilateral; flattened to slightly convex. Beak prosogyrous, anterior, rounded and weak, not projecting above the hinge line. Posterior auricle subtriangular, well separated from disc by a step-like fold. Disc distinctly oval in the juvenile part, with the long axis parallel to the hinge line. Angle of inclination (i) high (averaging 60.8°). Anterior margin convexly rounded passing into the broad rounded ventral margin; posterior margin rounded to slightly straight. Ornamentation consisting of closely spaced, narrow, concentric rugae in the juvenile part; more widely spaced, asymmetric, raised rounded rugae in the adult part; rugae covered with fine growth lines.

Table 9: Measurements of selected specimens of *M. hercynicus* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.284 (LV)	20,6	19.5	0,95	*26,4	27.3	1.03	8.0	125	62	138		*25.3
RT26.363 (RV)	37.4	33.9	0.91	*55.0	*58.0	1.05	16.4	122	55	140		*66.2
RT26.370 (RV)	25.5	32.0	1.25	*33.0	*51.0	1.54	18.0	132	58	138		31.0
RT26.377 (RV)	34.0	52.0	1.53	*45.0	*51.0	1.13	16.0	140	68	138		*46.0
RT26.389 (RV)	28.5	30.2	1.06	*36.1	*35.7	0.98	12.8	128	65	129		*34.9
RT26.393 (LV)	11.8	11.7	0.99	*17.6	*18.4	1.04	6.2	120	57	129		*18.0

Discussion. The specimens are very similar to those illustrated by Petrascheck (1903). Some of them show variation with respect to the ornamentation. Other specimens have a very large posterior auricle and a more convex disc, for example RT26.370 and 377 (Pl. 5, Figs 2, 3). Most specimens are flattened, e.g., RT26.363 and 626 (Pl. 5, Figs 8 and 9).

M. hercynicus differs of *M. subhercynicus* in having a distinctly oval disc, with higher SA/AL ratios (averages 1.11), and in being less oblique with a higher angle of inclination (i). In contrast, *M. subhercynicus* is markedly elongate posteroventrally and has an oblique outline. The similarities between the two species are discussed above under *M. subhercynicus*.

The specimens described and illustrated by Moskvin & Pavlova (1960) from the northern Caucasus as *M. hercynicus* have ornamentation and outline similar to this species. The same can be interpreted to the juvenile form illustrated by Sornay (1972) from Morocco as *I.* ex gr. *hercynicus*. However, on the basis of illustrations only it is difficult to confirm its specific position.

Some specimens referred by Walaszczyk (1992, pl. 8, figs 1 and 3) to *M. opalenis* (Böse) have an oval disc, with the long axis parallel to the hinge line, typical of *M. hercynicus*. *M. opalensis* has a more slender and less oblique outline than *M. hercynicus*.

Although most specimens from Sergipe are very similar to those illustrated by Petrascheck (1903), some have a more ovate outline, with the long axis parallel to the hinge line, a straighter and longer hinge line, and a more central beak, for example, specimens MC5.01 (Pl. 5, Fig. 1) from locality Muçuca 5 and RT26.377 (Pl. 5, Fig. 2) from Retiro 26. The same can be observed in specimen SA-208 (here Pl. 5, Fig. 4) referred by Hessel (1988; Fig. 32f) to *Sergipia hartti*, which has an oval disc and ornamentation typically of *M. hercynicus*.

Specimen MC5.03 (Pl. 6, Figs 1a, b) has already developed an anterior ligamental plate. This specimen might represent a transitional form to the genus *Didymotis* (see discussion of *Didymotis* aff. *posidonomyaformis*).

Occurrence. Lowermost middle Turonian of the Czech Republic, France, Germany, Poland, Portugal and Spain, possibly Morocco and northern Caucasus, the U.S. Western Interior, Mexico and Sergipe (Brazil).

Mytiloides hartti (Hessel, 1988)
Plate 5, Figures 5–6

v. 1988 *Sergipia hartti* n. sp.; Hessel, pp. 23–25, figs 32d–e and 34, non fig. 32f (= *M. hercynicus*).

Material. Eleven mainly incomplete specimens from locality Retiro 26 represented by shells and internal moulds of single LV or RV: RT26.378–380, 573, 574, 581, 586, 599, 606, 607, 622. Eight specimens of Hessel (1988): PMU SA-151/187, 204, 205, 208, 215/218, 219, 220, and DNPM 6107 (holotype)

Description. Small to medium-sized (Table 10). Outline oblique; subtriangular; inequilateral; slightly inflated to flattened. Hinge line short; umbo anterior, slightly projecting above the hinge line. Posterior auricle small and elongate, subtriangular, well separated form disc by a fold. Anterior, ventral and posterior margins rounded. Ornamentation consisting of low, narrow, regular and closely spaced concentric rugae, with growth lines in between; rugae becoming more widely spaced towards ventral margin.

Table 10: Measurements of selected specimens of *M. hartti* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.574 RV	21.5	26.0	1.21	27.0	*32.0	1.18	-	-	-	-	1.0	28.0
RT26.581 LV	21.0	28.0	1.33	35.0	*34.0	0.97	-	-	-	-	1.0	35.0
RT26.606 RV	21.0	25.0	1.19	26.5	29.5	1.11	-	-	60	126	2.0	30.0

Discussion. Based on the similarities of the external shell form and ornamentation, Hessel (1988) assigned *Mytiloides hartti* to the genus *Sergipia*. However, Hessel' species has an anterior umbo and lacks the anterior extension of the ligamental plate. For these reasons it is here considered a *Mytiloides*.

Hessel's specimens show similarities to *M. hercynicus* with regard to their ornamentation, but they differ from *M. hercynicus* in having a more triangular disc, an elongated posteroventral margin and a small posterior auricle. The ornamentation in the juvenile part consists of widely spaced rounded concentric rugae, whereas the adult part is covered with up to two or three growth lines, a feature also found in the specimen of *M. hercynicus* illustrated by Petrascheck (1903, text-fig. 1). Specimens PMU SA-208 of Hessel (1988, fig. 32f) and PMU SA-204 and 207 (not figured) referred to *S. hartti* have an oval disc typical of *M. hercynicus* and are here assigned to the latter species.

Occurrence. Lowermost middle Turonian of Sergipe (Brazil).

Mytiloides cf. *tourtenayensis* (Badillet & Sornay, 1980)

Plate 6, Figures 10–12

cf. 1980 *Inoceramus goppelnensis tourtenayensis* nov. subsp.; Badillet & Sornay, p. 325.
cf. 1982 *I. goppelnensis tourtenayensis* Sornay; Sornay, pp. 139–140, pl. 7, fig. 3.

Material. Three specimens from locality Retiro 26, represented by two incomplete internal moulds of RV and one LV shell with incomplete internal mould of RV: RT26.389, 587, 625.

Description. Small to medium-sized (Table 11). Outline rounded (juvenile part) to oval; flattened to inflated, maximum inflation in the anterodorsal part. Hinge line straight and short. Posterior auricle subtriangular, well separated from disc by fold. Anterior and ventral margin rounded. Ornamentation on juvenile part consisting of regular, fine, low rounded concentric rugae; rugae in the adult part broader and covered by growth lines.

Table 11: Measurements of the specimens of *M.* cf. *tourtenayensis* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL$_{max}$
RT26.389 RV	25.0	26.0	1.04	*35.0	*35.0	1.00	14.0	124	64	120	2.0	*36.5
RT26.587 LV	21.0	22.0	1.05	*26.0	*28.0	1.07	11.0	-	74	135	2.0	*30.0
RT26.625 RV	38.0	40.0	1.05	71.0	75.0	1.05	-	-	-	-	12.0	75.0

Discussion. The Sergipe specimens are incomplete but very similar to *Inoceramus goppelnensis tourtenayensis* described by Sornay (1982) from France. This form is a typical *Mytiloides*. In specimen RT26.625 (Pl. 6, fig 12a and b) the umbonal part and the hinge line are partially damaged. However, the abrupt transition between the juvenile and adult parts, giving the impression of a distinct geniculation, resembles that found in the holotype of the Sornay' species, here re-illustrated (Pl. 6, Fig. 9). The other specimens RT26.389 and 587 (Pl. 6, Figs 10 and 11) are incomplete and more flattened. However, they also show a gentle change between the juvenile and adult parts of the shell. Owing to the poor preservation and the small number of specimens at hand, it is not possible to determine the exact systematic position of the species.

Badillet & Sornay (1980) described *Mytiloides tourtenayensis* as a subspecies of *M. goppelnensis* on the basis of the geniculation between the juvenile and adult stages. However, the species *M. tourtenayensis* seems to be more closely related to the *hercynicus* group, especially by its distinct posterior auricle and its outline. Walaszczyk & Cobban (2000b) referred a specimen from Pueblo, with distinct geniculation to *M. subhercynicus tourtenayensis*. The Sergipe specimens have a more rounded to suboval outline, and their SA/AL ratios are comparable to those found in *M. hercynicus*.

Occurrence. *Mytiloides tourtenayensis* occurs in the lower Turonian to basal middle Turonian of France. In Sergipe (Brazil), *M.* cf. *tourtenayensis* is found in the lower middle Turonian.

Mytiloides striatoconcentricus (Gümbel, 1868)
Plate 7, Figures 1–4

1868 *Inoceramus striato-concentricus*; Gümbel, p. 69, pl. 2, fig.4.
1928b *Inoceramus striato-concentricus* Gümbel; Heinz, p. 68, pl. 4, fig. 3.
1939 *Inoceramus striatoconcentricus* Gümbel; Dacqué, p. 209, pl. 17, fig. 5.
1967 *Inoceramus striatoconcentricus striatoconcentricus* Gümbel; Tröger, pp. 84–86, pl. 9, figs 11–15, 17 (with synonymy list).
1982 *Inoceramus striatoconcentricus striatoconcentricus* Gümbel, 1868; Keller, pp. 105–107, pl.7, fig. 4.
1982 *Inoceramus labiatoidiformis* Tröger, 1967; Keller, pp. 100–103, pl. 5 fig. 7 (variety “a”).
1992 *Mytiloides striatoconcentricus* (Gümbel); Walaszczyk, pp. 24–25, pl. 13, figs 1–7.
1998 *Mytiloides striatoconcentricus*; Villamil, fig. 22e.
2000a *Mytiloides striatoconcentricus* (Gümbel); Walaszczyk & Cobban, pp. 68–69, text-fig. 17.
2004 *Mytiloides striatoconcentricus* (Gümbel); Wiese *et al.*, fig. 5g.
2004 *Mytiloides striatoconcentricus* (Gümbel); Wood *et al.*, pl. 2, fig. 10.

Material. 13 mainly incomplete specimens from locality Mata 11, represented by internal moulds of single LV or RV and shell fragments: MT11.35, 46, 47, 129, 132, 145–147, 182–184, 201, 374.

Description. Medium-sized (Table 12). Outline elongate-ovate; inequilateral; left valve more inflated, maximum inflation dorsocentrally; growth axis oblique. Hinge line straight and long. Posterior auricle triangular, medium to large, well separated from disc. Anterior margin slightly convex to straight, with anterior side slightly concave at the umbonal part. Anteroventral margin convex, passing into rounded ventral margin; posterior margin almost straight and concave. Ornamentation consisting of symmetrical, fine, regularly spaced, raised growth lines.

Table 12: Measurements of selected specimens of *M. striatoconcentricus* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL$_{max}$
MT11.35 RV	38.5	26.5	0.69	*42.0	*39.0	0.92	18.0	78	60	99	9.0	*39.5
MT11.132 LV	41.0	31.0	0.75	*52.5	*41.0	0.78	*11.0	75	56	97	14.0	63.0

Discussion. The specimens from Mata 11 display only slight variations of the ornamentation. Specimen MT11.132 (Pl. 7, Figs 2a and b) has a strongly inflated shell, with a regular ornamentation in the juvenile part, characterized by fine growth lines, and a more irregular ornamentation in the adult part. It shows similarities to *Mytiloides bellefourchensis* Walaszczyk & Cobban, 2000, but the latter is much less inflated.

The ornamentation of the juvenile part of *M. striatoconcentricus* closely resembles that of *M. herbichi* (Atabekjan, 1969). However, the latter species possesses a straight growth axis and is much less inflated.

Keller (1982) described two varieties (“a” and “b”) of *Inoceramus labiatoidiformis* Tröger, 1967. However, both forms differ from the original concept of Tröger’s species. Variety “a” has the diagnostic features of *M. striatoconcentricus* (Gümbel), with an ornamentation consisting of very fine regular growth lines, whereas variety “b” was included in the new species *M. ratonensis* by Walaszczyk & Cobban (2000a).

Occurrence. Lower upper Turonian of the U.S. Western Interior, Czech Republic, England, Germany, France, Poland, Venezuela, Peru and Sergipe (Brazil). In Colombia Villamil (1998) placed the species at the Turonian–Coniacian boundary.

Mytiloides incertus (Jimbo, 1894)

Plate 7, Figures 4–7

1894	*Inoceramus incertus* Jimbo, p. 189, pl. 24, fig. 7.
pars 1940	*Inoceramus incertus* Jimbo; Nagao & Matsumoto, pp. 10–13, pl. 3, figs 1–3, pl. 10, fig. 2.
v. 1967	*Inoceramus fiegei fiegei* Tröger, p. 105, pl.11, fig. 3, pl. 13, figs 14–15, 17, 20.
1974	*Inoceramus striatus* Mantell; Kotsyubinskij, p. 78, pl. 14, fig. 2.
1976	*Inoceramus incertus* Jimbo; Noda & Matsumoto, sheet 270, fig. 7.
1978	*Mytiloides fiegei fiegei* (Tröger); Kauffman *et al*., pl.15, fig.1; pl. 16, fig. 4.
1982	*Inoceramus fiegei fiegei* Tröger, 1967; Keller, pp. 110–112, pl. 7 fig. 5.
1983	*Mytiloides incertus* (Jimbo); Matsumoto & Noda, pp. 109–112, figs 2–4.
1984	*Mytiloides incertus* (Jimbo); Noda, pp. 458–467, text-figs 1–8; pl. 84, pl. 85; pl. 86, figs 1–8.
v. 1985	*M. fiegei* (Tröger) lineage; Kauffman & Bengtson, p. 313.
1992	*Mytiloides incertus* (Jimbo, 1894); Walaszczyk, p. 22, pl. 12, figs 11–12.
1997	*Mytiloides incertus* (Jimbo); Wiese, pl. 17, fig. 7.
1999	*Mytiloides incertus* (Jimbo, 1894); Noda & Matsumoto, pp. 460–461, pl. 14, figs 1a–d, 2, 5a–d; pl. 15, figs 1–5.
2000a	*Mytiloides incertus* (Jimbo); Walaszczyk & Cobban, p. 54, pl. 7 figs 1–2, 6–7; pl. 10, fig. 5; pl. 11, fig. 3; pl. 12, figs 1–12; pl. 13, figs 1–8, 10; pl. 14, fig. 5.
2004	*Mytiloides incertus* (Jimbo); Wiese *et al*., fig. 5h.
2004	*Mytiloides incertus* (Jimbo); Wood *et al*., pl. 2, figs 6–7.

Material. Seven specimens from locality Mata 11, preserved as internal moulds of LV and RV and/or shell fragments: MT11.28, 32, 33, 138, 199, 215, 221.

Description. Medium-sized (Table 13). Outline subrounded to subquadrate; inequilateral; equivalve; valves slightly to moderately inflated; growth axis straight to slightly convex. Umbo terminal, not prominent. Hinge line straight, relatively short. Posterior auricle small. Anterior margin rounded to almost straight; posterior margin slightly convex; ventral margin long and convex. Anterodorsal part of valve more convex, gradually passing into flattened posterodorsal part. Ornamentation consisting of rounded, regularly spaced concentric rugae, covered with growth lines; most rugae showing some variation in size and density of growth lines.

Table 13: Measurements of selected specimens of *M. incertus* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
MT11.28 LV	31.0	29.0	0.94	*67	*71	1.05	19.0	-	58	106	-	*61.0
MT11.32 RV	54.0	52.0	0.96	54.0	*52	0.96	-	-	-	-	-	49.0
MT11.33 LV	40.0	42.6	1.07	*61	*58	0.95	-	-	-	-	-	*57.0

Discussion. The specimens of *M. incertus* from Mata 11 show variations in outline and ornamentation as discussed by Noda (1984). The concentric rugae vary from fine, low and regularly spaced ones, as in specimen MT11.33 (Pl. 7, Fig. 4), to broad, rounded rugae, as in MT11.28 and MT11.221 (Pl. 7, Figs 6 and 7). Some specimens are more flattened, such as MT11.33 and MT11.32 (Pl. 7, Figs 4 and 5).

The junior synonym *Inoceramus fiegei fiegei* Tröger was reported from North America (Kauffman *et al*., 1978), Germany (Keller, 1982) and Brazil (Kauffman & Bengtson, 1985).

Noda (1984) carried out a biometric, taxonomic and stratigraphic study of *Inoceramus incertus* Jimbo, 1894, and assigned it to the genus *Mytiloides*. He also regarded *Inoceramus fiegei fiegei* Tröger as a junior synonym of *M. incertus* (Jimbo), which confirmed the interpretation of Matsumoto & Noda (1983).

Noda (1984) also showed that *M. incertus* has a considerable variation in shell form and ornamentation. This is confirmed by the Sergipe material from Mata 11 and additional localities of Bengtson (1983) such as Cajaíba 7, Estiva 11, 13, Mata 1, Oiteiro 3, 4, 7, 13, 19-21 and Pilar 9.

Occurrence. Upper Turonian of Germany, Spain, Czech Republic, Poland, Russia, Japan, the U.S. Western Interior and Sergipe (Brazil).

Mytiloides turonicus Walaszczyk, 1992
Plate 7, Figures 8 and 9

v. pars 1871 *I. latus* Mant.; Geinitz, pp. 45–46, pl. 13, fig. 5 (*non* fig. 4 = *I. dresdensis* Tröger).

1928b *Inoceramus striato-concentricus* Gümb. var. aff. *carpathica* SIM.; Heinz, p. 34, pl. 1, fig. 3.

v. 1967 *Inoceramus striatoconcentricus* Gümbel aff. *carpathicus* Simionescu, 1899; Tröger, pp. 87–88, pl. 9, figs 10?, 18.

1982 *Inoceramus striatoconcentricus* Gümbel aff. *carpathicus* Simionescu, 1899; Keller, pp. 107–109, pl. 5, fig. 2.

v. 1992 *Mytiloides turonicus* sp. n.; Walaszczyk, pp. 25–26, text-fig. 8.

Material. Four specimens from locality Mata 11, represented by three incomplete internal moulds of single LV or RV, and one double-valved specimen, with incomplete shell on RV: MT11.27, 144, 148, 381.

Description. Medium-sized (Table 14). Outline elongate-ovate, equivalve, inequilateral; valves moderately convex; growth axis straight to slightly convex. Umbo slightly projecting above hinge line. Posterior auricle small to medium sized, not separated from the disc. Anterior margin slightly convex passing into rounded ventral margin; posterior margin concave to almost straight. Ornamentation consisting of asymmetrical, lamellate, concentric, almost regularly spaced ribs, ribs passing onto posterior auricle.

Table 14: Measurements of selected specimens of *M. turonicus* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	T	W	AL_{max}
MT11.27 RV	33.0	25.0	0.76	*33.0	*34.0	1.03	14.0	-	60	100	9.0	*35.0
MT11.144 LV	33.0	26.0	0.79	*39.0	*36.0	0.92	20.0	-	64	96	7.0	*34.0

Discussion. Walaszczyk (1992) introduced *Mytiloides turonicus* for the form referred to *Inoceramus striatoconcentricus* var. aff. *carpathicus* Simionescu by Heinz (1928b pl. 1, fig. 3). This corresponds to the specimen described and figured by Geinitz (1871, pl. 13, fig. 5) and re-illustrated by Tröger (1967, pl. 9, fig. 18).

M. turonicus Walaszczyk differs from *M. carpathicus* (Simionescu) in its general outline and ornamentation. *M. carpathicus* has asymmetrical, sharp-edged concentric rugae that are widely spaced, with flat interspaces, which increase towards the ventral margin.

The specimens from Mata 11 resemble the holotype of *M. turonicus* Walaszczyk, 1992. The species differs from *M. striatoconcentricus* in being less oblique and having lamellate concentric ribs. It is possible that these characteristics fall within the variability of *M. striatoconcentricus*. However, to resolve this problem more material needs to be studied, since *M. turonicus* is very rare and represented by few specimens.

Occurrence. Upper Turonian of Germany, England, Poland and Sergipe (Brazil).

Mytiloides labiatoidiformis (Tröger, 1967)

Plate 7, Figure 10; Plate 8, Figures 1–4

v. 1967 *Inoceramus dresdensis*? *labiatoidiformis* n. sp.; Tröger, pp. 125–127, pl. 10, figs 5–6.

non 1982 *Inoceramus labiatoidiformis* Tröger, 1967; Keller, pp. 100–103, pl. 5, figs 5, 7.

1992 *Mytiloides labiatoidiformis* (Tröger, 1967); Walaszczyk, pp. 21–22, pl. 12, figs 1–2.

1999 *Mytiloides labiatoidiformis* (Tröger, 1967); Walaszczyk & Wood, pp. 426–427, pl. 1, figs 1–2, 6, 8, ?12.

2004 *Mytiloides labiatoidiformis* (Tröger); Wiese *et al.*, fig. 5e.

2004 *Mytiloides labiatoidiformis* Tröger, 1967; Wood *et al.*, pl. 2, fig. 8.

Material. Ten specimens from locality Mata 11, preserved as nine internal moulds of single RV or LV and shell fragments, one double-valved specimen: MT11.06, 08, 09, 50, 73, 126, 256, 258, 259, 379.

Description. Medium-sized (Table 15). Mytiloid outline; equivalve; inequilateral; valves moderately inflated. Hinge line relatively short, straight. Posterior auricle small, subtriangular, separated from the disc by a distinct auricular sulcus. Anterior margin long, convex, passing into narrowly rounded ventral margin; posterior margin convex; ventral margin rounded. Ornamentation consisting of regularly spaced, asymmetrical concentric rugae, which may increase in size towards the ventral margin.

Table 15: Measurements of selected specimens of *M. labiatoidiformis* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL$_{max}$
MT11.06 RV	49.5	32.0	0.65	91.0	64.0	0.70	-	87	65	102	8.0	*93.0
MT11.08 RV	48.7	32.6	0.67	*59.0	*55.0	0.93	25.0	-	50	108	7.0	*64.0
MT11.09 RV	37.9	26.0	0.69	76.0	55.0	0.72	*14.0	82	56	103	11.0	83.0

Discussion. The specimens of *M. labiatoidiformis* from Mata 11 are similar to those of Tröger (1967). They show some variation in outline, with some specimens more elongate, e.g., MT11.09 and 126 (Pl. 8, Figs 1 and 3). The concentric ornamentation varies to some extent, from more closely spaced, feeble to raised rugae. Specimen MT11.50 (Pl. 7, Fig. 10) is a very small, probably juvenile form, but shows the characters of Tröger' species.

Keller (1982) described two varieties ("a" and "b") of *Inoceramus labiatoidiformis* Tröger. Both forms differ from Tröger's concept of the species. Variety "a" is a typical

Mytiloides striatoconcentricus (Gümbel) and variety "b" was referred to the new species *Mytiloides ratonensis* by Walaszczyk & Cobban (2000a).

Occurrence. Upper Turonian of England, Germany, Poland, Czech Republic, Spain and Sergipe (Brazil).

Mytiloides herbichi (Atabekjan, 1969)
Plate 8, Figures 5–10

pars 1899	*Inoceramus labiatus* Schloth.; Simionescu, pp. 259–260, pl. 1, fig. 9 (only).
1899	*Inoceramus labiatus* Schl var. *regularis*; Simionescu, pp. 260–261, pl.2, fig. 3.
1969	*Inoceramus herbichi* nom. n.; Atabekjan, p. 11.
pars 1992	*Mytiloides carpathicus* (Simionescu); Walaszczyk, pp. 26–28, pl. 14, figs 1–6, 8; pl. 15, figs 1–3, 5–7.
1997	*Mytiloides herbichi* (Atabekian); Walaszczyk & Szasz, pp. 774–775, figs 3a, g, h; 5h.
1999	*Mytiloides herbichi* (Atabekian); Walaszczyk & Wood, pp. 425–426, pl. 1, figs 3, 5, 7.
2004	*Mytiloides herbichi* (Atabekian); Wood *et al*., pl. 1, fig. 2; pl. 2, fig. 2.

Material. 13 specimens from locality Mata 11, preserved as internal moulds of single LV or RV with shell fragments: MT11.10–12, 66–68, 127, 130, 133, 149, 154, 155, 169.

Table 16: Measurements of selected specimens of *M. herbichi* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
MT11.10 LV	43.5	27.5	0.63	*52.0	*46.0	0.88	*17.0	-	-	-	5.0	*50.0
MT11.11 LV	41.0	26.0	0.63	*50.0	*43.0	0.86	*22.0	-	-	-	6.0	*47.0
MT11.12 LV	43.0	31.5	0.73	*48.0	*52.0	1.08	29.0	67	58	98	7.0	*49.0
MT11.127 LV	40.0	27.5	0.69	*42.0	47.5	1.13	34.0	-	58	97	9.0	*44.0
MT11.155 LV	41.0	26.0	0.63	*55.0	47.0	0.85	21.0	66	55	-	10.0	64.0
MT11.169 RV	44.0	32.0	0.73	*46.5	*43.5	0.93	-	-	50	-	6.0	*52.0

Description. Medium-sized (Table 16). Outline subrectangular; inequilateral; slightly to moderately inflated, maximum inflation dorsocentrally; growth axis straight or slightly convex anteriorly. Hinge line long and straight. Beak-umbo erect, slightly projecting above hinge line. Posterior auricle large, well separated from the disc by a sulcus. Anterior margin straight to slightly convex; posterior margin concave; ventral margin rounded and wide.

Ornamentation consisting of raised, sharp, closely spaced growth lines; ornamentation passes onto posterior auricle, with growth lines markedly curved outwards.

Discussion. Most specimens from Mata 11 are incomplete, with the umbonal region or the ventral margin damaged. A few better preserved specimens show some variation in shell convexity. The Sergipe specimens are very similar to *M. herbichi* found in Germany (Salzgitter-Salder section). *M. herbichi* closely resembles *M. striatoconcentricus* (Gümbel); however, the latter possesses an oblique growth axis, has a more uniform ornamentation and is much more inflated.

Walaszczyk & Szasz (1997) revised specimens originally described by Simionescu (1899) from Romania. They described *M. carpathicus* (Simionescu) and *M. herbichi* (Atabekjan) as distinct species, and recognized that some specimens referred to *M. carpathicus* (Simionescu) by Walaszczyk (1992) represent *M. herbichi*. This opinion was subsequently confirmed by Walaszczyk & Wood (1999). *M. carpathicus* differs from *M. herbichi* in having widely spaced, sharp concentric rugae, with flat interspaces, which increase fairly regularly towards the ventral margin.

Occurrence. Upper Turonian of England, Germany, Romania, Poland and Sergipe (Brazil).

Mytiloides scupini (Heinz, 1930)
Plate 9, Figures 3–5, 7–8

v. 1911 *Inoceramus frechi* Flegel; Andert, p. 51, pl. 1, fig. 8, pl. 7, fig. 6.
pars 1928a *Inoceramus stillei* n. sp.; Heinz, pp. 72–73.
1930 *Inoceramus stillei* var. *scupini* Heinz, p. 26.
1934 *Inoceramus frechi* Flegel; Andert, pp. 120–123, pl. 5, figs 5–9, pl. 6, fig. 1.
1982 *Inoceramus frechi* Flegel, 1904; Keller, pp. 96–98, pl. 7, fig. 1.
1978 *Mytiloides*? *frechi* (Flegel); Kauffman *et al*., pl. 13, fig. 21.
v. pars 1985 *Mytiloides lusatiae* (Andert) lineage; Kauffman & Bengtson, p. 313.
pars 1992 *Mytiloides carpathicus* (Simionescu); Walaszczyk, p. 26, pl. 15, fig. 4 only.
1996 *Mytiloides scupini* (Heinz); Walaszczyk & Tröger, p. 400, figs 3C–E.
1999 *Mytiloides scupini* (Heinz); Walaszczyk & Wood, p. 425, pl. 1, fig. 10.
2000a *Mytiloides scupini* (Heinz); Walaszczyk & Cobban, p. 64–68, pl. 16, figs 1–8, 10–11; pl. 17, figs 1–8; pl. 18, figs 10–13.

2004 *Mytiloides scupini* (Heinz); Wiese *et al*., fig. 5a.
v. 2005 *Mytiloides scupini* (Heinz); Patarroyo *et al*., pp. 92–93.

Material. 20 specimens from locality Mata 11, preserved as mainly incomplete single internal moulds of RV or LV and shell fragments: MT11.04, 05, 07, 15, 16, 69, 80–82, 85, 92, 99, 191, 192, 196, 210, 211, 226, 244, 377. Specimen MT11.07 is preserved as a composite mould of RV with incomplete shell of LV.

Description. Medium-sized to large (Table 17). Outline subrectangular-ovate; inequilateral; inequivalve; slightly inflated, maximum inflation dorsocentrally; growth axis straight. Hinge line straight and long. Beak erect, projecting above hinge line. Anterior margin moderately long, slightly convex to straight, passing into long anteroventral margin; ventral margin rounded. Posterior auricle moderately large, flat and subtriangular. Ornamentation consisting of evenly spaced, rounded concentric, sharp rugae, with relatively wide, flat interspaces, which increase in width towards the venter. Ornament passes slightly onto auricle; juvenile part usually covered only with growth lines.

Table 17: Measurements of selected specimens of *M. scupini* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
MT11.07 RV	82.0	54.5	0.66	*87.0	85.0	0.97	31.0	70	63	106	9.0	*107.0
MT11.07 LV	33.0	24.0	0.72	*37.0	52.0	1.40	*24.5	-	-	-	7.0	*34.0
MT11.196 RV	*58.0	41.0	0.71	*83.0	*57.0	0.68	-	-	-	-	6.0	*69.0

Discussion. Some specimens of *M. scupini* from Mata 11 display a variation in ornamentation. The rugae vary in width and spacing. Specimens MT11.04 (Pl. 9, Fig. 8) and MT11.196 (Pl. 9, Fig. 5), for example, have sharp rugae, whereas specimen MT11.07 (Pl. 9, Fig. 4) has rounded rugae. Specimens MT11.04 and 196 have the retractor and posterior adductor muscle scars preserved.

Specimens MT11.15 (Pl. 9, Fig. 7), MT11.16 and MT11.244 are more slender, with a more regular ornament passing onto posterior auricle, with rugae curved outwardly. They resemble specimens referred by Wood *et al*. (2004) to *Inoceramus* aff. *glatziae* sensu Andert (1934, pl. 6, Fig. 4). However, these three specimens from Mata 11 are not well preserved; more and better preserved material will be necessary to confirm the presence of the latter form in Sergipe.

According to Walaszczyk & Tröger (1996) most of the hitherto published forms referred to *I. frechi* represent mytiloid-like, flat forms, which should be referred to *Mytiloides scupini* (Heinz) (= *I. frechi* sensu Andert, 1911). The problem was that Andert's concept of

Inoceramus frechi Flegel was regarded as the "classical concept" of the species. However, the difference between Andert's specimens and the original description of Flegel (1905) as well as Scupin's (1913) concept, was emphasised by Heinz (1928a, 1930), who designated the specimen of Scupin (1913, pl. 11, fig. 10) as the type of *Inoceramus frechi* Flegel and referred *I. frechi* sensu Andert to a separate form, *Inoceramus stillei* var. *scupini* Heinz. Walaszczyk & Tröger (1996), in their revision of *Inoceramus frechi*, compared the original material of Andert (1911) and Scupin (1913), and suggested that *I. frechi* sensu Andert (1911, pl. 1. fig. 8), the commonly accepted concept of *I. frechi* of authors, represents a separate species, which they referred to *Mytiloides scupini* (Heinz).

M. scupini differs from *I. frechi*, in having a more slender and erect form, a more irregular ornamentation and a much less inflated disc. The posterior auricle is not clearly separated from the disc by a marked sulcus as in *I. frechi*.

M. scupini was previously not recognized in Sergipe. However, study of the collection of P. and S. Bengtson has shown that some specimens referred to *M. lusatiae* by Kauffman & Bengtson (1985), but not figured or described, are representatives of *M. scupini*. In addition, new collecting from other localities (Oiteiro 7, Socorro 15 of Bengtson, 1983) besides Mata 11, shows that *M. scupini* is very common in the upper Turonian of Sergipe.

Recent work carried out by Patarroyo *et al*. (2005) yielded *M. scupini* associated with *Prionocycloceras guayabanum* (Steinmann) in the uppermost Turonian of the Loma Gorda Formation in the upper Magdalena Valley, southwest of Bogotá, Colombia.

Occurrence. Upper Turonian of the U.S. Western Interior, England, France, Spain, Poland, Czech Republic, Germany, Romania, Colombia and Sergipe (Brazil).

Mytiloides mytiloidiformis (Tröger, 1967)
Plate 9, Figure 9

v. 1967 *Inoceramus fiegei mytiloidiformis* n. sp. n. ssp.; Tröger, pp. 108–110, pl. 11, fig. 4; pl. 13, figs 16, 18.
1976 *Mytiloides hercynicus* (Petrascheck); Offodile, p. 71, pl. 15, figs 4, 5.
1978 *Mytiloides fiegei mytiloidiformis* (Tröger); Kauffman *et al*., pl. 14, fig. 4.
1983 *Mytiloides* sp. aff. *mytiloidiformis* (Tröger); Matsumoto & Noda, p. 111, fig. 5.
1984 *Mytiloides* sp. aff. *mytiloidiformis* (Tröger); Noda, p. 467, pl. 86, fig. 9.

1999 *Mytiloides mytiloidiformis* (Tröger); Noda & Matsumoto, pp. 461–463, pl. 15, figs 6, 7a–c.

2000a *Mytiloides mytiloidiformis* (Tröger, 1967); Walaszczyk & Cobban, pp. 58–60, pl. 10, figs 1–2, 4; pl. 14, figs 2, 3, 7–8, 10–11, 13.

2001 *Mytiloides* cf. *labiatoidiformis* (Tröger); Gebhardt, p. 202–203, fig. 5.1–5.3.

2004 *Mytiloides mytiloidiformis* (Tröger); Wiese *et al*., fig. 5b.

Material. Seven specimens from locality Mata 11, represented by incomplete internal moulds of five RV and two LV. One juvenile specimen and two with shell fragments preserved: MT11.13, 194, 218, 222, 257, 262, 380.

Description. Small to medium-sized; specimens mostly incomplete, height 36–41 mm, length 34−40 mm. Outline oblique; elongate along growth axis; disc moderately inflated, maximum inflation anterodorsally to centrally. Hinge line short. Umbo terminal, projecting above hinge line. Posterior auricle narrow, in some specimens poorly preserved. Anterior margin short, slightly convex passing into a widely anteroventral convex margin; posteroventral margin rounded and flattened. Ornamentation consisting of regularly spaced, narrow, concentric rugae, covered with growth lines; on adult part low and wide concentric rugae.

Discussion. Although the Sergipe specimens are poorly preserved, their ornamentation, outline and other characters agree well with those of the specimens described as *M. mytiloidiformis* by Tröger (1967).

M. mytiloidiformis was originally described as a subspecies of *I. fiegei* (= *M. incertus*) (Tröger, 1967). Studies carried out by Noda & Matsumoto (1999) on populations of *M. incertus* showed that this extremely elongate form is an independent species. Because the co-occurrence of two subspecies is unreasonable from a biological viewpoint, *M. mytiloidiformis* was assigned specific status (Noda & Matsumoto, 1999).

Occurrence. Upper Turonian of Germany, England, Romania, Czech Republic, Nigeria, Japan, the U.S. Western Interior and Sergipe (Brazil).

Mytiloides spp. indet.

Material. 85 specimens from locality Retiro 26: RT26.24, 28, 29, 31, 32, 53, 55, 57, 67, 71, 77, 80, 87, 92–94, 96, 107, 108, 114, 117, 119, 120, 122, 123, 125, 139, 141, 146, 147–148, 150, 156, 162, 163, 166, 175, 176, 179, 194, 196, 197, 201, 202, 204, 209–212, 223, 247, 253–255, 281, 329, 407, 408, 412–414, 423, 427, 430, 432, 436–445, 449, 471, 474, 480, 483, 489, 496, 590 and 612; 32 specimens from Mata 11: MT11.45, 49, 51–54, 83, 84, 101–103, 128, 153, 156–158, 160, 168, 177–181, 185–188, 198, 202, 207, 261. All specimens are incomplete and poorly preserved, represented by internal moulds and/or shell fragments.

Discussion. The poor preservation of these specimens hampers their specific assignment. This material probably includes several species of *Mytiloides* described above.

Occurrence. Turonian of Sergipe.

Genus *Rhyssomytiloides* Hessel, 1988

Type species: *Rhyssomytiloides mauryae* (Hessel, 1986).

Remarks. Hessel (1988) described the new genus *Rhyssomytiloides* based on five species from the lower Turonian of Sergipe. The genus is characterized by an ornamentation consisting of concentric rugae superposed by divergent radial ribs or rugae at a certain growth stage. At the Hamburg inoceramid workshop (October, 1992) an intense debate focused on the justification of this genus. Harries *et al*. (1996) mentioned that Hessel's species are very similar to the earliest growth stages of Santonian *Cladoceramus undulatoplicatus* (Heinz), suggesting that evolution of the group between the early Turonian and early Santonian involved great expansion and modification of the adult stage. The discussion resulted in two opinions. According to one, the genus *Rhyssomytiloides* should be synonymized with *Cladoceramus*, whereas the other was that the genus should not be synonymized until the interior shell structures could be compared to prove this linkage. Unfortunately, none of the specimens available is sufficiently well preserved to reveal internal structures that might resolve this question. The stratigraphical range of *Rhyssomytiloides* species in the lower Turonian of Sergipe, as well as in Madagascar, is very short. Moreover, there are no occurrences of similar forms between the middle Turonian and upper Coniacian, an interval that spans nearly 2 Ma.

It is probable that its similarity with *Cladoceramus* reflects a case of homeomorphy. According to Harries *et al*. (1996), most inoceramid specialists now recognize that homeomorphy in shell shape and external characters (ornamentation) is a common phenomenon, not only within the Inoceramidae but also between this family and related Permian inoceramid ancestors. Thus, *Rhyssomytiloides* is here considered a justified genus.

Rhyssomytiloides retirensis Hessel, 1988
Plate 4, Figure 1

v. 1988 *Rhyssomytiloides retirensis* n. sp.; Hessel, pp. 32–33, figs 36j–k, 40.

Material. Five specimens from locality Retiro 26, preserved as internal moulds of LV and RV: RT26.457, 458, 464, 475, 494. Three specimens of Hessel (1988): DNPM 6105 (holotype), PMU SA-157, 158.

Description. Medium-sized (Table 19). Outline elongate-ovate; inequilateral; subequivalve; valves oblique, prosocline, convex, maximum inflation anterodorsocentral. Hinge line straight. Umbo projecting above hinge line. Posterior auricle narrow and subtriangular. Anterior margin convex passing to the rounded anteroventral margin; posterior margin slightly rounded to straight, forming an obtuse angle with the posterior auricle. Ornamentation consisting of irregular concentric rugae, followed by irregular divergent rugae at the shell margins.

Table 19: Measurements of selected specimens of *R. retirensis* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL$_{max}$
RT26.475 RV	32.0	22.0	0.69	39.0	42.0	1.07	16.0	-	46	92	11.0	48.5
RT26.457 LV	30.5	22.5	0.74	*29.0	32.0	1.10	14.0	69	43	98	11.0	*34.0
RT26.458 RV	26.0	19.0	0.73	*35.0	*24.0	0.68	*13.0	70	42	95	9.0	*38.0
RT26.458 LV	30.0	26.0	0.86	40.0	42.0	1.05	16.0	-	43	-	-	45.5

Discussion. The transition between the genera *Mytiloides* and *Rhyssomytiloides* is clearly observed by the first occurrence of *R. retirensis* (Pl. 4, Fig. 1). This is also observed in specimen PMU SA-157 of Hessel (1988, not illustrated). *R. retirensis* shows some similarity with *M. labiatus* in its oblique and convex shell.

R. retirensis and *R. beurleni* are the earliest forms of *Rhyssomytiloides*. Both have a short stratigraphical range. *R. mauryae* appears with a development of the regular and strong divergent rugae, and is probably a descendant of *R. retirensis*. Hence, it remains unclear if the specimens of *R. retirensis* can be considered a distinct species or represent an earlier form of *R. mauryae*.

Occurrence. Uppermost lower Turonian of Sergipe (Brazil).

Rhyssomytiloides beurleni Hessel, 1988
Plate 4, Figures 2 and 3

v. 1988 *Rhyssomytiloides beurleni* n. sp. Hessel, pp. 31–32, figs 36i, 39.

Material. Thirteen mainly incomplete specimens from locality Retiro 26, preserved as internal moulds of LV or RV and shell fragments: RT26.453, 454, 460–463, 465, 468, 469, 473, 486, 497. The holotype of Hessel (1988): DNPM 6106.

Description. Small to medium-sized (Table 20). Outline subrounded; inequilateral; slightly inflated, maximum inflation anterodorsally. Hinge line straight, moderately long. Posterior auricle narrow and elongated. Umbo projecting slightly above hinge line. Anterior margin slightly straight, becoming curved towards the ventral margin; ventral margin rounded; posterior margin slightly rounded to straight, forming an obtuse angle with the posterior auricle. Ornamentation consisting of asymmetric raised concentric rugae, followed by irregular divergent rugae, with a nodular feature; concentric ornamentation occupying most of the shell; divergent rugae beginning 28 to 30 mm from the beak.

Table 20: Measurements of selected specimens of *R. beurleni* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL$_{max}$
RT26.460 LV	28.0	23.0	0.82	30.5	30.0	0.98	13.0	-	59	100	-	32.5
RT26.461 LV	29.0	24.0	0.82	*35.0	34.0	0.97	-	-	58	-	6.0	*36.0
RT26.465 LV	44.3	34.4	0.77	39.5	35.0	0.88	14.0	-	60	93	7.0	47.0

Discussion. Most specimens of *R. beurleni* are incomplete and poorly preserved. The specimens show a variable ornamentation, mainly concerning the distance of the concentric rugae, which may be widely spaced or irregularly distributed. The species has a very short stratigraphical range.

R. beurleni differs from *R. mauryae* in having irregular divergent rugae. The shell is less convex and less oblique than in *R. mauryae* and *R. retirensis*. The concentric surface ornamentation on the earlier stages of *R. beurleni* resembles that of *M. goppelnensis* and *M. peruanus*. It might represent a descendant from one of those *Mytiloides* species.

Occurrence. Uppermost lower Turonian of Sergipe (Brazil).

Rhyssomytiloides mauryae (Hessel, 1986)
Plate 4, Figures 4–6

1934 *Cladoceramus* cf. *diversus* Stol.; Basse, pp. 87, 93–96.
?1977 *Sphenoceramus* aff. *S. schmidti*; Klinger, p. 91, fig. 8e.
v. 1986 *Sphenoceramus mauryae* n. sp.; Hessel, pp. 228–234, pl. 1, figs 1a–b, 2, 3, text-fig. 5.
v. 1986 *Sphenoceramus alatus* n. sp.; Hessel, p. 234, pl. 1, figs 4a–c, text-fig. 6.
v. 1988 *Rhyssomytiloides mauryae* (Hessel); Hessel, pp. 26–28, figs 35, 36a–c.
v. 1988 *Rhyssomytiloides* aff. *mauryae* (Hessel); Hessel, pp. 28–29, figs 36d–e.
v. 1988 *Rhyssomytiloides alatus* (Hessel); Hessel, pp. 30–31, figs 36h, 38.
v. ?1988 *Rhyssomytiloides bengtsoni* n. sp.; Hessel, pp. 29–30, figs 36f–g, text-fig. 37.
v. 1999 *Rhyssomytiloides* sp.; Seeling, pp. 99–100, pl. 1, figs 10, 11.

Material. 40 specimens from locality Retiro 26, represented by shells and/or internal moulds: RT26.213, 220, 226, 236, 239, 244, 245, 248, 249, 258–260, 264, 266, 275, 476–478, 484, 492, 499–502, 505–512, 514, 516, 635–640. Fifteen specimens of Hessel (1988): DNPM 6055, 6067 (holotype), 6108, PMU SA-149, 150, 161, 163, 167–169, 171, 172, 173, 225, 227.

Description. Small to medium-sized (Table 18). Elongate-ovate to subquadrate; inequilateral; prosocline; moderately inflated, maximum inflation anterodorsally. Umbo anterior, projecting above hinge line. Posterior auricle narrow, elongate and subtriangular. Anterior margin convex; posterior margin flattened and almost straight, forming an angle with the ventral margin. Ornamentation consisting of raised, subequal concentric rugae on the umbo and early adult part of the disc, followed by coarse divergent radial folds or plicae on the adult part of the shell, which are covered with growth lines; concentric rugae vary from raised to low; radial folds in the transitions between concentric and radial ornamentation usually gentle, becoming stronger through ontogenetic development.

Table 18: Measurements of selected specimens of *R. mauryae* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	H/L	HLL	a	i	t	W	AL_{max}
RT26.244 LV	34.1	25.5	0.74	30.5	*31.0	1.02	-	82	40	94	7.0	35.0
RT26.478 LV	37.1	27.8	0.75	39.0	34.0	0.87	-	78	43	85	16.0	42.0
RT26.500 RV	55.0	51.0	0.92	60.0	55.0	0.91	14.0	94	56	-	-	*63.0
RT26.506 LV	46.0	37.0	0.78	56.0	52.0	0.93	19.5	85	40	85	13.0	67.0
RT26.508 LV	49.0	41.0	0.83	45.0	44.0	0.97	15.5	-	43	86	15.0	49.0
RT26.640 LV	37.0	26.0	0.70	35.0	*29.0	0.83	15.0	70	38	80	-	*41.0

Discussion. *R. mauryae* is well represented in Sergipe and found in different ontogenetic stages. The specimens studied here are very similar to those described by Hessel (1986, 1988). The early form of *R. mauryae* is represented by several specimens, for example, RT26.248 (Pl. 4, Figs 4a–b), RT26.478 and RT26.476. Some of them are strongly convex and oblique and show regular radial ornamentation. Specimens RT26.500 and RT26.506 (Pl. 4, Fig. 6) are the largest *R. mauryae* found to date.

Hessel (1986) defined her new species *Sphenoceramus alatus* on the basis of two specimens and later assigned it to the new genus *Rhyssomytiloides* (Hessel, 1988). The holotype of *R. alatus* (DNPM 6055) is an incomplete double-valved composite mould that has been laterally compressed and deformed. The second specimen (PMU SA-161) is an incomplete internal mould of a right valve. The ornamentation of these specimens is very similar to that of *R. mauryae*. Hessel (1986, 1988) separated the two species on the basis of a more elongate and highly biconvex outline in *R. alatus*. However, comparison of the holotype of *R. alatus* with specimen PMU SA-173 (Fig. 36b of Hessel, 1988), a typical adult *R. mauryae*, proves that the two forms are very similar. Moreover, the biconvex shape of *R. alatus* was enhanced by the compression of the valves. Besides that, the umbo is not preserved on both valves of the holotype. Thus, there is no reason to consider *R. alatus* a distinct species and it is here synonymized with *R. mauryae*.

Hessel (1988) also described the new species *R. bengtsoni*. According to her, *R. bengtsoni* differs from other species of the genus in having a more prominent divergent ornamentation without forming a nodule at the intersection of the rugae. In the description was also noticed that the concentric rugae are poorly developed. However, in the holotype of *R. bengtsoni* the juvenile and central parts of the disc are not well preserved, so that no rugae can be seen. The other two specimens are also incomplete. This form is very similar to *R. mauryae*, and considering the detailed collecting recently carried out in the area studied by Hessel, it is probable that the specimens referred to *R. bengtsoni* represent only a specific ontogenetic stage of *R. mauryae*.

Basse (1934) mentioned the occurrence of *Cladoceramus* cf. *diversus* in the lower Turonian of Madagascar without providing a description or an illustration. Hessel (1988) revised and described this specimen, based on the analysis of a plaster cast, and referred it to *R. mauryae*.

The specimen of *Sphenoceramus* aff. *S. schmidti* illustrated by Klinger (1977) from offshore deposits near Bogenfels, South West Africa, has a similar ornamentation, outline and size as *R. mauryae* (Hessel). Klinger suggested that this specimen derived from Santonian to Campanian deposits. He also reported *Rhynchostreon* cf. *suborbiculatum* and *Placenticeras merenski* mentioned by other workers as evidence for onshore Cretaceous deposits in South West Africa. The *Placenticeras* was reported from the same bed as *Rhynchostreon*, which suggests a Cenomanian to early Turonian age. It is probable that *Sphenoceramus* aff. S. *schmidti* from South West Africa is conspecific with *R. mauryae*. However, additional material (ammonites or inoceramids) from this locality is needed to resolve the systematic position and precise age of this fauna.

Inoceramus diversus described by Stoliczka (1871) from India also has divergent rugae but differs from *R. mauryae* in having a subquadrangular outline and less divergent ribs. The occurrence of this species seems somewhat confusing. Chiplonkar & Tapaswi (1975; 1979) reported *Sphenoceramus diversus* (Stoliczka) from the upper Turonian of the lower part of the Trichinopoly Group, but Ayyasami & Banerji (1984) assigned the species to the upper Cenomanian–lower Turonian. Ayyasami (1990), on the basis of heteromorph ammonites, proposed a mid-Turonian to Coniacian age for the Trichinopoly Group. None of these publications provide an illustration of *S. diversus*. However, judging from the original illustration and description of Stoliczka (1871) this species differs from all forms of *Rhyssomytiloides* from Sergipe.

Examination of the specimen described and illustrated by Seeling (1999, pl. 1, figs 10, 11) from Jardim 29 as *Rhyssomytiloides* sp. demonstrated that it has the typical characters and ornamentation of *R. mauryae*. Although this specimen is laterally compressed, the central part of the disc is still preserved (not seen in the illustration).

Occurrence. Lower Turonian of Madagascar, South West Africa (?) and Sergipe (Brazil).

Rhyssomytiloides spp. indet.

Material. 32 incomplete, poorly preserved specimens from locality Retiro 26, represented by fragments of internal moulds of LV or RV and shells: RT26.214, 216–218, 222, 224, 227–235, 237, 238, 240, 246, 257, 261, 265, 267, 268, 470, 481, 482, 504, 505, 515, 517, 641.

Discussion. All specimens show the typical ornamentation of *Rhyssomytiloides*. However, they are incomplete and owing to their poor preservation a specific assignment is not possible.

Occurrence. Lower Turonian of Sergipe (Brazil).

Genus *Inoceramus* J. Sowerby, 1814

Type species: *Inoceramus cuvieri* J. Sowerby, 1814, by subsequent designation of Cox (1969, p. N315).

Inoceramus longealatus Tröger, 1967

Plate 8, Figures 11–12

v. 1967 *Inoceramus vancouverensis longealatus* n. sp.; Tröger, pp. 95–96, pl. 10, fig. 2.
non 1978 *Inoceramus longealatus* Tröger, n. subsp. (with coarse ribs); Wiedmann & Kauffman, pl. 2, fig. 12.
1982 *Inoceramus costellatus longealatus* Tröger, 1967; Keller, pp. 94–96, pl. 7, fig. 2.
1997 *Inoceramus longealatus* Tröger 1967; Walaszczyk & Szász, pp. 776–777, figs 5c, d, 6d, h.
2000a *Inoceramus longealatus* Tröger, 1967; Walaszczyk & Cobban, pp. 52–53, text-fig. 15.
2001 *Inoceramus* cf. *longealatus* Tröger, 1967; Gebhardt, pp. 201–202, figs 4.5–4.6.

Material. Seven specimens from locality Mata 11, internal moulds of LV and RV, one specimen with shell fragments: MT11.14, 91, 131, 161, 165–167.

Description. Medium-sized (Table 21). Outline subquadrate to rectangular; inequilateral; slightly to moderately inflated. Hinge line long, almost straight. Beak erect, projecting above hinge line. Posterior auricle large, extended, with an auricular sulcus. Anterior margin straight and long; ventral margin slightly rounded, passing into posterior margin; ventral margin with sharp contact with the anterior margin; posterior margin concave. Ornamentation consisting of narrow, regularly to subregularly spaced, raised growth lines, passing onto posterior auricle; low irregular rugae present in the adult part of some specimens; ornamentation on surface of posterior auricle forming a sickle-shaped lobe in the dorsal part.

Table 21: Measurements of selected specimens of *I. longealatus* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
MT11.14 LV	24.7	36.0	1.46	42.8	66.0	1.54	20.0	104	85	128	11.0	*43.5
MT11.131 LV	22.0	29.0	1.32	*29.0	41.0	1.41	22.0	-	86	130	4.0	*26.0
MT11.161 LV	29.5	31.0	1.05	37.0	39.0	*1.05	*11.0	-	85	113	8.0	38.0

Discussion. The specimens of *Inoceramus longealatus* from Sergipe are very similar to those described by Tröger (1967). Some are juvenile forms and show a regular ornamentation with growth lines without rugae. Juvenile forms of *I. longealatus* are very similar to *I. dakotensis* Walaszczyk & Cobban, 2000, in their ornamentation and in having a widely extended posterior auricle. According to Walaszczyk & Cobban (2000a), it is almost impossible to distinguish juvenile forms of the two species. Based on the relative stratigraphical positions and morphological resemblances, these authors suggested an evolutionary relationship between the two taxa. Some phyletically advanced specimens of *I. dakotensis* display a widely extended posterior auricle and an ornamentation closely resembling that of *I. longealatus*. In Sergipe *I. longealatus* occurs in the upper part of the *M. incertus* Zone and in the lower part of the *M. scupini* Zone, from where it was also reported in the U.S. Western Interior (Walaszczyk & Cobban, 2000a). No typical specimens of *I. dakotensis* were found in Sergipe, except one small and incomplete specimen from the base of the Mata 11 section. In its ornamentation this specimen resembles *I. dakotensis*, but may represent a juvenile form of *I. longealatus*.

Wiedmann & Kauffman (1978) illustrated a specimen with coarse ribbing as a new subspecies of *I. longealatus*. However, their specimen has a quite different ornamentation compared to that of Tröger's species and also lacks an extended posterior auricle. Therefore, it is better referred to *I. perplexus*.

Occurrence. Upper Turonian of the U.S. Western Interior, Germany, Romania, Nigeria and Sergipe (Brazil).

Inoceramus cf. *perplexus* Whitfield, 1877
Plate 9, Figures 1–2

cf. 1877 *Inoceramus perplexus* n. sp. Whitfield, p. 31.

cf. 1880 *Inoceramus perplexus* Whitfield; Whitfield, p. 392, pl. 8, fig. 3; pl. 10, figs 4–5.

cf. 1982 *Inoceramus costellatus costellatus* Woods, 1904–13; Keller, pp. 92–94, pl. 7, fig. 3.

cf. 1992 *Inoceramus costellatus* Woods, 1911 [error for 1912]; Walaszczyk, pp. 31–32, pl. 12, figs 3–9.

cf. 2000a *Inoceramus perplexus* Whitfield, 1877; Walaszczyk & Cobban, pp. 32–36, pl. 5, figs 1–9; pl. 6, figs 1–2; pl. 9, fig. 7.

Material. Three specimens from locality Mata 11, preserved as incomplete internal moulds and shell fragments of LV and RV: MT11.162, 163, 164.

Description. Small to medium-sized; height 32–46 mm, length 28−47 mm. Outline subquadrate; inequilateral; slightly inflated, maximum inflation in dorsocentral part of the shell. Posterior auricle not separated from disc. Anterior margin nearly straight to slightly rounded; posterior margin poorly preserved; ventral margin rounded. Ornamentation of regular spaced concentric rugae, interspaces increasing gradually towards the ventral margin.

Discussion. Walaszczyk & Wood (1999) discussed the European forms usually referred to *Inoceramus costellatus* Woods, 1912, and compared these with the holotype of Woods (1912). They concluded that these forms are different from Woods' species and conspecific with *Inoceramus perplexus* Whitfield.

The Sergipe specimens are more similar to *I. perplexus* in shape and ornamentation. However, they also resemble the specimen of *M. scupini* (Heinz, 1930) illustrated by Tröger (1999, fig. 3). These specimens occur near the first occurrence of *M. scupini*, and may represent a transitional form between *I. perplexus* and *M. scupini*.

Occurrence. *I. perplexus* is known from upper Turonian of Europe and North America. Sergipe. In Sergipe (Brazil), *I.* cf. *perplexus* occurs in the upper Turonian.

Genus *Didymotis* Gerhardt, 1897

Type species: *Didymotis variabilis* Gerhardt

Remarks. The genus *Didymotis* was erected by Gerhardt (1897) and compared with other genera such as *Monotis* Bronn, *Posidonomya* Bronn, *Daonella* Mojsisovics and *Diotis* Simonelli. The original diagnosis reads: shell paper thin, elongate, equivalved; hinge line straight and long; anterior and posterior auricle present, with the posterior one larger; ornamentation consisting of concentric growth lines and folds, with or without radial ribs on the middle third of the shell.

Until recentely *Didymotis* was considered a genus of the family Posidoniidae. However, according to Ando (1991) the presence of a multivincular ligament in well-preserved specimens suggests its familial assignment to the Inoceramidae.

Didymotis posidonomyaformis (Maury, 1925)
Plate 10, Figures 1–12

1887 *Posidonomya*, sp. indet. White, pp. 12, 54, 271.
1925 *Inoceramus* (*Sergipia*) *posidonomya formis*, sp. nov.; Maury, pp. 596–599, pl. 22, fig. 6.
? 1928b *Inoceramus* (*Sergipia*) *posidonomya formis* Maury; Heinz, pp. 83–84, pl. 5, figs 3–5.
non 1928b *Inoceramus* (*Sergipia*) *posidonomya formis* Maury var. *scheibei* n. var.; Heinz, pp. 84–85, pl. 4, fig. 6 and pl. 5, fig. 6.
1937 *Inoceramus* (*Sergipia*) *posidonomya formis* Maury; Maury, p. 119, pl. 8, fig. 15.
1978 *Sergipia* aff. *posidonomyaformis* Maury; Offodile & Reyment, pp. 46–47, fig.15.
pars 1988 *Sergipia hartti* n. sp. Hessel, p. 23, only fig. 33 (*non* figs 32d–f = *M. hartti*).
pars 1998 *Sergipia* sp.; Villamil, figs 12e, 22b.
v. pars 2003b *Didymotis costatus* (Frič, 1893); Seeling & Bengtson, pp. 155–156, not figured (*non* figs 2a–g).

Material. 23 mainly incomplete and poorly preserved specimens from locality Sapucari 1, represented by six specimens from the original material of Maury (1925), housed in the Departamento Nacional da Produção Mineral (DNPM), Rio de Janeiro: DNPM 3017−3022, preserved as internal moulds of RV and LV; 14 specimens recently collected: SAP1.01, 06, 11–22, preserved as incomplete internal moulds and shell fragments; two specimens housed in the collections of the Geologisch-Paläontologisches Institut of the University of Heidelberg, GPIH-BR C494.13, 24; one specimen from locality Mata 11, preserved as an incomplete internal mould and shell: MT11.206.

Table 22: Measurements of selected specimens of *D. posidonomyaformis* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL$_{max}$
DNPM 3017 RV	8.0	10.0	1.25	*8.0	*13.5	1.68	*11.0	-	65	-	1.0	*8.0
DNPM 3019 RV	12.0	15.0	1.25	25.5	*28.0	1.09	-	-	-	-	1.0	*25.0
DNPM 3020 LV	24.0	31.5	1.31	35.0	*42.5	1.21	-	-	-	-	1.0	*34.0
DNPM 3021 RV	15.0	20.0	1.33	*20.0	*28.0	1.40	*15.0	-	70	-	1.0	*22.0
DNPM 3022 RV	14.0	19.0	1.35	*21.5	*27.0	1.25	-	-	-	-	1.0	*19.0
SAP1.06 LV	53.0	61.0	1.15	55.0	*66.0	1.20	-	-	-	-	1.0	55.0
SAP1.11 LV	23.0	30.0	1.30	25.0	31.0	1.24	-	-	-	-	1.0	23.0
SAP1.14 LV	14.0	19.0	1.35	*19.0	*23.0	1.21	*13.0	-	72	-	1.0	*19.0
MT11.206 RV	20.0	24.0	1.20	*24.0	*32.0	1.33	*23.0	-	66	-	1.0	*24.0
GPIH-BR C494.24 LV	16.0	21.0	1.31	30.0	*34.0	1.13	-	-	-	-	1.0	*29.0

Description. Medium-sized (Table 22). Outline subrounded to elongate-ovate; shell flattened, paper-thin. Beak prosogyrous, small, subcentral and very low. Hinge line straight. Ornamentation consisting of subequal concentric rugae, covered with fine growth lines in the adult part; very fine radial striae in the adult part of some specimens.

Discussion. On the basis of material from Sapucari 1, Sergipe, Maury (1925) erected *Sergipia* as a subgenus of *Inoceramus*, with *I. (S.) posidonomyaformis* Maury, 1925 as the type species by monotypy. She considered *Sergipia* as an intermediate form between *Inoceramus* Sowerby and *Posidonomya* Bronn. But Maury did not compare her new genus to *Didymotis* Gerhardt. In his orignal description of *Didymotis*, Gerhardt (1897) included the presence of a long and straight hinge line and an ornamentation consisting of concentric growth lines and folds with or without radial ribs in the concept of the genus. These characters agree very well with the original concept of *Sergipia* Maury. Thus, *Sergipia* is considered a junior synonym of *Didymotis*.

Some authors, e.g., Kauffman & Bengtson (1985), Ando (1991) and Seeling & Bengtson (2003b), have mentioned the possible descent of *Didymotis* from *Sergipia*. However, no comparison with the original description of *Didymotis* given by Gerhardt (1897, pp. 180–181) was made. The discussion of the genus *Didymotis* by Imlay (1954) also includes an ornamentation consisting of concentric lines or folds, with or without radial ribs. The justification of *Sergipia* was also stressed by Harries *et al*. (1996), though again without comparison with the original description of *Didymotis*. In that work, a revision of *Sergipia* by Kauffman & Villamil (1996, in manuscript) was mentioned, which has not been published until now.

Illustration of the original material of Maury (1925, 1937) consists of a single figure of *S. posidonomyaformis* represented by a sketch drawing (Pl. 10, Fig. 1 herein), which does not correspond in all aspects to the original material. Obviously, the drawing was based on more than one specimen, some of which are incomplete and/or juvenile forms. The original material of Maury (1925) from Sapucari 1 is illustrated herein (Pl. 10, Figs 2–7) for the first time.

Didymotis posidonomyaformis differs from *D. costatus* (Frič, 1893) by the absence of radial ribs and the presence of a small posterior auricle. However, in some specimens of *D. posidonomyaformis* (SAP1.13 and GPIH-BR C494.24, Pl. 10, Figs 9 and 10) faint radial lines or striae in the adult part can already be observed. These specimens may represent a transitional form between the two species.

The phylogenetic development of *Didymotis* passes through distinct morphotypes, for instance, in Europe (Wiese, 1997; Wiese & Kröger, 1998), which are interpreted as three events (*Didymotis* events 0, I and II). Unfortunately, there is no good description of the oldest morphotype (D0). *Didymotis* of event I (DI) is characterized by slightly elongate, simple-ribbed forms. Their concentric ribs are broader than the interspaces and the ridges of the ribs may be flattened. Moreover, they lack the radial ribbing. Wiese (1997) provisionally assigned this morphotype (DI) to *D. costatus*. However, he mentioned that the systematic position of this form, and also that illustrated by Čech (1989, pl. 1, fig. 5), was probably incorrect. The original specimens of *S. posidonomyaformis* Maury (Pl. 10, Figs 2–7) are closely similar to this morphotype (DI) from Europe, which also applies to the specimens illustrated by Villamil (1988, figs 12E and 22B) as *Sergipia* from Colombia. Thus, it is possible that *D. posidonomyaformis* is a representative of the *Didymotis* event I.

Seeling & Bengtson (2003b) referred two specimens from Sapucari 1 (GPIH-BR C494.13, 24) to *D. costatus* and assigned all the material from Sergipe to *Didymotis* event II (DII). However, re-analysis of the two specimens shows that these lack radial folding and only display radial striae (see Pl. 10, Fig. 10). Comparison with the original specimens of Maury (Pl. 10, Figs 1–7) and with newly collected specimens from Sapucari 1, also lacking radial folds, shows that the two specimens of Seeling & Bengtson (2003b) are better referred to *D. posidonomyaformis*.

Specimen GPIH-BR C608.3 of *D. costatus*, described but not illustrated by Seeling & Bengtson (2003), from locality Ilhas 2, which is stratigraphically positioned above Sapucari 1, displays the ornamentation in the juvenile part of the shell with widely spaced growth lines (see Pl. 10, Fig. 14) as found in *D. posidonomyaformis*, which suggests an evolutionary relationship between these two species.

The Nigerian specimen illustrated by Offodile & Reyment (1978, fig. 15) as *Sergipia* aff. *posidonomyaformis* was interpreted and refigured by Hessel (1988, fig. 33) as *S. hartti* Hessel. This specimen was assigned to *D. costatus* by Seeling & Bengtson (2003b). However, this specimen (PMU AF-404; here Pl. 10, Fig. 11) has the typical ornamentation of *D. posidomyaformis* Maury and can be compared with specimens from Sapucari 1 (Pl. 10 Figs 2–10). It also shows fine radial striae, as in specimen GPIH BR-C494.24 (Pl. 10, Fig. 10) from Sergipe, but lacks the radial folds of *D. costatus*. Thus, it is better referred to *D. posidonomyaformis*.

Didymotis trinidadensis Sommermeier, 1918, described from Trinidad, is also very similar to specimen GPIH-BR C494.24 of *D. posidonomyaformis* from Sergipe. The two species show some similarities in their outline and the presence of numerous fine radial lines in the adult part of the shell. Revision of the original material from Trinidad is necessary to determine if *D. posidonomyaformis* and *D. trinidadensis* are conspecific. If so, the former would be considered a junior synonym of *D. trinidadensis*. A revision of all *Didymotis* species is needed including all available type material.

Heinz (1928b) described *Inoceramus* (*Sergipia*) *posidonomyaformis* Maury and *I.* (*S.*) *posidonomyaformis* var. *scheibei* from Rio Pata (= Rio Batá) and the Utica–La Palma road, Colombia. The first form is very similar and probably conspecific with Maury’s species, but the second one is a mytiloid-like form and its ornamentation resembles that of *M. striatoconcentricus*. However, on the basis of incomplete material a specific assignment is not possible. Heinz (1928b) could not give a precise indication of the age of these localities. Based on a single poorly preserved specimen of *Inoceramus* sp. (? ex aff. *crippsi* Mantell) he suggested an age between late Cenomanian and “Emscher” (Coniacian to middle Santonian). Villamil (1998) remarked that Heinz did not provide an accurate stratigraphic position or detailed locality information for his specimens and that those localities include rocks of Berriasian to Hauterivian age. However, Villamil (1998) assigned specimens of *Sergipia* to the Turonian and early Coniacian of Colombia. The specimens that he illustrated from lower Coniacian beds are very similar to those found in the upper Turonian of Sergipe and probably conspecific with *D. posidonomyaformis*. In the stratigraphical zonation of the Turonian–Coniacian of Colombia established by Villamil, the fauna appears, at least in part, younger than in Sergipe and elsewhere.

Occurrence. Upper Turonian of Nigeria, Colombia and Sergipe (Brazil).

Didymotis? aff. *posidonomyaformis* (Maury, 1925)
Plate 6, Figures 2–8

v. 1988 *Sergipia* aff. *posidonomyaformis* (Maury, 1925); Hessel, pp. 22–23, figs 32a–c.
v. 1988 *Sergipia* sp.; Hessel, p. 25, fig. 32g.
2001 *Sergipia* aff. *posidonomyaformis* (Maury); Jolet *et al.*, figs 8.4–7.

Material. 15 specimens from locality Retiro 26: RT26.314, 369, 371, 373–375, 381, 382, 385, 386, 387, 388, 390, 392, 396, 397, 575, 596, 608. Nine specimens of Hessel (1988): PMU SA-170, 183, 203, 210, 211, 212, 214, 217 and 221. N.B.: The caption of Figure 32 of Hessel (1988) contains a typographic error; the specimen numbers should read 32b (PMU SA-210) and 32c (PMU SA-217).

Description. Small to medium-sized (Table 23). Outline rounded to subovate; inequilateral; shell thin, flattened to slightly inflated. Umbo subcentral, not prominent. Hinge line subrectilinear to straight, ligament plate extending on both sides of beak (amphidetic). Anterior auricle small; posterior auricle subtriangular, separated from the disc by a fold. Anterior, ventral and posterior margins rounded. Ornamentation consisting of concentric rounded rugae, covered with fine growth lines in the adult part.

Table 23: Measurements of selected specimens of *D.*? aff. *posidonomyaformis* (* = incomplete).

Specimen	AL	SA	SA/AL	H	L	L/H	HLL	a	i	t	W	AL_{max}
RT26.375 RV	22.5	25.5	1.13	*32.0	*38.0	1.18	14.0	-	68	120	1.0	31.0
RT26.381 LV	19.0	24.0	1.26	*37.0	*42.0	1.13	-	-	70	-	2.0	36.0
RT26.382 LV	21.0	24.0	1.14	26.0	*26.0	1.00	11.5	-	66	118	1.0	26.0
RT26.387 RV	19.0	26.0	1.37	*25.0	*29.0	1.16	12.0	120	70	125	1.0	31.0
RT26.388 LV	24.0	29.0	1.21	30.0	*31.5	1.05	12.0	125	63	118	1.0	*30.0
RT26.392 RV	19.0	24.0	1.26	*31.5	*30.0	0.95	-	125	68	128	1.0	*31.0
RT26.397 LV	27.0	36.0	1.33	59.0	*62.0	1.05	-	-	-	-	1.0	60.0

Discussion. The specimens show some affinities to *Didymotis posidonomyaformis* (Maury), especially with respect to the anterior extension of the ligamental plate and the subcentral umbo. Most specimens show a subrectilinear hinge line, which has a somewhat variable length. The ornamentation and outline vary to some extent.

Some specimens seem to represent a transitional form from *Mytiloides hercynicus* to *Didymotis*. This transition can be observed in the development of the hinge line extending to the anterior side, for example in specimen MC5.03 (Pl. 5, Figs 1a, b), from Muçuca 5 (*M. hercynicus* Zone) and in specimen PMU SA-217 (Pl. 5, Fig. 2) illustrated by Hessel (1988, fig. 32c). Both specimens have still a distinctly oval disc in the juvenile part and ornamentation typical of *M. hercynicus*.

Specimen RT26.314 (Pl. 6, Figs 6a, b) is incompletely preserved but has the typical form of *Didymotis*, with the hinge line extending to the anterior side, with excavated resilifers preserved on the anterior side. Unfortunately, in most specimens the ligamental plate is incompletely preserved.

Specimen RT26.608 (Pl. 6, Fig. 8) is a more convex form compared to other specimens and shows some similarities to *M. incertus* (Jimbo), especially with respect to the ornamentation, but it has the anterior margin clearly rounded and a large posterior auricle well separated from the disc.

Specimens of *Sergipia* aff. *posidonomyaformis* (Maury) illustrated by Jolet *et al.* (2001, figs 8.4–7) from Cassis, Provence (SE France), are very similar and probably conspecific with those from Sergipe. However, in their biostratigraphy, Jolet *et al.* reported *Sergipia* as well as *Mytiloides hercynicus* from the uppermost Cenomanian. Their dating is confusing as it points to a much older age than that known for these species from elsewhere in the world.

Although the Sergipe specimens resemble *Didymotis*, better preserved material will be needed to confirm the generic position. Confirmation of *Didymotis* in the middle Turonian would alter its origin, which, according to present knowledge, is in the late Turonian. The specimens probably represent a new species, related to *Didymotis posidonomyaformis*, but pending revision of the material from Sergipe, Cassis and elsewhere it is here left in open nomenclature.

Occurrence. Middle Turonian of Sergipe (Brazil). Uppermost Cenomanian (?) from Cassis, France.

Didymotis sp. indet.
Plate 10, Figure 13

Material. One specimen from Mata 11: MT11.214, poorly preserved as a LV shell with incomplete internal mould.

Description. Medium-sized (height = 38 mm, lenght = 57 mm). Outline oval; inequilateral; shell paper-thin, flattened. Beak subcentral. Hinge line straight, long. Posterior auricle elongated. Anterior margin rounded; posterior margin incompletely preserved. Ornamentation consisting of fine growth lines.

Discussion. The specimen is poorly preserved. In its outline it is similar to *Didymotis costatus* (Frič). However, no radial rugae are observed in this specimen, which seems somewhat crushed. Owing to its poor preservation a specific assignment is not possible.

Occurrence. Upper Turonian of Sergipe (Brazil).

Genus *Cremnoceramus* Cox, 1969 [*non Cremnoceramus* Heinz, 1932 (*nomen nudum*)]

Type species: *Inoceramus inconstans* Woods, 1912, by original designation (Cox, 1969).

Remarks. The genus was characterized by Kauffman (*in* Herm *et al*., 1979, p. 68) and Walaszczyk (1992), and recently discussed by Walaszczyk & Wood (1999). The geniculation is a common character, which occurs regularly, although variably developed, with an associated change in the ornamentation.

Cremnoceramus waltersdorfensis waltersdorfensis (Andert, 1911)
Plate 9, Figures 6, 10–11

1911 *Inoceramus waltersdorfensis* n. sp.; Andert, p. 53, pl. 5 figs 2, 5.
1911 *Inoceramus sturmis* n. sp.; Andert, p. 58, pl. 2, fig. 5.
1934 *Inoceramus waltersdorfensis* Andert; Andert, pp. 112–114, pl. 4, figs 2–7.
1963 *Inoceramus wanderleyi*, Santos, n. sp.; Santos, pp. 357–358, pl. 1, fig. 1; pl. 2 fig. 1.
1963 *Inoceramus remoratus*, Santos, n. sp.; Santos, pp. 358–359, pl. 1, fig. 2.
1967 *Inoceramus waltersdorfensis waltersdorfensis* Andert, 1911; Tröger, pp. 114–117, pl. 12 figs 1–2; pl. 13, figs 1–5.
1967 *Inoceramus inconstans inconstans* Woods; Tröger, pp. 101–102, pl. 13, fig. 19.
1978 *Inoceramus waltersdorfensis waltersdorfensis* Andert; Kauffman, pl. 5, figs 6–7.
v. part 1985 *Cremnoceramus*? *waltersdorfensis* (Andert) lineage; Kauffman & Bengtson, p. 313.

1992 *Cremnoceramus waltersdorfensis* (Andert, 1911); Walaszczyk, pp. 41–46.

1992 *Inoceramus waltersdorfensis waltersdorfensis* Andert, 1911; Elder & Box, pp. 25–26, figs 13.1–13.3.

1996 *Cremnoceramus waltersdorfensis* (Andert, 1911); Walaszczyk, pp. 374–376, figs 3c–f, 5f–g.

1999 *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert, 1911); Walaszczyk & Wood, pp. 413–414, pl. 5, figs 1, 3–7, 9–13, 15–18; pl. 15, figs 1–3; pl. 17, fig. 3.

2000a *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert, 1911); Walaszczyk & Cobban, pp. 72–76, pl. 18, figs 1–9.

2003 Inoceramidae sp. a; Cassab, p. 55, fig. 29b.

2004 *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert, 1911); Walaszczyk *et al.*, figs 4.4, 5.1–2, 5.4–5, 5.7.

2004 *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert, 1911); Wood *et al.*, pl. 3, figs 1–5, 7–9, 11–14.

Material. Two specimens from Mata 11, one incomplete internal mould of LV, one incomplete RV shell: MT11.263, MT11.376.

Description. Small to medium-sized (height = 33–55 mm and length = 32–46 mm). Outline subrounded to subquadrate, juvenile part subquadrate to ovate; inequilateral; slightly orthocline to slightly prosocline; moderately inflated. Umbonal part rounded, inflated, projecting slightly above hinge line. Posterior auricle large, indistinctly separated from the disc. Anterior margin straight to slightly convex, passing into broadly rounded ventral margin; posterior margin almost straight, concave. Ornamentation consisting of asymmetrical growth lines and irregular rugae in the juvenile part; adult part with regular to irregular, variably developed concentric rugae.

Discussion. The specimens from Mata 11 are incomplete and poorly preserved but fit well into Andert's (1911) concept of the species. Specimen MT11.263 (Pl. 9, Fig. 11) is incompletely preserved and has weakly developed rugae.

A detailed discussion of the *C. waltersdorfensis* (Andert) lineage was provided by Walaszczyk & Wood (1999). Within the species, these authors distinguished two stratigraphically successive morphotypes, which they interpreted as chronosubspecies and referred to *C. waltersdorfensis waltersdorfensis* (Andert) and *C. waltersdorfensis hannovrensis* (Heinz).

C. waltersdorfensis waltersdorfensis differs from the younger *C. waltersdorfensis hannovrensis* in its smaller size, subquadrate shape, less developed rugae, and in having an umbonal part that projects only slightly above the hinge line.

Santos (1963) described the new species *Inoceramus wanderleyi* and *Inoceramus remoratus* from Socorro (= Socorro 14 of Bengtson, 1983). She compared her specimens only with forms from Sergipe and Rio Grande do Norte described by Maury (1925, 1937). Santos' specimens are typical *Cremnoceramus*, although most of them are compressed by deformation, but in the inflated umbonal part the geniculation can still be observed. The holotype of *I. wanderleyi* (DNPM 4800, Pl. 9, Fig. 6 herein) has an ornamentation of more regular concentric rugae and its ligamental plate is still preserved. The holotype of *I. remoratus* (DNPM 4818, Pl. 9, Fig. 10 herein), the unique specimen of this species, has the anterior margin damaged and an ornamentation of more developed rugae. Both forms described by Santos (1963) show the same variation in ornamentation as that found in *C. waltersdorfensis waltersdorfensis* and are considered conspecific with that form.

Inoceramidae sp. "a" illustrated by Cassab (2003, fig. 29b) from the Jandaíra Formation, Rio Grande do Norte, has the typical outline and ornamentation of *C. waltersdorfensis waltersdorfensis* and is probably conspecific with the latter.

Occurrence. Uppermost Turonian of England, Germany, France, Spain, Poland, Czech Republic, Romania, Ukraine, Russia, South Africa (Zululand), the U.S. Western Interior, Gulf Coast, Alaska, Sergipe and Rio Grande do Norte (Brazil).

9. Biostratigraphy

Inoceramids and ammonites are the most useful macrofossil groups for Cretaceous biostratigraphy. In Sergipe, inoceramids are more abundant and allow a more refined zonation within the Turonian and Coniacian than in the Aptian, Albian and Cenomanian. In this chapter, the stratigraphical distribution of Turonian inoceramids and ammonites based on the Retiro 26 and Mata 11 sections is described and discussed. Details on the lithostratigraphy and the distribution of other macrofossil groups are given in Chapter 6 (Figures 6.4, 6.9).

Nine inoceramid and five provisional ammonite interval zones (Figures 9.1 and 9.2) are recognized in the Retiro 26 and Mata 11 sections. The base of each interval zone is defined by the first occurrence of its index species (lowest-occurrence zone; Salvador, 1994) and the top by the base of the succeeding interval zone.

Detailed stratigraphical collection of inoceramids and ammonites from the two sections has allowed new biostratigraphical interpretations. The results of this work, integrated with the ammonite collections of Bengtson (1983) from other localities allow revision and refinement of the previous ammonite zonation of Sergipe (Figures 9.2 and 9.4). However, the new ammonite zonation is provisional pending taxonomic revision of the fauna. For the upper Turonian–lower Coniacian a subdivision (Figure 9.4) based on the succession of ammonite genera is proposed by Bengtson *et al*. (in press).

A tentative correlation of the inoceramid zonation with previous zonations from Sergipe, the U.S. Western Interior and Europe is presented herein (Figure 9.2). Correlation with the succession of assemblages of Kauffman & Bengtson (1985) for Sergipe is very uncertain because the fauna was not described or illustrated. However, the Turonian inoceramid zonation of Sergipe allows a good correlation with the U.S. Western Interior and Europe, as most of the inoceramid taxa recognized in the studied area also occur in these areas. Differences, excluding endemic taxa, can be explained mainly by variable species concepts or acme-interval occurrences of species. Therefore, the integration of inoceramid and ammonite zonations is very important and enhances the correlation.

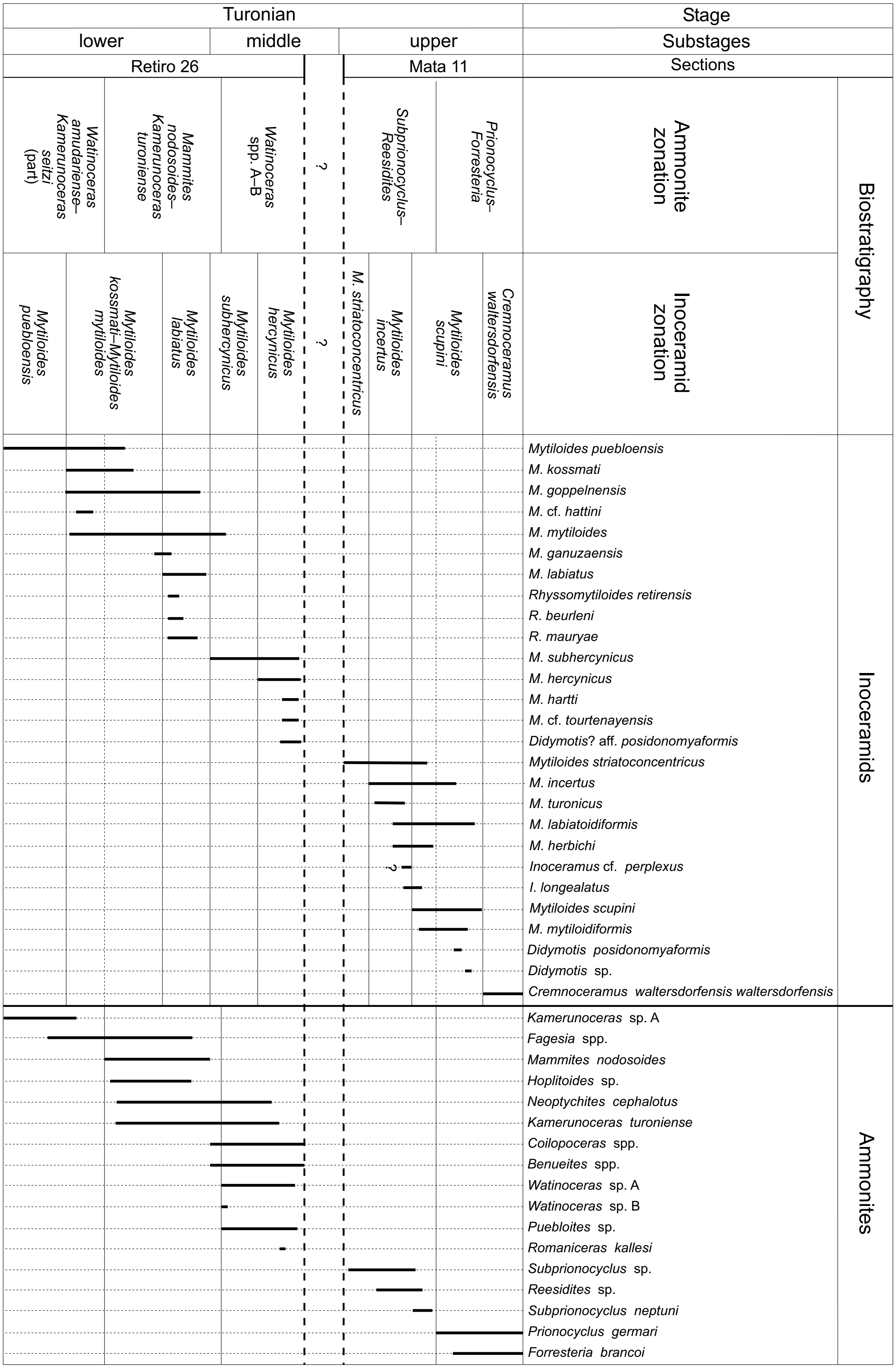


Figure 9.1 Stratigraphical distribution of inoceramids and selected ammonites in the Turonian of Sergipe based on the Retiro 26 and Mata 11 sections. Units not to scale.

Stages	Substages	Inoceramid assemblages, Sergipe (Kauffman & Bengtson, 1985; Hessel, 1988)	Inoceramid zonation, Sergipe (Seeling, 1999; Seeling & Bengtson, 2003b)	Inoceramid zonation, Retiro 26 and Mata 11 sections, Sergipe **(this study)**	Inoceramid zonation U.S. Western Interior (Walaszczyk & Cobban 2000a; Kennedy *et al*., 2000)	European inoceramid zonation (Ernst *et al*., 1983; Walaszczyk, 1992; Harries *et al.* 1996; Walaszczyk & Wood 1999; Wiese & Kaplan, 2001)	Provisional ammonite zonation, Retiro 26 and Mata 11 sections, Sergipe **(this study)**	Ammonite zonation, Sergipe (Smith & Bengtson 1991; Walter & Bengtson, 1998; Seeling & Bengtson, 2003)	"Standard" ammonite zonation (Hancock *et al*., 1993; Bengtson, 1996b; Kauffman *et al*., 1996; Tröger, 2004)	Ammonite subdivision, Tunisia (Robaszynski *et al*., 1990; Chancellor *et al*., 1994)
Coniacian	lower	*Didymotis* sp. *I. rotundatus* *C.? waltersdorfensis* *I. winkholdioides* *I. vancouverensis* *M. lusatiae* *M. fiegei* *M. dresdensis* *M. striatoconcentricus*	*Cremnoceramus deformis erectus* ? ? ?	not present	*Cremnoceramus deformis erectus*	*Cremnoceramus deformis erectus*	not present ? ? ?	*Solgerites armatus-Prionocycloceras lenti* ? ? ?	*Forresteria petrocorienis*	*Forresteria* sp.
Turonian	upper	*Sergipia* spp. *M. striatoconcentricus* *I. vancouverensis* *I. perplexus* *I. apicalis*	*Didymotis* Event II *C. waltersdorfensis* Interval not studied	*Cremnoceramus w. waltersdorfensis* (part) *Mytiloides scupini* *Mytiloides incertus* *M. striatoconcentricus*	*Cremnoceramus w. waltersdorfensis* *Mytiloides scupini* *Mytiloides incertus* *I. dakotensis* *I. perplexus*	*Cremnoceramus w. waltersdorfensis* *Mytiloides scupini* *M. labiatoidiformis* + *M. striatoconcentricus* *I. perplexus/cuvieri*	*Prionocyclus–Forresteria* *Subprionocyclus–Reesidites*	*Barroisiceras onilahyense-Forresteria* *Subprionocyclus–Reesidites*	*Prionocyclus germari* *Subprionocyclus neptuni*	*Prionocyclus* interval
	middle	*M. cuvieri* *M. hercynicus*	Interval not studied	*Mytiloides hercynicus* *Mytiloides subhercynicus*	*Inoceramus dimidius* *I. howelli* *Mytiloides subhercynicus*	*Inoceramus lamarcki–cuvieri* *I. apicalis* *M. hercynicus* *Mytiloides subhercynicus*	*Watinoceras* spp. *A–B*	*Mammites nodosoides–Kamerunoceras turoniense*	*Collignoniceras woollgari*	*Romaniceras deverianum* *Coilopoceras* interval *Romaniceras kallesi* *Kamerunoceras turoniense*
	lower	*Sergipia* spp. *M. hercynicus* *M. latus* *M. mytiloides*	*M. kossmati* *M. mytiloides* *M. kossmati*	*Mytiloides labiatus* *Mytiloides kossmati–M. mytiloides* *Mytiloides puebloensis* (part) not exposed	*Mytiloides mytiloides* *Mytiloides kossmati* *Mytiloides puebloensis*	*Mytiloides labiatus* *Mytiloides mytiloides* *Mytiloides kossmati* *Mytiloides kossmati* *Mytiloides hattini* *Mytiloides wiedmani*	*Mammites nodosoides–Kamerunoceras turoniense* *Watinoceras amudariense–Kamerunoceras seitzi* (part) not exposed	*Watinoceras amudariense–Kamerunoceras seitzi* *Pseudotissotia* spp.	*Mammites nodosoides* *Watinoceras coloradoense*: *Vascoceras birchbyi* *Pseudaspidoceras flexuosum* *Watinoceras devonense*	*Mammites nodosoides* *Choffaticeras* interval *Pseudaspidoceras flexuosum*

Figure 9.2: Tentative correlation of the inoceramid zonation and the provisional ammonite zonation for the Turonian of Sergipe based on the Retiro 26 and Mata 11 sections, with previous inoceramid and ammonite zonations for Sergipe, the U.S. Western Interior, Europe, Tunisia, and the "standard" ammonite zonation. Units not to scale.

Inoceramid correlation with adjacent geographic areas, such as northern and northwestern South America and West Africa, is difficult owing to the scarcity of taxonomic and biostratigraphical studies of these areas. Gebhardt (2001) described five inoceramid species from the upper Turonian of Nigeria, but did not establish a biozonation. The fauna of Nigeria is very similar to that of Sergipe and includes species of the *M. incertus* to *Cremnoceramus waltersdorfensis waltersdorfensis* zones. Most biostratigraphical studies from Africa are based on ammonites, which were integrated with microfossil zonations. A tentative correlation with the ammonite subdivision from Tunisia (Robaszynski *et al*., 1990; Chancellor, *et al*., 1994) is presented here (Figure 9.2).

The fauna of Colombia illustrated by Villamil (1998) and Villamil & Arango (1998) is very similar to that of Sergipe. The inoceramid species from the lower and upper Turonian can be well correlated with those of Sergipe.

9.1 Lower Turonian

Mytiloides puebloensis Interval Zone

This zone is defined as the interval between the first occurrence (FO) of *Mytiloides puebloensis* Walaszczyk & Cobban and the FO of *M. kossmati* (Heinz). It is characterized by the monospecific occurrence of the index species. The Cenomanian−Turonian boundary is not exposed in the Retiro 26 section. As this is the lowest zone represented in the Retiro 26 section the position of the base of the zone is unknown (Figure 9.2).

Correlation. The *M. puebloensis* Zone corresponds to part of the lower part of the *Watinoceras amudariense−Kamerunoceras seitzi* ammonite Zone of Koutsoukos & Bengtson (1993), and is represented by *Kamerunoceras* sp. A., *Fagesia* sp. and coilopoceratids. Koutsoukos & Bengtson (1993) defined the base of this zone by the FO of *Watinoceras amudariense* (Arkhangel'skij), with *Kamerunoceras seitzi* (Riedel) occurring within the zone (OWZ). However, the occurrence of the index species is rare in Sergipe, and according to Seeling (1999) this zone is characterized by a diverse ammonite fauna including *Fagesia* and relatively abundant coilopoceratids, which occur in the lower part of the Retiro 26 section (see Chapter 6, Figure 6.4).

The base of the Turonian in Sergipe is currently positioned at the level of first occurrence of the ammonites *Pseudotissotia* spp. by Walter & Bengtson (1998) and Ferré *et al*., (in press). The *Pseudotissotia* spp. Zone of Sergipe was correlated with the lowermost part of the *Watinoceras coloradorense* Zone in the U.S. Western Interior by Walter (2000) and Ferré *et al*. (in press), which corresponds to the inoceramid *M. puebloensis* Zone. The *Pseudotissotia* spp. Zone is not represented in the Retiro 26 section. However, this zone seems to be of very short duration; its index taxa occur within an interval of only 2–3 m in the Japaratuba area (Seeling, 1999; Walter, 2000; Gale *et al*., in press). No inoceramids were found in this interval but the overlying ammonite zone is marked by the presence of *M. kossmati* and *M. mytiloides* (Seeling, 1999). The fact that *Pseudotissotia* was not found in the Retiro 26 section, suggests that the base of the *Watinoceras amudariense*−*Kamerunoceras seitzi* ammonite Zone is not represented in this section.

***Mytiloides kossmati–Mytiloides mytiloides* Interval Zone**

This zone is defined as the interval between the FO of *Mytiloides kossmati* (Heinz) and the FO of *M. labiatus* (Schlotheim). *M. mytiloides* (Mantell) occurs immediately above the FO of *M. kossmati*. The lower part of the zone is dominated by *M. kossmati* and *M. goppelnensis* Badillet & Sornay, with rare occurrences of *M. mytiloides* and *M.* cf. *hattini* Elder. The middle and upper parts of the zone are dominated by *M. mytiloides*, with *M. ganuzaensis* (López) occurring only at the top of the zone.

Correlation. The lower part of the *M. kossmati–M. mytiloides* Zone corresponds to the upper part of the *Watinoceras amudariense*−*Kamerunoceras seitzi* ammonite Zone, characterized by *Kamerunoceras*, Fagesia sp. and coilopoceratids. The upper part of the zone lies within the lower part of the *Mammites nodosoides*−*Kamerunoceras turoniense* ammonite Zone as redefined herein (*non* Koutsoukos & Bengtson, 1993), characterized by the index species along with *Hoplitoides* sp., *Fagesia* spp., *Neoptychites cephalotus* and *Pachydesmoceras denisonianum*.

Seeling (1999), in his tentative inoceramid zonation, correlated *M. kossmati* to his ammonite interval 4 [corresponding to the *Pseudotissotia* spp. Zone of Walter & Bengtson (1998) and Ferré *et al.* (in press)]. Although he did not find inoceramids together with the ammonite assemblage of this zone, he proposed a lower position for the base of the *Mytiloides kossmati* Zone. However, he remarked that *M. kossmati* does not mark the Cenomanian–Turonian boundary and that the zones were tentatively placed because of the rare occurrence of the inoceramids. Most specimens were also found loose (J. Seeling, 2005, personal communication).

The *M. kossmati–M. mytiloides* Interval Zone is here considered as a single zone because the FOs of both index species are very close. Furthermore, there is a problem with the varying species concepts for *M. mytiloides*. For instance, forms of *M. submytiloides* (Seitz), considered to lie within the variability of *M. mytiloides* were reported by Kauffman (1978) and Harries *et al.* (1996) from the upper part of the Cenomanian to the basal part of the Turonian in North America and Europe. Therefore, it is very difficult to use only this species as an index species for a single interval zone, as was proposed by Kennedy *et al.* (2000) for the U.S Western Interior, although in the upper part of the *M. kossmati–M. mytiloides* Interval Zone only the latter index species is present.

Mytiloides labiatus Interval Zone

The zone is defined as the interval between the FO of *Mytiloides labiatus* (Schlotheim) and the FO of *M. subhercynicus* (Heinz). The lower part of the zone is dominated by *M. labiatus* together with *M. ganuzaensis*, *M. goppelnensis*, *M. mytiloides*, *Rhyssomytiloides retirensis*, *R. beurleni* and *R. mauryae*. Species of *Rhyssomytiloides* occur only within this zone but because of their restricted geographical distribution they are not suitable for defining a zone, although they may be used as regional markers.

Correlation. The *M. labiatus* Zone corresponds to the upper part of the *Mammites nodosoides−Kamerunoceras turoniense* ammonite Zone as redefined herein (*non* Koutsoukos & Bengtson, 1993), which is characterized by the index species, together with *Hoplitoides* sp., *Fagesia* cf. *superstes*, *Neoptychites cephalotus*, and *Pachydesmoceras denisonianum*.

9.2 Middle Turonian

Mytiloides subhercynicus Interval Zone

The zone is defined as the interval between the FO of *Mytiloides subhercynicus* (Seitz) and the FO of *M. hercynicus* (Petrascheck). The lower part of the zone is dominated by *M. subhercynicus* with rare *M. mytiloides*.

Correlation. The *M. subhercynicus* Zone corresponds to the topmost of the *Mammites nodosoides*−*Kamerunoceras turoniense* ammonite Zone and the lower part of the *Watinoceras* spp. A−B ammonite zone, which is dominated by *Benueites* spp., *Watinoceras* sp. A, *Watinoceras* sp. B, *Coilopoceras* spp. and *Puebloites* sp.

This inoceramid interval zone corresponds broadly to the *Collignoniceras woollgari* ammonite Zone in the U.S. Western Interior and Europe. Although the index species is not found in Sergipe, owing to the local abundance of *Watinoceras* spp. in the *M. subhercynicus* Zone, which also applies to other localities in Sergipe, such as Muçuca 4 and 5 (of Bengtson, 1983), *Watinoceras* spp. A–B is here informally proposed as an ammonite assemblage zone.

Mytiloides hercynicus Interval Zone

The zone is defined as the interval between the FO of *Mytiloides hercynicus* (Petrascheck) and the FO of *M. striatoconcentricus* (Gümbel). The lower part of the zone is dominated by *M. subhercynicus* and *M. hercynicus*. The middle to upper part is dominated by both species together with *M. hartti*, *M.* cf. *tourtenayensis* and *Didymotis*? aff. *posidonomyaformis*.

Correlation. The *M. hercynicus Zone* corresponds to the upper parts of the *Watinoceras* spp. A−B ammonite Zone. The assemblage contains *Benueites* spp., *Watinoceras* sp. A, *Coilopoceras* spp., *Pachydesmoceras denisonianum*, *Romaniceras kallesi* and *Puebloites* sp. This zone corresponds to the *Collignoniceras woollgari* ammonite Zone in the U.S. Western Interior and *C. woollgari* and *Romaniceras kallesi* zones in Europe. However, in Sergipe *R. kallesi* is a rare species that is only found in the upper part of the *M. hercynicus* Zone.

Although the *M. hercynicus* Interval Zone was not defined as a zone by Kennedy *et al.* (2000) in the U.S Western Interior, the index species is reported to occur at a higher level within the *Collignoniceras woollgari* Zone.

9.3 Upper Turonian

At the Second International Symposium on Cretaceous Stage Boundaries, in Brussels, 1995, the FO of *Inoceramus costellatus* Woods, 1912 (=*Inoceramus perplexus* Whitfield, 1877) was suggested as an alternative for defining the base of the upper Turonian , a level that lies near the FO of the ammonite *Subprionocyclus neptuni* (Geinitz, 1849) (Bengtson, 1996). The *Inoceramus* *perplexus* Interval Zone of the U.S. Western Interior (Walaszczyk & Cobban, 2000a) has not been recognized in Sergipe.

Mytiloides striatoconcentricus Interval Zone

This zone is defined as the interval between the FO of *Mytiloides striatoconcentricus* (Gümbel) and the FO of *M. incertus* (Jimbo). It is characterized by the monospecific occurrence of *M. striatoconcentricus*.

Correlation. The *M. striatoconcentricus* Zone corresponds to the lower part of the *Subprionocyclus–Reesidites* ammonite Zone, characterized by *Subprionocyclus* sp.

In the U.S. Western Interior, the FO of *M. striatoconcentricus* occurs at the base of the *Inoceramus dakotensis* Interval Zone. Although *I. dakotensis* is not recorded in Sergipe, the *M. striatoconcentricus* Zone of Sergipe can be correlated with the *I. dakotensis* Zone on account of the occurrence of *M. striatoconcentricus* throughout this zone in the North Belle Fourche section (Walaszczyk & Cobban, 2000a, Text-fig. 6).

Mytiloides incertus Interval Zone

This zone is defined as the interval between the FO of *Mytiloides incertus* (Jimbo) and the FO of *M. scupini* (Heinz). The zone is characterized by a variable inoceramid assemblage of *M. incertus*, *M. striatoconcentricus*, *M. labiatoidiformis* (Tröger), *M. turonicus* Walaszczyk, *Inoceramus* cf. *perplexus* Whitfield and *I. longealatus* Tröger

Correlation. The *M. incertus* Zone corresponds to the middle part of the *Subprionocyclus–Reesidites* Zone, characterized by *Subprionocyclus* sp. and *Reesidites* sp., together with *Coilopoceras* sp. and *Desmophyllites* sp.

Kauffman & Bengtson (1985) mentioned *I. perplexus* from the upper Turonian of Sergipe, but re-examination of their material demonstrated that these specimens (for example, GPIHD BR-33.17), though poorly preserved, are better referred to *Mytiloides incertus*. The form here referred to *I.* cf. *perplexus* was found only in the upper part of the *M. incertus* Zone.

Mytiloides scupini **Interval Zone**

This zone is defined as the interval between the FO of *Mytiloides scupini* (Heinz) and the FO of *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert). The lower part of the zone is characterized by *M. scupini*, *M. herbichi*, *M. labiatoidiformis*, and *I. longealatus*. The upper part of the zone it is dominated by *M. scupini*, *M. mytiloidiformis* and *M. labiatoidiformis*, with rare occurrences of *M. incertus*, *Didymotis posidonomyaformis* and *Didymotis* sp.

Correlation. The *M. scupini* Zone corresponds to the upper part of the *Subprionocyclus–Reesidites* ammonite Zone and the lower part of the *Prionocyclus–Forresteria* ammonite interval zone. The base of the latter zone is here provisionally proposed at the FO of *Prionocyclus germari* (Reuss), above which follows the FO of *Forresteria brancoi* (Solger). The top of the zone cannot presently be defined and must be sought outside the Mata 11 section studied. The *Prionocyclus–Forresteria* zone is characterized by the occurrence of the index species together with *Gaudryceras* sp. and *Mossamedites serratocarinatus* (Kennedy & Cobban). The FO of *F. brancoi* in the U.S. Western Interior lies in the upper part of the *M. scupini* Zone.

Cremnoceramus waltersdorfensis waltersdorfensis **Interval Zone**

This zone is defined as the interval between the FO of *Cremnoceramus waltersdorfensis waltersdorfensis* **(**Andert) and the FO of *C. deformis erectus* (Meek). It is characterized by the monospecific occurrence of the index species. This zone is represented in Europe and the U.S. Western Interior by a short interval. The top of the zone, which marks the Turonian–Coniacian (T–C) boundary, is not present in the Mata 11 section but is exposed in the Nossa Senhora do Socorro area, in the Socorro 11 and Cajaíba 8 localities of Bengtson (1983) (Andrade *et al*., 2003a; Bengtson & Andrade, 2005).

Correlation. The *C. waltersdorfensis waltersdorfensis* Zone corresponds to the upper part of the *Prionocyclus–Forresteria* ammonite zone, characterized by *Prionocyclus germari* and *Forresteria brancoi*, together with *Hypophylloceras* sp.

Inoceramus winkholdioides Andert, mentioned but not illustrated by Kauffmann & Bengtson (1985) from Sergipe (Figure 9.2), is probably a junior synonym of *Cremnoceramus brongniarti* (Mantell) (Walaszczyk, 1996) Examination of material collected by Bengtson (1983) did not indicate the presence of this species. It is possible that *I. winkholdioides sensu* Kauffmann

& Bengtson (1985) refers to the Coniacian species *C. deformis erectus* (Meek), a form present in the Bengtson collection. In general, the inoceramid assemblage reported by Kauffman & Bengtson as lower Coniacian (Figure 9.2) is characterized by upper Turonian species, with the exception of their *I. winkholdioides* and *I. rotundatus* (= *C. deformis erectus*).

The uppermost Turonian to lowermost Coniacian of the U.S. Western Interior and Europe comprises the following identical inoceramid succession: *Mytiloides scupini*, *Cremnoceramus waltersdorfensis waltersdorfensis* and *Cremnoceramus deformis erectus*. This succession correlates very well with the Sergipe succession.

A tentative correlation of the inoceramid and provisional ammonite zonations of this study with the planktonic and benthic foraminiferal zonations of Koutsoukos & Bengtson (1993) is presented here (Figure 9.3). The foraminiferal zonations presented by these authors based were based on the integration of the planktonic and benthic foraminiferal study of Koutsoukos (1989) with the ammonite data of Bengtson (1983).

An integrated calcareous nannofossil and planktonic foraminiferal zonation of well SE-2, in Sergipe, was presented by Cunha & Koutsoukos (2001, fig. 8). In their study they also analysed samples from the Retiro 26 section (Votorantim quarry). A tentative correlation of their nannofossil zonation of well SE-1 and SE-2, the planktonic foraminiferal zonation of well SE-2 and the inoceramid and provisional ammonite zonations of the Retiro 26 and Mata 11 sections is presented in Figure 9.3.

The samples from part of the Retiro 26 section analysed by Cunha & Koutsoukos (2001) show a nannofossil assemblage characterized by *Eprolithus eptapetalus*, *E. floralis*, *Radiolithus planus*, and *Watznaueria barnesae*, which indicated that the sampled interval belongs of the UC 6b Zone (Figure 9.3). The planktonic foraminferal assemblage indicated the *Hedbergella* (*W.*) *aprica–H.* (*W.*) *baltica* Zone (Figure 9.3).

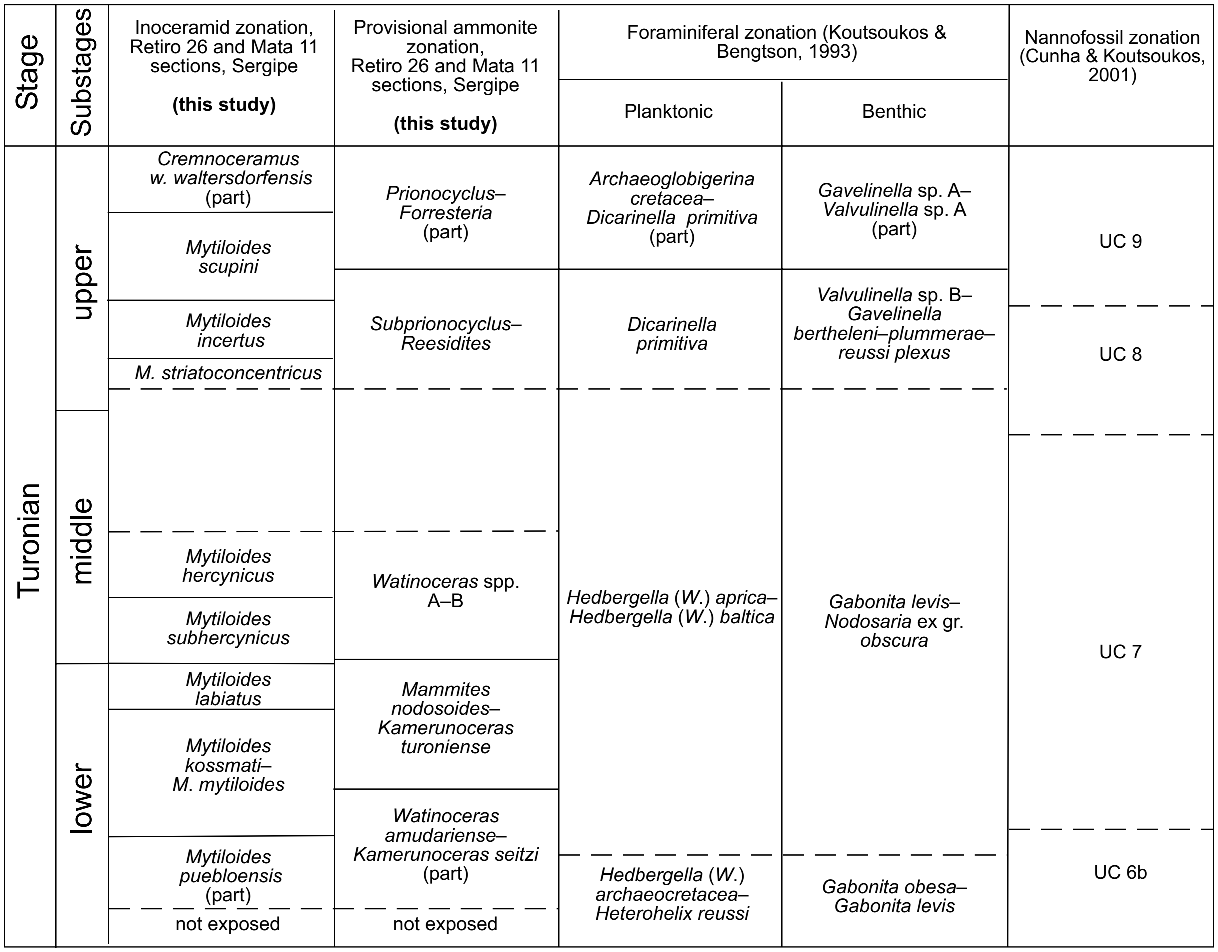


Figure 9.3: Tentative correlation of the inoceramid zonation and the provisional ammonite zonation based on the Retiro 26 and Mata 11 sections, with integrated planktonic and benthic foraminiferal and nannofossil zonations of wells SE-1 and SE-2 (cf. Cunha & Koutsoukos, 2001). Units not to scale.

The Turonian–Coniacian boundary in Sergipe was previously positioned on the basis of ammonite assemblages (Bengtson, 1983; Smith & Bengtson, 1991; Koutsoukos & Bengtson, 1993), where the genera *Barroisiceras*, *Forresteria*, *Solgerites* and *Prionocycloceras* marked the Coniacian (Figure 9.4). Consequently, the upper part of the Mata 11 section was considered as Coniacian. However, during the past few years, a number of changes concerning the boundary definition have been proposed. According to the Coniacian Working Group, as discussed in Brussels, 1995, the base of the Coniacian is best defined by the FO of the inoceramid *Cremnoceramus rotundatus* (sensu Tröger *non* Fiege) (=*C. deformis erectus* (Meek)), which lies between the last occurrence (LO) of the ammonite *Prionocyclus germari* (Eurasia and North America), and the FOs of *Forresteria* (*Harleites*) *petrocoriensis* (Europe) and *F. peruana* and *F. brancoi* (North America) (Kauffman *et al*., 1996). However, Walaszczyk & Cobban (2000a) argued that the final statement referring to ammonites should be excluded from the definition of the Turonian–Coniacian boundary, because the FO of *Forresteria* (in Eurasia and North America) lies distinctly below the FO of *C. deformis erectus*. This is confirmed by data from Sergipe.

As stated above, the integration of the stratigraphical results of this work, based on the inoceramid and ammonite succession of the Mata 11 section, with inoceramid and ammonite data from other localities, has led to a refinement of the upper Turonian–Coniacian biostratigraphy of Sergipe. The development of the biostratigraphical concepts for this interval as well as the new generic ammonite succession established by Bengtson *et al*. (in press) is presented in Figure 9.4., including *Subprionocyclus*, *Prionocyclus*, *Barroisiceras*, *Forresteria* (*Harleites*), *Forresteria* (*Solgerites*), and *Peroniceras*. However, it should be noted that the stratigraphical position of the genus *Barroisiceras* remains uncertain, as representatives of this genus was not found in the Mata 11 section studied. *Barroisiceras* occurs, however, in the stratigraphically equivalent adjacent outcrops Mata 9 and 10, where it is overlain by beds with *Forresteria* (=*Solgerites* of Koutsoukos & Bengtson, 1993; P. Bengtson, personal communication, 2005. Further detailed collection of this succession is needed in order to elucidate the position of *Barroisiceras* in the succession. A taxonomic revision of the ammonites of Sergipe is currently being carried out by P. Bengtson & S.I. Bengtson (in progress).

9.4 The stratigraphical interval between the Retiro 26 and Mata 11 sections

Comparison of the Sergipe biozonal succession with the schemes for North America and Europe suggests that at least three inoceramid zones may be missing between the Retiro 26 and Mata 11 sections, representing the upper middle Turonian and basal upper Turonian (Figure 9.2). A depositional break for this interval was actually suggested by Kauffman & Bengtson (1985), Koutsoukos & Bengtson (1993) and Koutsoukos (1998). However, as the two sections are separated by an unexposed interval of possibly as much as 250 m of sedimentary thickness (Figure 6.11), the most plausible explanation for the missing zones would appear to be lack of exposures. Unfortunately, there are presently no outcrops in the area between the two sections. Additional collecting from selected Turonian localities of Bengtson (1983) and examination of collections by Bengtson (1983) from over 100 localities NE and SE of the Retiro 26 and Mata 11 sections, did not reveal any inoceramids or ammonites that could be referred to the "missing" stratigraphical interval between the sections but all belong to forms that also occur in the upper Retiro 26 or lower Mata 11 sections.

The absence of a number of biozones between the Retiro 26 and Mata 11sections cannot readily be explained on the basis of available data. A number of explanations are possible, for example, there may be a depositional or erosional gap comprising the middle to lowermost upper Turonian in Sergipe; or the uppermost biostratigraphical zone of Retiro 26 and/or the lowermost zone of Mata 11 may be considerably thicker than average and/or of longer duration than those of the international zonation; or local adverse conditions for the inoceramids, such as those manifested above bed 802 in the Retiro 26 section, may have prevailed; or the missing zones may actually lie within the unexposed interval between the quarries. The answer to this problem will depend on the expansion of the Votorantim quarry (Retiro 26) towards the southeast, or the Nassau quarry stratigraphically downwards, or the appearance of outcrops in the area between the two quarries.

Stage	Substage	Ammonite zonation (Smith & Bengtson, 1991; Koutsoukos & Bengtson, 1993)	Ammonite zonation, Sergipe (Seeling & Bengtson, 2003; Ferré *et al*., in press)	Sucession of ammonite genera, Sergipe (this study + Bengtson *et al*., 2005 in, progress)	"Standard" ammonite zonation (Hancock *et al*., 1993; Kauffman *et al*., 1996; Walaszczyk & Cobban, 2000a) emended	Inoceramid zonation, Sergipe (Andrade *et al*., 2003a; Bengtson & Andrade, 2005; this study)
Coniacian	middle	*Solgerites armatus–Prionocycloceras lenti*	*Solgerites armatus-Prionocycloceras lenti*	*Peroniceras*	*Peroniceras*	*Cremnoceramus deformis erectus*
	lower	*Barroisiceras* (*B.*) *onilahyense–Forresteria*				
			? ? ?	*Forresteria*	*Forresteria petrocoriensis*	
Turonian	upper	*Subprionocyclus–Reesidites*	*Barroisiceras onilahyense-Forresteria*			*Cremnoceramus w. waltersdorfensis*
						Mytiloides scupini
				Barroisiceras	*Prionocyclus germari*	
				Prionocyclus		
			Subprionocyclus–Reesidites	*Subprionocyclus*	*Subprionocyclus neptuni*	
						Mytiloides incertus
						M. striatoconcentricus

Figure 9.4: Historical development of the ammonite biostratigraphy in the upper Turonian–Coniacian of Sergipe correlated with the inoceramid zonation.

10. Palaeobiogeography

Palaeobiogeographical studies of Cretaceous inoceramids have been carried out by Kauffman (1973), Tröger (1978, 1989, 1998), Dhondt (1992) and Voigt (1995, 1996). The latter (Voigt, 1995, 1996) presented biogeographical distribution of endemic and cosmopolitan species in a series of maps, covering the Cenomanian to Maastrichtian.

In general, the inoceramids do not play an important role in the definition of palaeobiogeographical provinces because of their largely cosmopolitan occurrence (Tröger, 1989). Their rapid and widespread dispersal was probably caused by long-living planktonic larvae and a broad adaptive environmental range of the adult stage. However, in some areas endemic forms existed, which makes it possible to determine differences between the large intercontinental seas (Voigt, 1995).

Biogeographical study is complicated by a number of methodological problems (e.g. Bengtson & Kakabatze, 1999). Biogeographical interpretations based only on published species lists, without proper taxonomic descriptions and illustrations, is highly imprecise method, because of taxonomical bias and dating inconsistencies. Nevertheless, most palaeobiogeographical work is based primarily on published faunal list. An example is Voigt (1995, 1996), who based her studies on literature data. Her report of *Sergipia* Maury from Mexico, was based on information of Hessel (1988), which was a typing error for Colombia.

To avoid taxonomic inconsistencies and repetition of errors, the palaeobiogeographical interpretations presented here are based exclusively on the distribution of species that are described and/or illustrated. The distribution is presented in two palaeogeographical maps for the early and late Turonian, respectively (Figures 10.1, 10.2). The published occurrences and pertinent references for the species are given in Chapter 8 “Systematic palaeontology”.

The Turonian was an extremely prosperous time for the inoceramids. The Cenomanian−Turonian transition is characteristically marked by appearance of a group of flattened, elongate inoceramids, previously known as the *Inoceramus labiatus* group (after *I. labiatus* Schlotheim, 1813), and currently as the *Mytiloides* group *sensu lato*. The genus *Mytiloides* replaced *Inoceramus* at the Cenomanian–Turonian boundary and attained a worldwide distribution (Dhondt, 1992; Voigt, 1995, 1996). The typical early Turonian forms of the *M. labiatus* group, which is represented by the cosmopolitan species *M. kossmati* (Heinz, 1933), *M. goppelnensis* (Badillet & Sornay, 1980), *M. mytiloides* (Mantell, 1822) and *M. labiatus* (Schlotheim), occur in Brazil (Sergipe), Colombia, Eurasia and North America (Figure 10.1).

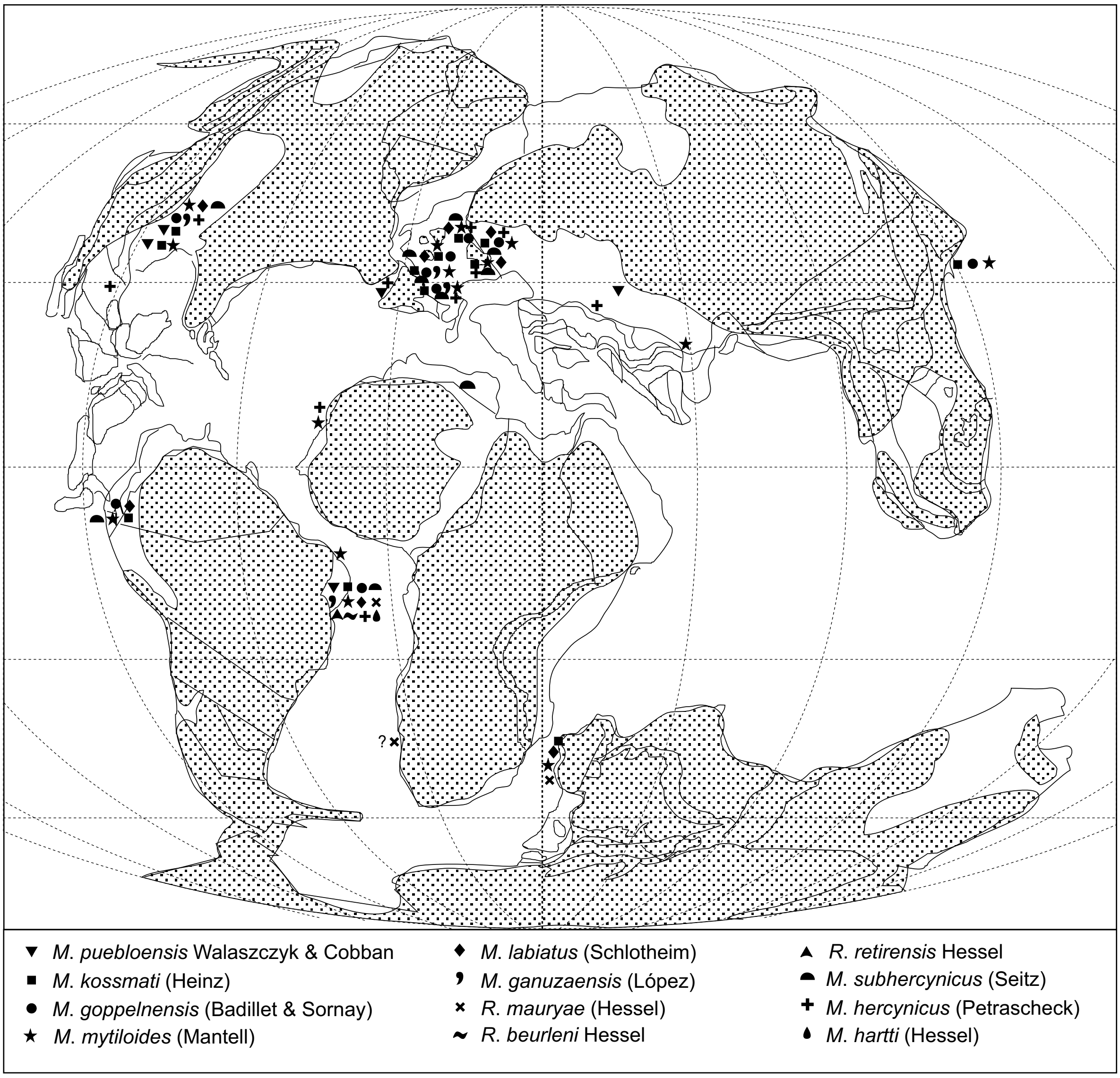


Figure 10.1: Distribution of inoceramids in the early to mid Turonian. Palaeogeographical map modified after Hay *et al*. (1990) and Voigt (1995; 1996).

It is difficult to evaluate the distribution of the inoceramids in the West African basins owing to the scarcity of publications. Moreover, the fauna reported is most cases only listed without descriptions or illustrations, which make specific comparisons next to meaningless. For example, Voûte (1951) discussed the stratigraphical value of the inoceramids of Algeria and cited *I. labiatus* Schlotheim, in the lower Turonian, without description or illustration. Basse de Ménorval (1963) illustrated incomplete specimens from the upper Turonian of Angola, and referred to them as *Inoceramus* α and *Inoceramus* β, though without description. These specimens are similar to what was described and illustrated as *Mytiloides* cf. *carpathicus* (Simionescu) of Nigeria by Gebhardt (2001).

Seibertz (1992) discussed that in Egypt inoceramids were able to occupy favourable regions only during larger transgressive cycles. Nevertheless, all Upper Cretaceous stages are represented at least by one species.

Tröger (1987) suggested that the early Turonian was marked by widespread dispersal of the inoceramids, whereas regression in the middle Turonian caused widespread depositional breaks, for example in Eastern Europe. According to Harries & Kauffman (1992) the lithofacies are not the chief restrictive factor that controls the distribution of inoceramids, but rather differences in water chemistry and the physiological response of the populations to maximum flooding episodes and to those associated with transgressive and regressive phases.

The scarcity of inoceramid in Africa may also be associated with ecological factors. An example is the faunal associations in the upper Cenomanian–lower Turonian of Niger (Mathey *et al.*, 1995), which consist of gryphaeid and ostreid bivalves, and echinoids. The absence of other bivalves (including inoceramids) and brachiopods could be due, for example, to several factors, as severe competition with pioneer bivalves. This ecological factor was also cited by Seibertz (1992) to explain the scarcity of inoceramids in Egypt.

Apart from the globally distributed early Turonian *Myiloides* faunas, a more endemic fauna of *Rhyssomytiloides* is known. *R. mauryae* (Hessel, 1986) occurs in Sergipe, Madagascar and perhaps South West Africa, whereas *R. retirensis* Hessel, 1988 and *R. beurleni* Hessel, 1988 are known only from Sergipe (Figure 10.1).

The mid Turonian saw the virtually cosmopolitan species *M. subhercynicus* (Seitz, 1935) and *M. hercynicus* (Petrascheck, 1904), but also endemic forms, such as *M. hartti* (Hessel, 1988).

During the late Turonian the diversity of the genus *Mytiloides* increased, represented by the cosmopolitan assemblages of *M. incertus* (Jimbo, 1894), *M. striatoconcentricus* (Gümbel, 1868) and *M. scupini* (Heinz, 1930). Some species appear to be more common in Eurasia, such as *M. herbichi* (Atabekjan, 1969), *M. labiatoidiformis* (Tröger, 1967) and *M. turonicus* Walaszczyk, 1992 (Figure 10.2), although, they also occur in Sergipe. These restricted occurrences may in fact reflect the scarcity of published taxonomic work. *Didymotis posidonomyaformis* (Maury, 1925) has been considered an endemic species, with a restricted geographical distribution to Sergipe, Nigeria and Colombia. However, a revision of all the species of this genus may change this distribution pattern.

The Turonian–Coniacian boundary marked a significant change for the inoceramids with the appearance of the genus *Cremnoceramus* Cox, 1969, the extinction of most species of *Mytiloides*, and a sharp decline in diversity.

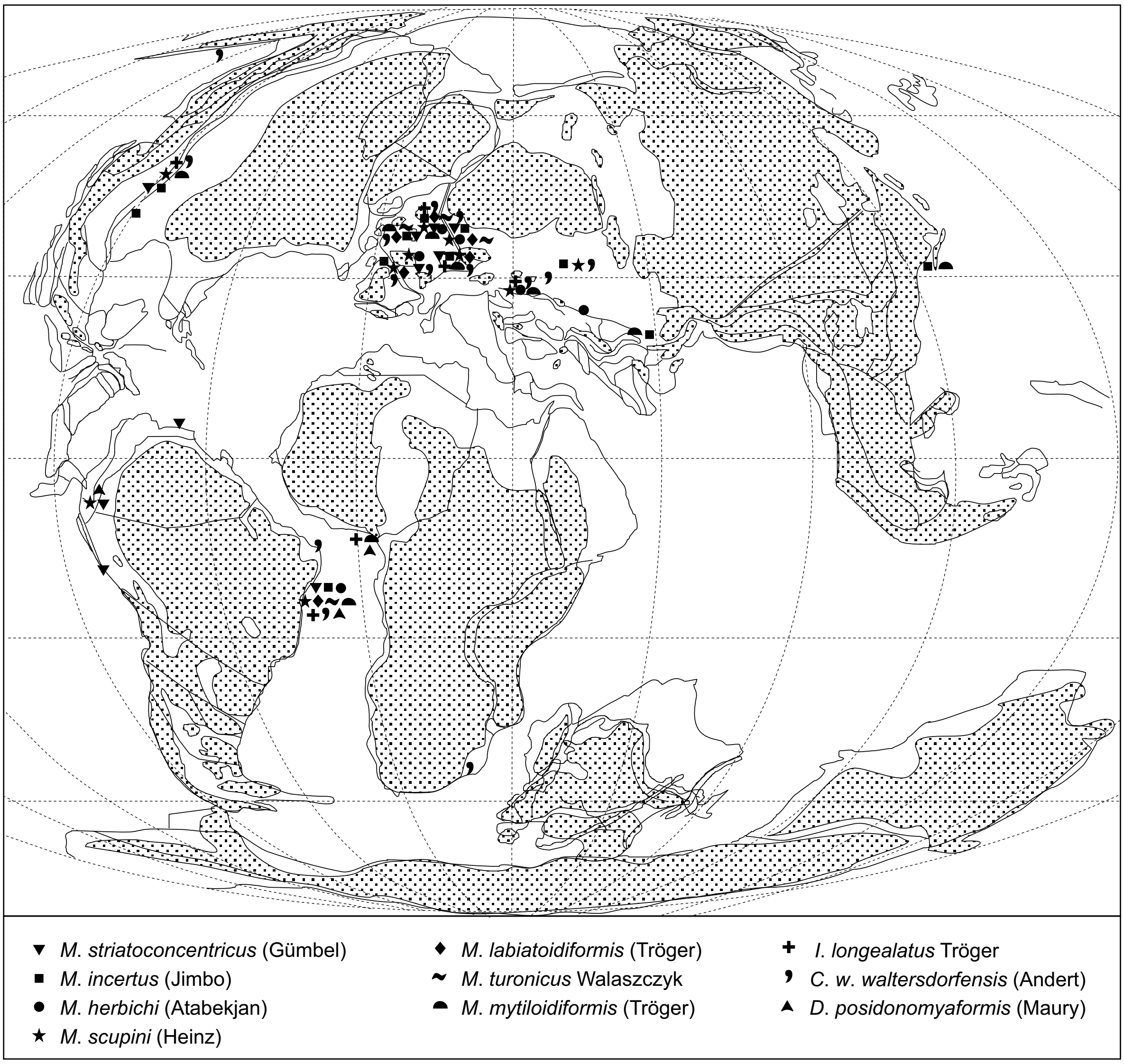


Figure 10.2: Distribution of inoceramids in the late Turonian. Palaeogeographical map modified after Hay *et al*. (1990) and Voigt (1995; 1996).

The Turonian inoceramids of the Jandaíra Formation, in the Potiguar Basin, Rio Grande do Norte, Brazil, described briefly by Cassab (2003), are poorly known, but represented by the cosmopolitan species *M. mytiloides* (Mantell) in the lower Turonian (Figure 10.1) and *C. waltersdorfensis waltersdorfensis* (Andert, 1911) in the upper Turonian (Figure 10.2).

11. Palaeoecology

Palaeoecological aspects of life habits of Cretaceous inoceramids have been discussed by several authors, for example, Tanabe (1973), Kauffman (1975), Elder (1987); Hessel, (1988), Harries *et al*. (1996) and Dhondt & Dieni (1996). In general, the ecology of the inoceramids must be inferred from the lithofacies associated with the specimens (Elder, 1987). Inoceramids are found in a wide range of lithofacies types/environments, from nearshore sandstones to basinal black shales. Their occurrence in black shales, where other fossil groups are rare or nonexistent, suggests that they were opportunists and had a high tolerance to dysaerobic conditions (Elder, 1987; Harries *et al*., 1996), possibly through chemosymbiosis (MacLeod & Hoppe, 1992). However, inoceramids are absent or extremely rare in facies associated with submarine swells and reefs (Tröger, 1989).

Inoceramids generally show peak abundances at times of low total faunal diversity and abundance, thus reflecting their opportunistic strategy of inhabiting substrates where conditions were deteriorated (Elder, 1987). The majority of species had a cosmopolitan distribution probably owing to long-lived planktonic larval stages, which allowed rapid and wide dispersal (Kauffman, 1975). The inoceramids were predominantly epifaunal recliners to semi-infaunal capable of living on a wide variety of substrates and probably non-selective filter feeders (Stanley, 1970; Elder, 1987).

Kauffman *et al*. (1977) discussed the mode of life of inoceramids in the U.S. Western Interior based on their mode of occurrence and the relation between shell morphology and lithofacies. A common assemblage associated with presumed soft substrates includes thin-shelled non-byssate to weakly byssate inoceramids with low convexity, as the *Mytiloides* species *M. kossmati* and *M. goppelnensis*. According to Kauffman *et al*. (1977), the thin delicate shells of the reclining epifaunal to semi-infaunal inoceramids, which lacked a byssus for attachment, such as species of *Didymotis*, suggests a habitat lacking strong current action, below the effective wave base and swept by only gentle bottom currents. *M. mytiloides* and *M. labiatus* were proposed as weakly byssate with a semi-infaunal life habit on mud to carbonate substrates of the middle to outer shelf (Stanley, 1972; Elder, 1987).

The development of divergent radial folds or plicae on the adult portion of the shell of *Rhyssomytiloides* is probably related to the life habit of the species, as interpreted by Toshimitsu *et al*. (1992) for the inoceramid *Sphenoceramus schmidti* (Michael). According to them, the shell arrangement of *S. schmidti* may be related to its feeding strategy. On the other hand, Tanabe (1973) associated the change of ornamentation from concentric to divergent ribs in *S. schmidti* as an adaptive morphology with the change of mode of life during ontogeny from pseudoplanktonic to benthonic.

Understanding the life habits of extinct organisms is commonly very difficulty because the available material generally represents taphocoenoses rather than undisturbed biocoenoses. Functional morphology or synecological analysis can be used to interpret the life position and mode of life of such extinct animals (Dhondt & Dieni, 1996).

A study of the mode of life of *Cladoceramus undulatoplicatus* (Roemer), a Santonian inoceramid very similar to *Rhyssomytiloides mauryae* (Hessel), was presented by Dhondt & Dieni (1996) on the basis of the distribution of numerous spondylid bivalves attached on both valves of *C. undulatoplicatus*, which suggested an erect, partly semi-infaunal mode of life for this species. According to Dhondt & Dieni (1996), an erect life position is the only explanation for the presence of spondylids on both valves. Their symmetrical settling on the inoceramid shell would have allowed them to live in a favourable environment, improved probably by small currents resulting from the pattern of the inoceramid shell folds. Moreover, in *C. undulatoplicatus*, as in *Rhyssomytiloides*, the inflated umbonal area and box-like antero-dorsal part could have functioned as an anchor in addition to a possible byssal attachment.

The appearance of *Rhyssomytiloides* in Sergipe is marked by an environmental change with high terrestrial input in the area. This increased terrestrial influx, indicated by the high abundances of phytoclasts, including plant remains, is continuous throughout the occurrence of *Rhyssomytiloides* (Jäger & Andrade, 2005). The development of radial folds in *Rhyssomytiloides* could be an adaptational strategy for a shallower and more agitated environment. The folds could provide better stability for the shell. Although all fossils collected in this area seem to have been transported, it is probable that *Rhyssomytiloides* occupied a different niche than that of other *Mytiloides* species. Evidence for this is the association of recrystallized specimens of *Rhyssomytiloides* and the echinoid *Mecaster*.

In general, the inoceramids are preserved as single valves indicating an allochthonous fauna. No epibionts were found on the Sergipe inoceramids, which can be explained by an assemblage that thrived in deeper environments and under low-oxygenated conditions. The absence of epibionts was also observed by Seeling (1999), who discussed the faunal indications for oxygen deficiency at the Cenomanian–Turonian boundary in the basin. Discussions of oxygen deficiency based on micropalaeontological and geochemical evidences in the Sergipe Basin were also given by Mello *et al*. (1989) and Koutsoukos *et al*. (1990; 1991).

The scarcity or absence of inoceramids in some intervals can be explained by additional factors. Seibertz (1992) suggested that the general rareness of inoceramids in the Upper Cretaceous of Egypt is caused by (i) strong adverse ecological factors, as for example, large areas with shallow water depths (high energy and temperatures), and strong occupancy of the biotopes by other bivalves, – this may explain the absence of inoceramid in the upper part of the Retiro 26 section (Votorantim quarry), where other bivalve groups are abundant – or (ii) high sedimentation rates, which may explain, at least in part, the absence of inoceramids and other molluscs in the middle part of the Retiro 26 section (between beds 363 and 455). In this case, another possibility would be a deepening of the basin in this area (towards the Divina Pastora Low), caused by tectonic activity evidenced by the presence of carbonate breccias, which hindered the establishment of the macrofauna.

The macrofaunas of Sergipe suggest a decrease in water depth from the early to late Turonian. This is indicated by the change of assemblages dominated by inoceramids and ammonites in the lower Turonian trough part of the middle Turonian, which decrease in the uppermost Turonian with a corresponding increase in other bivalve groups, gastropods and echinoids. The bivalves are represented by a diverse fauna of epifaunal, semi-infaunal and infaunal taxa.

12. Conclusions

The detailed stratigraphical and macropalaeontological survey of measured outcrop sections in the Turonian of the Sergipe Basin in northeastern Brazil has allowed the following conclusions to be drawn:

1. The Turonian macrofauna of the Retiro 26 (Votorantim quarry) and Mata 11 (Nassau quarry) sections is dominated by molluscs, characterized by relatively abundant and well diversified bivalve and ammonite assemblages, with bivalves representing the dominant group, whereas gastropods are rare. The bivalves are dominated by inoceramids. Echinoids show an overall low diversity, in the upper Turonian represented by a monospecific though fairly abundant fauna. Other macrofossil groups are chondrichtyan and osteichthyan fishes, crustaceans, bryozoans and serpulids.

2. The Turonian inoceramid fauna in the studied sections is represented by 29 species belonging to the genera *Mytiloides* Brongniart, *Rhyssomytiloides* Hessel, *Inoceramus* J. Sowerby, *Didymotis* Gerhardt, and *Cremnoceramus* Cox. The species are herein described systematically. Although less abundant than the inoceramids, the ammonites are represented by 28 species.

3. Re-evaluation of the genus *Sergipia* Maury, 1925 has shown it to be a junior synonym of *Didymotis* Gerhardt, 1897.

4. *Rhyssomytiloides* Hessel, 1988 is considered to be a justified genus. Its similarity with *Cladoceramus* Heinz, 1932 is interpreted as a case of homeomorphy.

5. The Turonian of Sergipe is best subdivided on the basis of inoceramids. Inoceramids are generally more abundant and also more cosmopolitan than ammonites and therefore provide a more efficient and precise tool for correlation with the international “standard” zonation.

6. Nine successive inoceramid interval zones are recognized in the Turonian of Sergipe and calibrated with the local ammonite biozonation. The lower Turonian is subdivided into the *Mytiloides puebloensis*, *M. kossmati*–*M. mytiloides* and *M. labiatus* zones, the middle Turonian into the *M. subhercynicus* and *M. hercynicus* zones, and the upper Turonian into the *M. striatoconcentricus*, *M. incertus*, *M. scupini* and *Cremnoceramus waltersdorfensis*

waltersdorfensis zones. The Turonian–Coniacian boundary is not recognized in the Mata 11 section, but exposed in the Nossa Senhora do Socorro area, east of the section. The boundary is marked by the first occurrence of *C. deformis erectus* (Meek), which is reliably correlated with the corresponding level in the proposed candidate Global boundary Stratotype Section and Point (GSSP), in the Salzgitter-Salder quarry, Lower Saxony, Germany.

7. Comparison of the Sergipe biozonation with those of North America and Europe suggests that at least three inoceramid zones may be missing between the Retiro 26 and Mata 11 sections, corresponding to the upper middle Turonian to basal upper Turonian. Whether this is evidence of a stratigraphical gap or whether the missing zones are concealed in the unexposed interval between the two sections cannot be resolved on the basis of available data.

8. Study of the ammonite fauna allowed a refined, though provisional ammonite zonation. The inoceramid zonation and the provisional ammonite zonation are integrated with previously established planktonic and benthic foraminiferal and calcareous nannofossil zonations.

9. The Turonian inoceramid zonation of Sergipe is reliably correlated with the European and U.S. Western Interior zonations. The uppermost Turonian in the three regions contains an identical inoceramid fauna.

10. Although most Turonian inoceramids are cosmopolitan, a more endemic element is represented by the *Rhyssomytiloides* species *R. mauryae* (Hessel, 1986), which is known only from Sergipe, Madagascar and perhaps South West Africa, and by *R. retirensis* Hessel, 1988 and *R. beurleni* Hessel, 1988, both so far known only from Sergipe.

11. It is suggested that *Rhyssomytiloides* occupied a different niche than that of other *Mytiloides* species. The development of radial folds in *Rhyssomytiloides* could be an adaptational strategy for a shallower and more agitated environment. An erect, partly semi-infaunal mode of life is suggested. The inflated umbonal area and box-like antero-dorsal part of the shell could have functioned as an anchor.

12. This study contributes to the stratigraphical knowledge of the Sergipe Basin, with a Turonian inoceramid zonation and a refined provisional ammonite zonation, including taxonomic descriptions and palaeobiogeographical interpretations of the inoceramids. Integrated inoceramid–ammonite zonation serve as a standard zonation for the northwestern South Atlantic and will provide a chronostratigraphical framework for further investigations of the Sergipe Basin and adjacent areas.

Acknowledgements

I express my sincere gratitude to my supervisor Prof. Dr. Peter Bengtson for inviting me and giving me the opportunity to carry out a PhD project at the University of Heidelberg. For supervising my thesis work, for helpful discussions, support and careful reading of the manuscript I thank Prof. Bengtson and Privat-Dozent Dr. Eduardo A. M. Koutsoukos (Petrobras, Rio de Janeiro, Brazil and University of Heidelberg).

My work was supported by a German Academic Exchange Service (DAAD) scholarship. My thanks go to Frau Maria Salgado Martinez and Frau Helga Wahre (DAAD) for their kind assistance.

I am very grateful to Prof. Dr. Volker Schweizer and the late Privat-Dozent Dr. Noor Farsan for their reviews in support of my annual applications for scholarship renovation.

For field work assistance, I am very grateful to my brother Milton Andrade (Aracaju), who contributed tirelessly during all three field seasons. Without his help it would have been impossible to collect the large number of fossils needed for this study. I also thank my friends Adnilton Costa, Elias Silva and Mário Dantas for assistance in the field.

My gratitude goes to Eng. Paulo F. Damasceno (Votorantim Group) and Eng. Diogo Júnior for allowing extensive field work in the Votorantim quarry and for help with practical matters, to their colleagues of the Votorantim Group who contributed to the field work, and to Eng. Tilson Coelho and Eng. Omar Aguiar of the Nassau Group.

I thank Dr. Diógenes de Almeida Campos (Departamento Nacional da Produção Mineral, Rio de Janeiro) and Geologist Luiz Alberto Oliveira (Departamento Nacional da Produção Mineral, Aracaju) for authorization to export the fossil material for study in Heidelberg.

My special thanks go to Dr. Jens Seeling for his helpful and constructive discussions, for improving the English of my thesis, and also for his cooperation on our joint publications and his friendship.

I am very grateful to Dr. Wagner Souza Lima (Petrobras, Fundação Paleontológica Phoenix, Aracaju) for his helpful geological discussions, suggestions and friendship. I also thank geologists Paulo Roberto Santos, Paulo Galm (Petrobras, Fundação Paleontologica Phoenix, Aracaju), Gilvan Hamsi Júnior and Wédimo Santos (Petrobras, Aracaju) for their geological discussions.

Many thanks to Prof. Dr. habil. Karl-Armin Tröger for giving me the opportunity to examine his collections of inoceramids at the TU Bergakademie Freiberg, for his helpful discussions on taxonomic problems and for his friendship during my stays in Freiberg. My thanks also go to Mr. Manuel Röthel (Museum für Mineralogie und Geologie, Dresden), who kindly made available specimens of inoceramids from Saxony, as well as providing technical support.

I am very grateful to Prof. Dr. Ireneusz Walaszczyk (University of Warsaw) for helpful discussions on inoceramids and for critical opinions about my inoceramid plates. Thanks also to Dr. Ekbert Seibertz (Braunschweig) and Dr. Christopher J. Wood (Croydon, U.K.) for their helpful discussions.

I thank Privat-Dozent Dr. Frank Wiese (University of Heidelberg and Freie Universität Berlin) for helpful discussions and suggestions, Dr. Hartmut Jäger (Heidelberg) for providing palynological analyses and helpful discussions, and Dr. Laureen S. da Rosa Alves (UERJ, Rio de Janeiro), Prof. Dr. Margot Guerra-Sommer (UFRGS, Porto Alegre), and Dr. Lutz Kunzmann (Museum für Mineralogie und Geologie Dresden), for discussions about plant remains. Prof. Dr. Valéria Galo (UERJ, Rio de Janeiro) for helpful discussions about fish remains.

I am grateful to Dr. Rita de Cássia T. Cassab for providing photographs and plaster casts of inoceramid types housed at the Departamento Nacional da Produção Mineral (DNPM), Rio de Janeiro, and to Suzana Bengtson (Heidelberg), who helped me to cast the inoceramid specimens and also for her cooperation, friendship and hospitality. I thank Klaus Will (Universität Heidelberg), for photographic work and assistance, Rolf Koch and Iúri Santana (UFS, Sergipe) for help with some illustrations.

I thank Prof. Dr. Thilo Bechstädt, Prof. Dr. Reinhard O. Greiling, Privat-Dozent Dr. Rainer Zühlke, Privat-Dozent Dr. Agnes Kontny (Geologisch-Paläontologisches Institut), Prof. Dr. Volker Storch (Zoologisches Institut), and Prof. Dr. Volker Stähle (Mineralogisches Institut), Heidelberg, for their support.

The Palaeontological Museum of Uppsala University kindly loaned the inoceramid collection previously studied by Hessel. I thank Dr. Maria Helena Hessel (UFPE, Recife), Prof. Maria Helena Zucon (UFS, Aracaju) for awakening my interest in palaeontology, and Dr. Erle G. Kauffman (Indiana University, Bloomington) for his preliminary remarks on the inoceramids of the Bengtson collections.

I thank all my friends and colleagues at the Geologisch-Paläontologisches Institut, Heidelberg, in particular, Dr. Jens Seeling (and Dagmar Sattler), Dr. Juan A. Pérez, Dr. John Malinky, Dr. Anja Schleicher, Dr. Jana Just, Dr. Axel Emmerich, Dr. Zbynek Veselovsky, Dr. Jens Grimmer, Birgit Dietrich, Friederike Bauer, Michael Seeling, Fabio Lapponi, Stefanie Schneider, and Peter Schlicht.

I thank the entire staff of the Geologisch-Paläontologisches Institut for all the hospitality and friendship during my stay: Ayten Eicher, Elfriede Hofmann, Francisco Cueto, Gabriele Fröhlich-Nagel, Hans Ebert, Heike Lehner, Joachim Fillauer, Johanna Kontny, Karin Seehaus, Klaus Will, Markus Thiel, Michael Bühler, Rolf Koch, Roswitha Marioth, Susanne Paetzold, Tania van der Beeck, and in particular Karin Dietzschold for her kind help with the English.

I am deeply grateful to my friends Hedwig and Hans Lang, who took care of me as their own daughter and helped me to improve my German. I will never forget my Christmas celebrations by them and our discussions about methods of fossil preparation. My thanks also to Birgit and Günther Seybold for their friendship.

Special mention goes to my Brazilian friends Marcelo and Daisy Fonseca, Olga C. Lima, Wagner Souza Lima, Cynthia Manso, Ana Denise Santana, and Marcelo A. Carvalho, and to Adriano Bof de Oliveira, Desiree Rocha de Sá, Paula and George Luvizotto, Solange and Augusto Lima, whom I had the opportunity to get to know in Germany.

Last but not least I am very grateful to my parents Andrelina and Manoel Pereira de Andrade, my sister Cristina and my brother Milton for their continuous help, support and patience. To all friends and colleagues who helped me in one way or another to conclude this work, my sincere thanks!

References

Andert, H. 1911. Die Inoceramen des Kreibitz-Zittauer Sandsteingebirges. *Festschrift des Humboldt-vereins zur Feier seines 50 jährigen Bestehens*, 33-64.

Andert, H. 1934. Die Kreideablagerungen zwischen Elbe und Jeschken Teil III: Die Fauna der obersten Kreide in Sachsen, Böhmen und Schlesien. *Abhandlungen der Preußischen Geologischen Landesanstalt, Neue Folge*, **159**, 1-447.

Ando, H. 1991. Systematic and paleobiogeographic significance of the Upper Cretaceous *Didymotis* (Bivalvia). Proceedings of Shallow Tethys 3, Sendai, 1990. *Saito Ho-on Kai Special Publication*, **3**, p. 323.

Andrade, E.J. & Seeling, J. 2000. Os fósseis da bacia de Sergipe-Alagoas: Os moluscos bivalves. *Phoenix*, **18**, 1-2.

Andrade, E.J., Seeling J., & Bengtson, P. 2003a. Cenomanian–Coniacian (Cretaceous) inoceramid biostratigraphy of the Sergipe Basin, Brazil. *In*: 18. Geowissenschaftliches Lateinamerika-Kolloquium, Freiberg, *Zusammenfassungen der Tagungsbeiträge-Abstracts*, *Terra Nostra*, **2**, p. 24.

Andrade, E.J., Seeling, J. & Bengtson, P. 2003b. No more *Sergipia* in Sergipe! – a controversial Cretaceous inoceramid reassessed. *In*: 73. Jahrestagung der Paläontologischen Gesellschaft, Mainz, *Terra Nostra*, **5/3**, p. 22.

Andrade, E.J., Seeling, J., Bengtson, P. & Souza-Lima, W. 2004. The bivalve *Neithea* from the Cretaceous of Brazil. *Journal of South American Earth Sciences*, **17**, 25-38.

Asmus, H.E. 1981. Geologia das bacias marginais atlânticas mesozóicas-cenozóicas do Brasil. *In*: W. Volkheimer & E.A. Musacchio (Eds*): Cuencas sedimentarias del Jurásico y Cretácico de America del Sur*. Comité Sudamericano del Jurásico y Cretácico, Buenos Aires, 127-155.

Atabekjan, A.A. 1969. On some homonyms in Jurassic and Cretaceous inoceramids. *Izvestia Akademii Nauk Armianskoy SSR*, **1**, 3-15. [*In Russian*]

Ayyasami, K. 1990. Cretaceous heteromorph ammonoid biostratigraphy of southern India. *Newsletter on Stratigraphy*, **22**, 111-118.

Ayyasami, K. & Banerji, R.K. 1984. Cenomanian–Turonian transition in the Cretaceous of southern India. *Bulletin of the Geological Society of Denmark,* **33**, 21-30.

Azambuja Filho, N.C., Arienti, L. & Cruz, F.E.G. 1998. Guidebook to the rift-drift Sergipe-Alagoas passive margin basin, Brazil. *Associação Brasileira de Geólogos de Petróleo*, Digital field trip (CD-ROM).

Badillet, G. & Sornay, J. 1980. Sur quelques formes du groupe d'*Inoceramus labiatus* décrites par O. Seitz. Impossibilité d'utiliser ce groupe pour une datation stratigraphique du Turonien inférieur du Saumurois (France). *Comptes Rendus de l'Academie des Sciences Paris*, **290**, 323-325.

Bandeira Júnior, A.N. 1978. Sedimentologia e microfacies calcárias das formações Riachuelo e Cotinguiba da Bacia Sergipe/Alagoas. *Boletim Técnico da Petrobrás*, **21**, 17-69.

Basse, É. 1934. Étude géologique du Sud-Ouest de Madagascar. *Mémoires de la Société Géologique de France, Série A*, **24**, 5-157.

Basse de Ménorval, É. 1963. Quelques Ammonites nouvelles du Crétacé supérieur d'Angola. *Bulletin de la Société Géologique de France*, **4,** 871-876. [for 1962].

Bender, F. 1959. Zur Geologie des Küsten-Beckens von Sergipe. *Geologisches Jahrbuch*, **77**, 1-34.

Bengtson, P. 1979. *Mid-Cretaceous Biostratigraphy of the Sergipe-Alagoas Basin, Northeastern Brazil*. Unpublished Ph.D. thesis, Paleontologiska institutionen, Uppsala Universitet. 187 pp.

Bengtson, P. 1979. A bioestratigrafia esquecida - Avaliação dos métodos bioestratigráficos no Cretáceo médio do Brasil. *Anais da Academia Brasileira de Ciências*, **51**, 535-544.

Bengtson, P. 1983. The Cenomanian–Coniacian of the Sergipe Basin, Brazil. *Fossils and Strata*, **12**, 1-78.

Bengtson, P. 1988. Open nomenclature. *Palaeontology*, **31**, 223-227.

Bengtson, P. 1995. Ammonite and inoceramid biostratigraphy of northeastern Brazil: a status report. *SAMC News*, **2**, 11-12.

Bengtson, P. 1996a. Cretaceous ammonites of Brazil. *In*: Jost Wiedmann Symposium, Tübingen, *Geologisch-Paläontologisches Institut der Universität Kiel, Berichte-Reports*, **76**, 207-213.

Bengtson, P. (compiler) 1996b. The Turonian stage and substage boundaries. *In*: P.F. Rawson, A.V. Dhondt, J.M. Hancock & W.J. Kennedy (Eds), Proceedings "Second International Symposium on Cretaceous Stage Boundaries", Brussels, 8-16 September

1995, *Bulletin de l'Institut Royal des Sciences naturelles de Belgique, Sciences de la Terre*, **66** (Supplément), 69-79.

Bengtson, P. 1999. Research on Cretaceous ammonites of Brazil in the 20th century and the state of the art. *In*: D. Dias-Brito, J. Carneiro de Castro, & R. Rohn (*Eds*), *Boletim do 5° Simpósio sobre o Cretáceo do Brasil*, pp. 591-598. Rio Claro.

Bengtson, P. & Kakabadze, M.V. 1999. Biogeography of Cretaceous ammonites - a review of procedures and problems. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **212**, 221-239.

Bengtson, S.I. & Andrade, E.J. 2005. Ammonite biostratigraphy around the Turonian–Coniacian boundary in the Sergipe Basin, Brazil. *In*: 19th Colloquium on Latin American Geosciences. *Terra Nostra*, **05/1**, 20-21.

Bengtson, S.I., Bengtson, P. & Andrade, E.J. (in press). A revised ammonite biostratigraphy for the upper Turonian–lower Coniacian of the Sergipe Basin, Brazil. *In*: 19. Congresso Brasileiro de Paleontologia e 6. Congresso Latino-Americano de Paleontologia, *Abstracts*. Aracaju.

Berthou, P.-Y. 1984. Albian–Turonian stage boundaries and subdivisions in the western Portuguese Basin, with special emphasis on the Cenomanian–Turonian boundary in the ammonite facies and rudist facies. *Bulletin of the Geological Society of Denmark*, **33**, 41-55.

Berthou, P.-Y. & Bengtson, P. 1988. Stratigraphic correlation by microfacies of the Cenomanian-Coniacian of the Sergipe Basin, Brazil. *Fossils and Strata*, **21**, 1-88.

Besairie, H. 1930. Recherches géologiques à Madagascar. Contribution à l'étude des ressources minérales. *Thèses présentées à la Faculté des Sciences de l'Université de Paris*, 272 pp.

Beurlen, G. 1970. Uma nova fauna de amonóides da formação Sapucari/Laranjeiras (Cretáceo de Sergipe) - considerações sôbre sua bioestratigrafia. *Boletim Técnico da Petrobrás*, **12**, 147-169. [for 1969].

Beurlen, K. 1961a. Die Kreide im Küstenbereich von Sergipe bis Paraíba do Norte (Brasilien). *Zeitschrift der deutschen geologischen Gesellschaft*, **112**, 378-384. [for 1960].

Beurlen, K. 1961b. O Turoniano marinho do Nordeste do Brasil. *Boletim da Sociedade Brasileira de Geologia*, **10**, 39-52.

Beurlen, K. 1964. *A fauna do Calcário Jandaíra da região de Mossoró (Rio Grande do Norte)*. 215 pp. Editora Pongetti (Coleção Mossoroense); Rio de Janeiro.

Beurlen, K. 1967a. *Geologia da região de Mossoró*. 173 pp. Editora Pongetti (Coleção Mossoroense, Série C, XVIII); Rio de Janeiro.

Beurlen, K. 1967b. Estratigrafia da faixa sedimentar costeira Recife–João Pessoa. *Boletim da Sociedade Brasileira de Geologia*, **16**, 43-53.

Böse, E. 1923. Algunas faunas cretácicas de Zacatecas, Durango y Guerrero. *Boletín del Instituto Geológico de México*, **42**, 1-219.

Brito, I.M. 1967. Novas ocorrências de lamelibrânquios no Cretáceo da Bahia. *Departamento Nacional da Produção Mineral, Divisão de Geologia, Notas preliminares e estudos*, **139**, 1-9.

Brüggen, H. 1910. Die Fauna des unteren Senons von Nord-Perú. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie Beilageband* **30**, 717-788.

Bürgl, H. 1957. Biostratigrafia de la Sabana de Bogota y sus alrededores. *Boletin Geologico*, **5**, 113-185.

Burnett, J.A 1998. Upper Cretaceous. *In*: P.R. Bown (Ed.), *Calcareous nannofossil biostratigraphy*. British Micropalaeontological Society Series, pp. 132-199. Chapman & Hall; London.

Burrer, N. Dietzel, S. & Bengtson, P. 2002. Cenomanian–Coniacian (Cretaceous) gastropods from the Sergipe Basin, Brazil. *In*: 3rd European Meeting on the Palaeontology and Stratigraphy of Latin America (EMPSLA). *Extended Abstracts*, pp. 37-39. Toulouse.

[Burrer, N. 2002. *Gastropoden aus dem Cenoman-Coniac des Sergipe-Beckens, Brasilien. Teil 1*: Die Gattungen *Aporrhais*, *Avellana*, *Drepanocheilus*, *Epitonium*, *Fasciolaria*, *Fusus*, *Globiconcha*, *Lunatia*, *Piestochilus*, *Pterocera*, *Ringinella*, *Turbo*, *Turritella*, *Tylostoma*, *Voluta*, *Volutilithes*, *Volutomorpha*. Unpublished Diplom thesis, Universität Heidelberg, 101 pp.]

Carmo, A. M. 1997. *An isotopic and geochemical study of climatic and oceanographic factors influencing organic-matter preservation during the late Cretaceous in Sergipe Basin, Brazil.* Unpublished Ph.D. thesis, Department of Geological Science, Indiana University, Bloomington, 191 pp.

Carmo, A.M. & Pratt, L.M. 1999. Deciphering Late Cretaceous subequatorial ocean-climate interactions in the Sergipe Basin, Brazil. *In*: E. Barrera & C.C. Johnson (*Eds*), Evolution of the Cretaceous Ocean-Climate System. *Geological Society of America*, *Special Paper*, **332**, 231-243.

Carvalho, M.A. 2001. *Paleoenvironmental reconstruction based on palynological and palynofacies analyses of the Aptian–Albian succession in the Sergipe Basin, northeastern Brazil*. Unpublished Ph.D. thesis, Ruprecht-Karls-Universtät Heidelberg. 192 pp.

Cassab, R.C T. 2003. *Paleontologia da Formação Jandaíra, Cretáceo Superior da Bacia Potiguar, com ênfase na paleobiologia dos gastrópodos*. Unpublished Ph.D. thesis, Universidade Federal do Rio de Janeiro, Instituto de Geociências, Rio de Janeiro, 186 pp.

Čech, S. 1989. Upper Cretaceous *Didymotis* events from Bohemia. *In*: J. Wiedmann, (Ed.), Cretaceous of the Western Tethys. *Proceedings of the 3rd International Cretaceous Symposium, Tübingen* 1987, pp. 657-676. E. Schweizerbart'sche Verlagsbuchhandlung; Stuttgart.

Chancellor, G.R., Kennedy, W.J. & Hancock, J.M. 1994. Turonian ammonite faunas from central Tunisia. *Special Papers in Palaeontology*, **50**, 1-118.

Chang, H.K., Kowsmann, R.O. & Figueiredo, A.M.F. 1988. New concepts on the development of east Brazilian marginal basins. *Episodes*, **11**, 194-202.

Chang, H.K., Kowsmann, R.O. & Figueiredo, A.M.F. 1990. Novos conceitos sobre o desenvolvimento das bacias marginais do leste brasileiro. *In*: G.P. Raja Gabaglia, & E.J. Milani (*Eds*), *Origem e Evolução de Bacias Sedimentares*, pp. 269-289. Petrobras; Rio de Janeiro.

Chang, H.K., Kowsmann, R.O., Figueiredo, A.M.F. & Bender, A.A. 1992. Tectonic and stratigraphy of the East Brazil Rift system: an overview. *Tectonophysics*, **213**, 97-138.

Chiplonkar, G.W. & Tapaswi, P.M. 1975. Biostratigraphy of the inoceramids in the Upper Cretaceous of Trichinopoly District, South India. *Biovigyanam*, **1**, 11-15.

Chiplonkar, G.W. & Tapaswi, P.M. 1979. Biostratigraphy, age and affinities of the bivalve fauna of the Cretaceous of Tiruchirapalli District, South India. *Geological Survey of India, Miscellaneous Publication*, **45**, 137-164.

Cox, R.R. 1969. The family Inoceramidae, Giebel, 1852. *In*: R.C. Moore (Ed.), *Treatise on Invertebrate Paleontology. Part N, Mollusca 6 (1), Bivalvia*, pp. 314-321. Geological Society of America and University of Kansas; Boulder.

Cunha, A.S.C. 2001. *Cicloestratigrafia no Cenomaniano superior e Turoniano do Oceano Atlântico Sul*. Unpublished Ph.D. thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, 317 pp.

Cunha, A.S.C. & Koutsoukos, E.A.M. 2001. Orbital cyclicity in a Turonian sequence of the Cotinguiba Formation, Sergipe Basin, NE Brazil. *Cretaceous Research*, **22**, 529-548.

Dacqué, E. 1939. Die Fauna der Regensburg-Kelheimer Oberkreide (mit Ausschluss der Spongien und Bryozoen). *Abhandlungen der Bayerischen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Abteilung, Neue Folge*, **45**, 1-281.

[Dietzel, S.V. 2002. *Gastropoden aus dem Cenomanium-Coniacium des Sergipe-Beckens, Brasilien.* Teil 2: Die Gattungen *Akera*, *Ampullina*, *Cerithium*, *Cimolithium*, *Dicroloma*, *Drepanocheilus*, *Drilluta*, *Euomphalus*, *Fasciolaria*, *Mesalia*, *Piestochilus*, *Pterodonta*, *Scalaturris*, *Solarium*, *Turbo*, *Turritella*, *Tylostoma*, *Uchauxia*, *Voluta*. Unpublished Diplom thesis, Universität Heidelberg, 215 pp.]

Dhondt, A.V. 1992. Cretaceous inoceramid biogeography: a review. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **92**, 217-232.

Dhondt, A.V. & Dieni, I. 1996. Synecology of an unusual Late Cretaceous inoceramid-spondylid association from northern Italy. *Ann. Mus. Civ. Rovereto (Sez.: Arch., St., Sc. nat.)* **11**, 327-338. [for 1995]

Dhondt, A.V., Walaszczyk, I., Tchegliakova, N. & Jaillard, E. 2004. What is *Inoceramus peruanus* Brüggen, 1910? *Acta Geologica Polonica*, **54**, 535-539.

Dias, A.E.S., Pereira, E. & Rodrigues, R. 2003. Carbon and oxygen isotope data from Cenomanian–Turonian boundary in the Laranjeira area, Sergipe–Alagoas Basin, Brazil. *In*: *IV South American Symposium on Isotope Geology*, *Short Papers*, pp. 337-340. Salvador.

Elder, W.P. 1987. The Paleoecology of the Cenomanian−Turonian (Cretaceous) Stage boundary extinction at Black Mesa, Arizona. *Palaios*, **3**, 24-40.

Elder, W.P. 1991. *Mytiloides hattini* n. sp.: a guide for the base of the Turonian in the Western Interior of North America. *Journal of Paleontology*, **65**, 234-241.

Elder, W.P. & Box, S.E. 1992. Late Cretaceous inoceramid bivalves of the Kuskokwim Basin, southwestern Alaska, and their implications for basin evolution. *The Paleontological Society Memoir (Supplement of Journal of Paleontology* 62 (2) II.), **26**, 1-39.

Ernst, G., Schmid, F. & Seibertz, E. 1983. Event-Stratigraphie im Cenoman und Turon von NW-Deutschland. *Zitteliana*, **10**, 531-554.

Falkenhein, F.U.H. (Coord.) 1986. Análise da bacia Sergipe-Alagoas. PETROBRAS/DEPEX/CENPES. *Relatório interno da PETROBRAS*, 210 pp. Aracaju.

Feijó, F.J. 1995. Bacias de Sergipe e Alagoas. *Boletim de Geociências da Petrobras,* **8**, 149-161. [for 1994]

Feijó, F.J. & Vieira, R.A.B. 1991. Sequências cretáceas das bacias de Sergipe e Alagoas. *Geociências* **10**, 153-168.

Ferré, B., Walter, S. & Bengtson, P. (in press). Roveacrinids in mid-Cretaceous biostratigraphy of the Sergipe Basin, northeastern Brazil. *In*: P. Bengtson (Ed.), Mesozoic palaeontology and stratigraphy of South America and the South Atlantic, Part II. *Journal of South American Earth Sciences*.

Flegel, K. 1905. *Heuscheuer und Adersbach-Weckelsdorf. Eine Studie über die obere Kreide im böhmischen-schlesischen Gebirge*. Inaugural-Dissertation, Breslau. 36 pp.

Freitas, L.C.S. 1984. *Nanofósseis calcários e sua distribuição (Aptiano−Mioceno) na Bacia Sergipe-Alagoas*. Unpublished M.Sc. thesis, Universidade Federal do Rio de Janeiro, Instituto de Geociências, Rio de Janeiro, 256 pp.

Gale, A.S., Bengtson, P. & Kennedy, W.J. (in press). Isotopes and ammonites at the Cenomanian–Turonian boundary in the Sergipe Basin, Brazil. *Bulletin of the Geological Society of Denmark*.

Gebhardt, H. 2001. Inoceramids, *Didymotis* and ammonites from the Nkalagu Formation type locality (late Turonian to Coniacian, southern Nigeria): biostratigraphy and palaeoecologic implications. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, **4**,193-212.

Geinitz, H.B. 1871-1875. Das Elbthalgebirge in Sachsen. *Palaeontographica*, **20**, 1–319, pls 1–67 (1–74, pls 1–23, 1871; 95–207, pls 24–45, 1872; 207–235, pls 46–52, 1873; 237–276, pls 53–60, 1874; 277–319, pls 61–67, 1875).

Gerhardt, K. 1897. Beitrag zur Kenntnis der Kreideformation in Columbien. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie Beilageband*, **11**, 118-208.

Gradstein, F.M., Ogg, J.G. & Smith, A.G. 2005. *A Geologic Time Scale 2004*. 384 pp. Cambridge University Press; Cambridge.

Hamsi Júnior, G.P., Campos Neto, O.P.A., Araújo, C.V. & Frota, E.S.T. 1999. Intervalos potencialmente geradores das seqüências mesocretáceas da bacia Sergipe-Alagoas, NE Brasil. *In*: D. Dias-Brito, J.C. Castro & R. Rohn (*Eds*), *Boletim do 5° Simpósio sobre o Cretáceo do Brasil, 1er Simpósio sobre el Cretácico de América del Sur*, pp. 97-102. Serra Negra.

Hancock, J.M., Kennedy, W.J. & Cobban, W.A. 1993. A correlation of the upper Albian to basal Coniacian sequences of northwest Europe, Texas and the United States Western Interior. *Geological Association of Canada, Special Paper*, **39**, 453-476.

Harries, P.J. & Kauffman, E.G. 1992. Evolutionary trends in the Inoceramidae across the Cenomanian–Turonian boundary, Western Interior Basin, U.S.A. *In*: *4th International Cretaceous Symposium*, *Abstract*. Hamburg.

Harries, P.J., Kauffman, E.G. & Crampton, J.S. (Eds). 1996. Lower Turonian Euramerican Inoceramidae: a morphologic, taxonomic, and biostratigraphic overview. *In*: C. Spaeth (Ed.): New developments in Cretaceous research topics. *Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg* **77**, 641-671. Hamburg.

Hartt, C.F. 1870. *Geology and Physical Geography of Brazil*, 620 pp. Fields Osgood, Boston; [Reprinted in 1975 by Robert E. Krieger Publ. Co]; New York.

Hattin, D.E. 1987. Pelagic/hemipelagic rhythmites of the Greenhorn Limestone (Upper Cretaceous) of northeastern New Mexico and southeastern Colorado. *In*: S.G. Lucas & A.P. Hunt (Eds), Northeastern New Mexico, *New Mexico Geological Society 38th Annual Field Conference*, pp. 237-247.

Hay, W.W., Wold, C.N., Shaw, C.A. & Wilson, K.M. 1990. Paleogeographic maps, a status report. *In*: R.N. Ginsburg & B. Beaudoin (Eds), *Cretaceous Resources, Events and Rhythms*, pp. 203-219. Kluwer Academic Publishers; Dordrecht.

Heinz, R. 1928a. Das Inoceramen-Profil der Oberen Kreide Lüneburgs. Mit Anführung der neuen Formen und deren Kennzeichnung. Beiträge zur Kenntnis der oberkretazischen Inoceramen I. *Jahresbericht des Niedersächsischen geologischen Vereins zu Hannover*, **21**, 64-81.

Heinz, R. 1928b. Über die Oberkreide-Inoceramen Süd-Amerikas und ihre Beziehungen zu denen Europas und anderer Gebiete. Beiträge zur Kenntnis der oberkretazischen Inoceramen V. *Mitteilungen aus dem Mineralogisch-Geologischen Staatsinstitut, Hamburg*, **10**, 42-97.

Heinz, R. 1930. Zur stratigraphischen Stellung der Sonnenbergschichten bei Waltersdorf i. Sa. (westsüdlich von Zittau). Beiträge zur Kenntnis der oberkretazischen Inoceramen IX. *Jahresbericht des Niedersächsischen geologischen Vereins zu Hannover*, **23**, 25-30.

Heinz, R. 1932. Aus der neuen Systematik der Inoceramen. Beiträge zur Kenntnis der Inoceramen XIV. *Mitteilungen aus dem Mineralogisch-Geologischen Staatsinstitut in Hamburg*, **13**, 1-26.

Heinz, R. 1933. Inoceramen von Madagaskar und ihre Bedeutung für die Kreide-Stratigraphie. Beiträge zur Kenntnis der Inoceramen XII. *Zeitschrift der Deutschen Geologischen Gesellschaft*, **85**, 241-259.

Heinz, R. 1935 Unterkreide-Inoceramen von der Kapverden-Insel Maio. Beiträge zur Kenntnis der Inoceramen XVIII. *Neues Jahrbuch für Mineralogie, Paläontologie und Geologie, Beilage-Band, Abteilung B*, **73**, 302-311.

Herm, D., Kauffman, E.G. & Wiedmann, J. 1979. The age and depositional environment of the “Gosau”-Group (Coniacian–Santonian) Brandenberg/Tirol, Austria. *Mitteilungen der Bayerischen Staatssammlung für Paläontologie und historische Geologie*, **19**, 27-92.

Hessel, M. H. R. 1984. Inoceramideos brasileiros: passado, presente e futuro. *In*: *Anais do 33. Congresso Brasileiro de Geologia*, Rio de Janeiro, *Sociedade Brasileira de Geologia*, pp. 606-614. Rio de Janeiro.

Hessel, M.H.R. 1986. Alguns inoceramídeos (Bivalvia) radialmente ondulados do Turoniano inferior de Sergipe. In: 8. Congresso Brasileiro de Paleontologia [Rio de Janeiro, 1983]. *Departamento Nacional da Produção Mineral, Série Geologia*, **27**, 227-237.

Hessel, M.H.R. 1988. Lower Turonian inoceramids from Sergipe, Brazil: systematics, stratigraphy and palaeoecology. *Fossils and Strata*, **22**, 1-49.

Holmer, L.E. & Bengtson, P. 1996. Implications of the rare occurrence of brachiopods in the Upper Cretaceous of Sergipe, Brazil. In: *Boletim do 4° Simpósio sobre o Cretáceo do Brasil*, UNESP, pp. 67-69. Rio Claro.

Hyatt, A. 1870. Report on the Cretaceous from Maroim, province of Sergipe, Brazil, in the collection of Professor Hartt. *In* Hartt, C.F. *Geology and Physical Geography of Brazil*, pp. 385-393. Field Osgood & Co.; Boston.

Imlay, R.W. 1954. Stratigraphic and geographic range of the Late Cretaceous pelecypod *Didymotis*. *Journal of Paleontology*, **28**, 548-550.

International Commission on Zoological Nomenclature. 1999. *International Code of Zoological Nomenclature*. 4th ed. 306 pp. The International Trust for Zoological Nomenclature; London.

Jäger, H. & Andrade, E.J. 2005. Palaeoenvironmental changes in the lower Turonian of the Sergipe Basin, NE-Brazil – the palynofacies analysis approach. *In*: 19th Colloquium on Latin American Geosciences. *Terra Nostra*, **05/1**, 61-62.

Johnson, C.C., Pratt, L.M., Kauffman, E.G., Mora, G. & Carmo, A. M. 2003. High-frequency oceanographic and climatic fluctuations in a subequatorial mid-Cretaceous Basin, northeastern Brazil. *In*: Geological Society of America (GSA) (*Eds*), Seattle Annual Meeting, November, 2-5, 2003. Washington. *Abstracts with programs* (http: // gsa.confex.com/gsa/2003AM/finalprogram/abstract_60852.htm).

Jolet, P., Philip, J., Cecca, F., Thomel, G., López, G., Tronchetti, G. & Babinot, J.-F. 2001. Integrated platform/basin biostratigraphy of the upper Cenomanian-lower Turonian in Provence (SE. France). *Geobios*, **34**, 225-238.

Jimbo, K. 1894. Beiträge zur Kenntnis der Fauna der Kreideformation von Hokkaido. *Paläontologische Abhandlungen, Neue Folge*, **2**, 140-198.

Kauffman, E.G. 1975. Dispersal and biostratigraphic potential of Cretaceous benthonic Bivalvia in the Western Interior. *Geological Association of Canada, Special Paper*, **13**, 163-194.

Kauffman, E.G. 1978. An outline of middle Cretaceous marine history and inoceramid biostratigraphy in the Bohemian Basin, Czechoslovakia. *Annales du Muséum d'Histoire Naturelle de Nice*, **4** (13), 1-12. [for 1976]

Kauffman, E.G. 1979. Bivalves. *In*: Herm, D., Kauffman, E.G. & Wiedmann, J. The age and depositional environment of the "Gosau"-Group (Coniacian–Santonian) Brandenberg/Tirol, Austria. *Mitteilungen der Bayerischen Staatssammlung für Paläontologie und historische Geologie*, **19**, 27-92.

Kauffman, E.G. & Bengtson, P. 1985. Mid-Cretaceous inoceramids from Sergipe, Brazil: a progress report. *Cretaceous Research*, **6**, 311-315.

Kauffman, E.G. & Powell, J.D. 1977. Palaeontology. *In*: E.G. Kauffman, D.E. Hattin & J.D. Powell. Stratigraphic, paleontologic, and paleoenvironmental analysis of the Upper Cretaceous rocks of Cimarron County, Northwestern Oklahoma. *Geological Society of America, Memoir*, **149**, 47-150.

Kauffman, E.G., Hattin, D.E. & Powell, J.D. 1977. Stratigraphic, paleontologic, and paleoenvironmental analysis of the Upper Cretaceous rocks of Cimarron County, Northwestern Oklahoma. *Geological Society of America, Memoir*, **149**, 1-150.

Kauffman, E. G., Cobban, W. A. & Eicher, D. L. 1978. Albian through lower Coniacian strata, biostratigraphy and principal events, Western Interior United States. *Annales du Muséum d'Histoire Naturelle de Nice*, **4** (23), 1-32. [for 1976]

Kauffman, E.G., Kennedy, W.J. & Wood, C.J. 1996. The Coniacian stage and substage boundaries. *In*: Rawson, P.F., Dhondt, A.V., Hancock, J.M. & Kennedy, W.J.: Proceedings "Second International Symposium on Cretaceous Stage Boundaries", *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre*, **66**, (Supplément), 81–94.

Keller, S. 1982. Die Oberkreide der Sack-Mulde bei Alfred (Cenoman–Unter-Coniac) Lithologie, Biostratigraphie und Inoceramen. *Geologisches Jahrbuch*, **A64**, 1-171.

Kennedy W.J., & Cobban, W.A. 1991. Stratigraphy and interregional correlation of the Cenomanian–Turonian transition in the Western Interior of the United States near Pueblo, Colorado, a potential boundary stratotype for the base of the Turonian stage. *Newsletters on Stratigraphy*, **24**, 1-33.

Kennedy, W.J., Wright, C.W. & Hancock, J.M. 1987. Basal Turonian ammonites from west Texas. *Palaeontology*, **30**, 27-74.

Kennedy, W.J., Walaszczyk, I. & Cobban, W.A. 2000. Pueblo, Colorado, USA, candidate Global boundary Stratotype Section and Point for the base of the Turonian Stage of the Cretaceous, and for the base of the Middle Turonian Substage, with a revision of the Inoceramidae (Bivalvia). *Acta Geologica Polonica*, **50**, 295-334.

Klinger, H.C. 1977. Cretaceous deposits near Bogenfels, South West Africa. *Annals of the South African Museum*, **73**, 81-92.

Kotsyubinskij, S.P. [Kociubinskij, S.P.] 1974. Semejstvo Inoceramidae Heinz, 1932. *In* Kotsyubinskij, S.P. & Savchinskaya, O.V.: Klass Bivalvia - Dvustvorchatye. *In* Krymgol'ts, G. Ya. (ed.): *Atlas verkhnemelovoj fauny Donbassa*, 76-86, Nedra, Moscow. [*In Russian*]

Koutsoukos, E.A.M., 1989. *Mid- to Late Cretaceous microbiostratigraphy, palaeo-ecology and palaeogeography of the Sergipe Basin, northeastern Brazil*. Unpublished Ph.D.

thesis, Council for National Academic Awards, Polytechnic South West, Plymouth, UK, 2 volumes, 886 pp.

Koutsoukos, E.A.M., 1998. Upper Cretaceous palaeogeography of the Sergipe Basin, NE Brazil: area of the Divina Pastora and Mosqueiro lows. *Zentralblatt für Geologie und Paläontologie,* **1**, 1325-1337.

Koutsoukos, E.A.M. & Bengtson, P. 1993. Towards an integrated biostratigraphy of the upper Aptian–Maastrichtian of the Sergipe Basin, Brazil. *Documents du Laboratoire de Géologie de Lyon*, **125**, 241-262.

Koutsoukos, E.A.M., Leary, P.N. & Hart, M.B. 1990. Latest Cenomanian-earliest Turonian low-oxygen tolerant benthonic foraminifera: a case study from the Sergipe Basin (N.E. Brazil) and the western Anglo-Paris basin (southern England). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 77, 145-177.

Koutsoukos, E.A.M., Mello, M.R. & Azambuja Filho, N.C. 1991. Micropalaeontological and geochemical evidence of mid-Cretaceous dysoxic-anoxic environments in the Sergipe Basin, northeastern Brazil. *In*: Tyson, R.V. and Pearson, T.H. (Eds). Modern and ancient continental shelf anoxia. *Geological Society of London Special Publication*, **58**, 427-447.

Koutsoukos, E.A.M., Destro, N., Azambuja Filho, N.C. & Spadini, A.R. 1993. Upper Aptian–lower Coniacian carbonate sequences in the Sergipe Basin, northeastern Brazil. *In*: T Simo, B. Scott, & J.-P. Masse (Eds). Cretaceous carbonate platforms. *American Association of Petroleum Geologist, Memoir* **56**, 127-144.

Krömmelbein, K. 1964. Ostracoden aus der marinen "Küsten-Kreide" Brasiliens: 1. *Brachycythere* (*Brachycythere*) *sapucariensis* n. sp. aus dem Turonium. *Senckenbergiana Lethaea*, **45**, 489-495.

Krömmelbein, K. 1966. Preliminary remarks on some marine Cretceous ostracodes from northeastern Brazil and west Africa. *In*: Hinte, J. E. van (Ed.), *Proceedings of the Second West African Micropaleontological Colloquium*, Ibadan 1965, pp. 119-123.

Küchler, T. 1998. Upper Cretaceous of the Barranca (Navarra, northern Spain): integrated litho-, bio- and event stratigraphy. Part I: Cenomanian through Santonian. *Acta Geologica Polonica*, **48**, 157-236.

Küchler, T. & Ernst, G. 1989. Integrated biostratigraphy of the Turonian–Coniacian transition interval in northern Spain with Comparison to NW Germany. *In*: J. Wiedmann (Ed.), Cretaceous of the Western Tethys. *Proceedings of the 3rd International Cretaceous*

Symposium, Tübingen 1987, pp. 161-190. E. Schweizerbart'sche Verlagsbuchhandlung; Stuttgart.

Lamolda, M.A., López, G. & Martínez, R. 1989. Turonian integrated Biostratigraphy in the Estella Basin (Navarra, Spain). *In*: J. Wiedmann (Ed.), Cretaceous of the Western Tethys. *Proceedings of the 3rd International Cretaceous Symposium, Tübingen* 1987, pp. 145-159. E. Schweizerbart'sche Verlagsbuchhandlung; Stuttgart.

Lamolda, M.A., Gorostidi, A., Martinez, R., López, G. & Peryt, D. 1997. Fossils occurrences in the upper Cenomanian–lower Turonian at Ganuza, northern Spain: an approach to Cenomanian/Turonian boundary chronostratigraphy. *Cretaceous Research*, **18**, 331-353.

Lana, M. C. 1990. Bacia de Sergipe-Alagoas: uma hipótese de evolução tectono-sedimentar. *In*: Raja Gabaglia, G. P. and Milani, E. J. (*Eds*), *Origem e Evolução de Bacias Sedimentares*, pp. 311-332, Petrobras; Rio de Janeiro.

López, G. 1992. Paleontología y bioestratigrafía de los inocerámidos (Bivalvia) del Cretácico Superior de la Cuenca Navarro-Cántabra y de la Plataforma Norcastellana. Parte II: Estudio sistemático de los subgéneros *Mytiloides* Brongniart y *Magadiceramus* Seitz. *Boletín Geológico y Minero*, **103**, 478-543.

MacLeod & Hoppe, 1992. Evidence that inoceramid bivalves were benthic and harboured chemosynthetic symbionts. *Geology*, **20**, 117-120.

Magalhães, J. 1952. Contribuição ao conhecimento do Cretácico de Sergipe (Calcário Laranjeiras), com descrição de duas formas novas de cefalopodos: Engonoceratidae - Mollusca. *Revista Científica* **3**, 7-23.

Magalhães, J. 1953. Nova espécie de *Hoplitoides* do Cretácico de Sergipe. *Revista Científica*, **4**, 47-55.

Mantell, G.A. 1822. *The fossils of the South Downs; or Illustrations of the geology of Sussex*, 327 pp. Lupton Relfe; London.

Marcinowski, R., Walaszczyk, I. & Olszewska-Nejbert, D. 1996. Stratigraphy and regional development of the mid-Cretaceous (upper Albian trough Coniacian) of Mangyshlak Mountains, Western Kazakhstan. *Acta Geologica Polonica*, **46**, 1-60.

Mathey, B. Alzouma, K., Lang, J., Meister, C., Néradeau, D. & Pascal, A. 1995. Unusual faunal associations during upper Cenomanian-lower Turonian floodings on the Niger ramp (central West Africa). *Palaeogeography, Palaeoclimatology, Palaeoecology* **119**, 63-75.

Matsumoto, T. & Nishida, T. 1995. Stratigraphy occurrences of *Mytiloides* (Bivalvia) in the mid-Upper Cretaceous sequence of Hokkaido. *Fossils*, **59**, 47-66.

Matsumoto, T. & Noda, M. 1983. Restudy of *Inoceramus incertus* Jimbo with special reference to its biostratigraphic implications. *Proceedings of the Japan Academy*, **59** (Ser. B), 109-112.

Maury, C.J. 1925. Fosseis terciarios do Brasil, com descripção de novas formas cretaceas. *Serviço Geologico e Mineralogico do Brasil*, *Monographia* **4**, 1-705.

Maury, C.J. 1930. O Cretaceo da Parahyba do Norte. *Serviço Geológico e Mineralógico do Brasil*, *Monographia,* **8**, 1-305.

Maury, C.J. 1937. O Cretaceo de Sergipe. *Serviço Geologico e Mineralogico do Brasil*, *Monographia,* **11**, 1-283. [for 1936]

Mello, M.R., Koutsoukos, E.A.M., Hart, M.B., Brassel, S.C. & Maxwell, J.R. 1989. Late Cretaceous anoxic events in the Brazilian continental margin. *Organic Geochemistry*, **14**, 529-542.

Mendes, J.M.C. 1994. *Análise estratigráfica da seção neo-aptiana/eocenomaniana (Fm. Riachuelo) na área do Alto de Aracaju e adjacências – Bacia de Sergipe/Alagoas*. Unpublished MSc thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil, 166 pp.

Moskvin, M.M. & Pavlova, M.M. 1960. Nizhnij turon na severnom Kavkaze. (The lower Turonian deposits in the North Caucasus). *Byulleten' Moskovskogo Obshchestva Ispytatelej Prirody, Otdel Geologii* **35** (5), 124-141. [*In Russian*]

Müller, H. 1966. Palynological investigations of Cretaceous sediments in northeastern Brazil. *In*: Hinte, J. E. van (Ed), *Proceedings of the Second West African Micropaleontological Colloquium*, Ibadan 1965, pp. 123-136.

Nagao, T. & Matsumoto, T. 1940. A monograph of the Cretaceous *Inoceramus* of Japan. Part 2. *Journal of the Faculty of Science, Hokkaido Imperial University*, **6**, 1-64.

Néraudeau, D. & Mathey, B. 2000. Biogeography and diversity of South Atlantic Cretaceous echinoids: implications for circulation patterns. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **156**, 71-88.

Noda, M. 1984. Notes on *Mytiloides incertus* (Cretaceous Bivalvia) from the upper Turonian of the Pombets area, central Hokkaido. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **136**, 455-473.

Noda, M. & Matsumoto, T. 1976. *Atlas of Japanese fossils*. **45**, sheets 265-270. [*In Japanese*]

Noda, M. & Matsumoto, T. 1999. Palaeontology and stratigraphy of the inoceramid species from the mid-Turonian through upper middle Coniacian in Japan. *Acta Geologica Polonica*, **48**, 435-482. [for 1998]

Offodile, M.E. 1976. The geology of the Middle Benue, Nigeria. *Publications from the Paleontological Institution of the University of Uppsala, Special volume*, **4**, 1-166.

Offodile, M.E. & Reyment, R.A. 1978. *Stratigraphy* of the Keana-Awe area of the middle Benue region of Nigeria. *Bulletin of the Geological Institutions of the University of Uppsala, New Series*, **7**, 37-66. [for 1977]

Ojeda, H.A.O. 1982. Structural framework, stratigraphy and evolution of Brazilian marginal basins. *American Association of Petroleum Geologists Bulletin*, **66**, 732-749.

Ojeda, H.A.O. & Fugita, A.M. 1976. Bacia Sergipe/Alagoas: Geologia regional e perspectivas petrolíferas. *In*: *28. Congresso Brasileiro de Geologia*, Porto Alegre, 1974. *Anais*, **1**, 137-158.

Oliveira, P.E. de 1958. Annual report. *In*: A.R. Lamego (Ed.), Relatório anual do Diretor, ano de 1957. Divisão de Geologia e Mineralogia, Departamento Nacional da Produção Mineral, 129-131.

Oliveira, P. E. & Brito, I. M. 1969. Amonitas turonianos do Estado de Sergipe. *Anais da Academia Brasileira de Ciências*, **41**, 215-233.

Patarroyo, P. Andrade, E.J. & Bengtson, P. 2005. Chronostratigraphic implications of the ammonite–inoceramid associations at the Turonian–Coniacian transition in the upper Magdalena Valley, Colombia. *In*: 19th Colloquium on Latin American Geosciences. *Terra Nostra*, **05/1**, pp. 92-93.

Pereira, M.J. 1994. *Sequências deposicionais de 2ª/3ª ordens (50 a 2,0 Ma) e tectono-estratigrafia no Cretáceo de cinco bacias marginais do Brasil. Comparações com outras áreas do globo e implicações geodinâmicas*. Unpublished M.Sc. thesis, Universidade Federal do Rio Grande do Sul, 2 vols, 295 pp.

Petrascheck, W. 1903. Ueber Inoceramen aus der Kreide Böhmens und Sachsens. *Jahrbuch der Kaiserlich-Königlichen Geologischen Reichsanstalt*, **58**, 153-168.

Petri, S. 1962. Foraminíferos cretáceos de Sergipe. *Boletim da Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo*, **265** (Geologia 20), 1-140.

Regali, M.S.P., Uesugui, N. & Santos, A.S. 1974. Palinologia dos sedimentos meso-cenozóicos do Brasil (I). *Boletim Técnico da Petrobrás*, **17**(3), 177-191.

Reyment, R. A. & Tait, E. A. 1972. Biostratigraphical dating of the early history of the South Atlantic Ocean. *Philosophical Transactions of the Royal Society of London*, *B. Biological Sciences*, **264 (858)**, 55-95.

Reyment, R. A., Bengtson, P. & Tait, E. A. 1976. Cretaceous transgressions in Nigeria and Sergipe-Alagoas (Brazil). *In*: F.F. Almeida (Ed.), Continental margins of Atlantic type. *Anais da Academia Brasileira da Ciências* **48** (Suplemento), 253-264.

Richter, A.J. & Simões, I.A. (Compilers) 1975. *Carta geológica da Bacia Sergipe/Alagoas*. [1:50,000] 33 map-sheets. Petrobrás S.A., Rio de Janeiro. Departamento da Produção Mineral, Brasília.

Robaszynski, F. 1978. Approche biostratigraphique du Cénomano-Turonien dans le Hainaut franco-belge et le Nord de la France. *Annales du Muséum d'Histoire Naturelle de Nice*, **4** (8), 1-23. [for 1976]

Robaszynski, F. (coord.), Alcaydé, G., Amédro, F., Badillet, G., Damotte, R., Foucher, J:C., Jardiné, S., Legoux, O., Manivit, H., Monciardini, C. & Sornay, J. 1982. Le Turonien de la région-type: Saumurois et Touraine. Stratigraphie, biozonations, sédimentologie. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, **6**, 119-225.

Robaszynski, F., Caron, M., Dupuis, C., Amédro, F., González Donoso, J.M., Linares, D., Hardenbol, J., Gartner, S., Calandra, F. & Deloffre, R. 1990. A tentative integrated stratigraphy in the Turonian of central Tunisia: Formations, zones and sequential stratigraphy in the Kalaat Senan area. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, **14**, 213-384.

Rossi Ronchetti, C. 1961. Fossili cretacei di Pull-i-Khumri (Afghanistan). *Rivista Italiana di Paleontologia*, **67**, 341-368.

Rutsch, R.F. & Salvador, A. 1954. Mollusks from the Cogollo and La Luna formations (Cretaceous) of the Chejendé area, western Venezuela. *Journal of Paleontology*, **28**, 417-426.

Salvador, A. (ed.). 1994. *International stratigraphic guide. A guide to stratigraphic classification, terminology, and procedure.* 2nd ed. 214 pp. The International Union of Geological Sciences and the Geological Society of America; Boulder, Colorado.

Santos, M.E.C.M. 1963. Inoceramus do Calcário Sapucari, Estado de Sergipe. *Anais da Academia Brasileira de Ciências*, **35**, 357-359.

Schaller, H. 1970. Revisão estratigráfica da Bacia Sergipe-Alagoas. *Boletim Técnico da Petrobras*, **12**, 21-86. [for 1969]

Schlotheim, von E.T. 1813. Beiträge zur Naturgeschichte der Versteinerungen in geognostischer Hinsicht. Leonhard's Taschenbuch für Mineralogie 5-7; 1-93. Frankfurt am Main.

Scupin, H. 1913. Die Löwenberger Kreide und ihre Fauna. *Palaeontographica*, *Supplement*, **6**, 1-276.

Seeling, J. 1999. *Palaeontology and biostratigraphy of the macroinvertebrate fauna of the Cenomanian–Turonian transition of the Sergipe Basin, northeastern Brazil - with systematic descriptions of bivalves and echinoids*. Unpublished Ph.D. thesis, Ruprecht-Karls-Universtät Heidelberg. 163 pp.

Seeling, J. 2004. Bioerosion of Late Cretaceous molluscs from Sergipe, Brazil. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, **7**, 413-426.

Seeling, J. & Bengtson, P. 1999. Cenomanian oysters from Sergipe Basin, Brazil. *Cretaceous Research*, **20**, 747-765.

Seeling, J. & Bengtson, P. 2002. Palaeobiogeography of the upper Cenomanian–lower Turonian macroinvertebrates of the Sergipe Basin, northeastern Brazil. *In*: M. Wagreich (*Ed*.), Aspects of Cretaceous Stratigraphy and Palaeobiogeography: Proceedings of the 6th International Cretaceous Symposium, Vienna, 2000. *Schriftenreihe der Erdwissenschaftlichen Kommissionen der Österreichischen Akademie der Wissenschaften* **15,** 151-168.

Seeling, J. & Bengtson, P. 2003a. The bivalve *Pinna cretacea* (Schlotheim, 1813) from the Cretaceous of Brazil. *Acta Palaeontologica Polonica*, **48**, 475-480.

Seeling, J. & Bengtson, P. 2003b. The Late Cretaceous bivalve *Didymotis* Gerhardt, 1897 from Sergipe, Brazil. *Paläontologische Zeitschrift*, **77**, 153-160.

Seibertz, E. 1992. Egyptian Upper Cretaceous inoceramids: stratigraphic spot lights in trans- and regressive cycles. 4th International Cretaceous Symposium, Hamburg, 1992, *Abstract*.

Seilacher, A. 1984. Constructional morphology of bivalves: evolutionary pathways in primary versus secondary soft-bottom dwellers. *Palaeontology*, **27**, 207-237.

Seitz, O. 1935. Die Variabilität des *Inoceramus labiatus* v. Schloth. *Jahrbuch der preußischen geologischen Landesanstalt*, **55**, 429-474.

Simionescu, J. 1899. Fauna cretacica superióra de la Ürmös (Transilvania). *Academia Romana, Publicatiunile Fondului Vasilie Adamachi*, **4**, 237-274.

Smith, A.B. 1991. Taxonomic descriptions *In* A.B. Smith, & P. Bengtson: Cretaceous echinoids from north-eastern Brazil. *Fossils and Strata*, **31**, 15-64.

Smith, A.B. & Bengtson, B. 1991. Cretaceous echinoids from north-eastern Brazil. *Fossils and Strata*, **31**, 1-88.

Sommermeier, L. 1918. Über einen Fossilfund aus der Unteren Kreide von Trinidad. *Centralblatt für Mineralogie, Geologie und Paläontologie*, **4**, 131-136.

Sornay, J. 1965. La faune d'Inocérames du Cenomanien et du Turonien inférieur du sud-ouest de Madagascar. *Annales de Paléontologie* (*Invertébrés*), **51**, 3-18.

Sornay, J. 1972. Faune d'Inocérames du Crétacé supérieur du bassin de Tarfaya (Maroc méridional*). Notes et Mémoires du Service Géologique du Maroc*, **228**, 31-35.

Sornay, J. 1981. Inocérames (Bivalvia) du Turonien inférieur de Colombie (Amérique du Sud). *Annales de Paléontologie (Invertébrés)*, **67**, 135-148.

Sornay, J. 1982. Inocérames du Saumurois. *In*: Robaszynski, F. (coord.), Alcaydé, G., Amédro, F., Badillet, G., Damotte, R., Foucher, J.C., Jardiné, S., Legoux, O., Manivit, H., Monciardini, C. & Sornay, J. Le Turonien de la région-type: Saumurois et Touraine. Stratigraphie, biozonations, sédimentologie. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, **6**, 138-140.

Souza-Lima, W. 2001. *Macrofaunas campanianas e ambientes deposicionais da Formação Calumbi, bacia de Sergipe-Alagoas, Brasil*. Unpublished Ph.D. thesis, Universidade Federal do Rio de Janeiro, Instituto de Geociências, Programa de Pós-Graduação em Geologia, 366 pp.

Souza-Lima, W., Andrade, E.J., Bengtson, P. & Galm, P.C. 2002. A bacia de Sergipe-Alagoas. Evolução geológica e conteúdo fóssil. The Sergipe-Alagoas Basin. Geological evolution, stratigraphy and fossil content. *Phoenix Especial* **1**, 1-34.

Stanley, S.M. 1970. Relations of shell form to life habits of the Bivalvia (Mollusca). *Geological Society of America, Memoir*, **125**, 1-296.

Stanley, S.M. 1972. Functional morphology and evolution of byssally attached bivalve mollusks. *Journal of Paleontology*, **46**, 165-212.

Steinmann, G. 1929. *Geologie von Perú.* 448 pp. Carl Winters Universitätsbuchhandlung; Heidelberg.

Stoliczka, F. 1870–1871. Cretaceous fauna of southern India. Vol. 3, Pelecypoda. *Paleontologica Indica* **3**, 1-207.

SUDENE, 1974. (Topographical map 1:100,000). *Folha SC.24-Z-B-IV Aracaju.* Superintendência do Desenvolvimento do Nordeste (SUDENE), Recife.

Tanabe, K. 1973. Evolution and mode of life of *Inoceramus* (*Sphenoceramus*) *naumanni* Yokoyama emend., an Upper Cretaceous bivalve. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **92**, 163-184.

Teodósio, C. & Bengtson, P. 2003. Macrobioestratigrafia da passagem Cenomaniano–Turoniano (Cretáceo médio) na área de Laranjeiras, bacia de Sergipe. *In*: *18. Congresso Brasileiro de Paleontologia* [Brasília], *Boletim de resumos*, pp. 324-325. Brasília.

Toshimitsu, S., Kano, M. & Tashiro, M. 1992. Mode of occurrence and palaeoecology of a Cretaceous bivalve *Sphenoceramus schmidti* (Michael). *Fossils*, **52**, 1-11.

Troelsen, J.C. & Quadros, L.P. 1971. Distribuição bioestratigráfica dos nanofósseis em sedimentos marinhos (Aptiano–Mioceno) do Brasil. *Anais da Academia de Ciências*, **43** (Suplemento), 577-609.

Tröger, K-A. 1967. Zur Paläontologie, Biostratigraphie und faziellen Ausbildung der unteren Oberkreide (Cenoman bis Turon). Teil I: Paläontologie und Biostratigraphie der Inoceramen des Cenomans bis Turons Mitteleuropas. *Abhandlungen des staatlichen Museums für Mineralogie und Geologie zu Dresden*, **12**, 13-207.

Tröger, K-A. 1978. Probleme der Paläontologie, Biostratigraphie und Paläobiogeographie oberkretazischer Faunen (Cenoman–Turon) Westeuropas und der Russischen Tafel. Berlin: *Zeitschrift für geologische Wissenschaften*, **6**, 557-570.

Tröger, K-A. 1989. Problems of Upper Cretaceous inoceramid biostratigraphy and paleobiogeography in Europe and Western Asia. *In*: J. Wiedmann, (Ed.), Cretaceous of the Western Tethys. *Proceedings of the 3rd International Cretaceous Symposium, Tübingen* 1987, pp. 911-930. E. Schweizerbart'sche Verlagsbuchhandlung; Stuttgart.

Tröger, K-A. 1998. Remarks concerning morphometric parameters, biostratigraphy and palaeobiogeography of Turonian inoceramids (Bivalvia) in Europe. *Zentralblatt für Geologie und Paläontologie Teil I,* **11/12**, 1489-1499. [for 1996]

Tröger, K-A. 1999. *Inoceramus scupini* Heinz im Ober-Turon der Subherzynen Kreidemulde. *Greifswalder Geowissenschaftliche Beiträge*, **6**, 209-215.

Tröger, K-A. 2004. Cenomanian through lower Coniacian events in the Upper Cretaceous of Saxony, Germany. *Acta Geologica Polonica*, **54**, 629-638.

Tupinambá, L.R., Pombo, E.R. & Pereira, E. 2002. Análise estratigráfica do intervalo Cenomaniano/Turoniano da Bacia de Sergipe/Alagoas, na região de Laranjeiras (SE). *In*: *6. Simpósio sobre o Cretáceo do Brasil, 2. Simpósio sobre el Cretácico de América del Sur*, *Boletim de resumos*, pp. 285-290. São Pedro.

Villamil, T. 1998. Chronology, relative sea-level history and a new sequence stratigraphic model for basinal Cretaceous facies of Colombia. *In*: J.L. Pindell & C.L. Drake (*Eds*), Paleogeographic evolution and non-glacial eustasy, northern South America. *Society for Sedimentary Geology, Special Publication*, **58**, 161-216.

Villamil, T. & Arango, C. 1998. Integrated stratigraphy of latest Cenomanian and early Turonian facies of Colombia. *In*: J.L. Pindell & C.L. Drake (*Eds*), Paleogeographic evolution and non-glacial eustasy, northern South America. *Society for Sedimentary Geology, Special Publication*, **58**, 129-159.

Viviers, M.C. Koutsoukos E.A.M., Silva-Telles Jr., A.C. & Bengtson, P. 2000. Stratigraphy and biogeographic affinities of the late Aptian−Campanian ostracods of the Potiguar and Sergipe basins in northeastern Brazil. *Cretaceous Research*, **21**, 407-455.

Voigt, S. 1995. Palaeobiogeography of early Late Cretaceous inoceramids in the context of a new global palaeogeography. *Cretaceous Research*, **16**, 343-356.

Voigt, S. 1996. Paläobiogeographie oberkretazischer Inoceramen und Rudisten – Ozeanographische und klimatologische Konsequenzen einer neuen Paläogeographie. *Münchner Geowissenschaftliche Abhandlungen, Reihe A, Geologie und Paläontologie*, **31**, 1-102

Voûte, C. 1951. Sur la valeur stratigraphique de quelques Inocérames algériens. *Bulletin de la Société géologique de France*, **1**, 23-30.

Walaszczyk, I. 1992. Turonian through Santonian deposits of the Central Polish Uplands; their facies development, inoceramid paleontology and stratigraphy. *Acta Geologica Polonica*, **42**,1-122.

Walaszczyk, I. 1996. Inoceramids from Kreibitz-Zittauer area (Saxony and northern Bohemia): revision of Andert's (1911) descriptions. *Paläontologische Zeitschrift*, **68**, 367-392.

Walaszczyk, I. & Tröger, K.-A. 1996. The species *Inoceramus frechi* (Bivalvia, Cretaceous); its characteristics, formal status, and stratigraphical position. *Paläontologische Zeitschrift*, **70**, 393-404.

Walaszczyk, I. & Cobban, W. A. 1999. The Turonian-Coniacian boundary in the United States Western Interior. *Acta Geologica Polonica*, **48**, 495-507. [for 1998]

Walaszczyk, I. & Cobban, W. A. 2000a. Inoceramid faunas and biostratigraphy of the upper Turonian–lower Coniacian of the Western Interior of the United States. *Special Papers in Palaeontology*, **64**, 1-117.

Walaszczyk, I. & Cobban, W. A. 2000b. Taxonomy of the lower and lower middle Turonian inoceramids from Pueblo. *In*: Kennedy W.J., Walaszczyk I. & Cobban W.A. Pueblo, Colorado, USA, candidate Global boundary Stratotype Section and Point for the base of the Turonian Stage of the Cretaceous, and for the base of the Middle Turonian Substage, with a revision of the Inoceramidae (Bivalvia). *Acta Geologica Polonica*, **50**, 295-334.

Walaszczyk, I. & Szasz, L. 1997. Inoceramid bivalves from the Turonian/Coniacian (Cretaceous) boundary in Romania: revision of Simionescu's (1899) material from Ürmös (Ormenis), Transylvania. *Cretaceous Research*, **18**, 767-787.

Walaszczyk, I. & Wood, C.J. 1999. Inoceramids and biostratigraphy at the Turonian/Coniacian boundary; based on the Salzgitter-Salder Quarry, Lower Saxony, Germany, and Slupia Nadbrzeżna section, central Poland. *Acta Geologica Polonica*, **48**, 395-434. [for 1998]

Walaszczyk, I., Kopaevich, L.F. &. Olferiev, A. G. 2004. Inoceramid/foraminiferal succession of the Turonian and Coniacian (Upper Cretaceous) of the Briansk region (central European Russia). *Acta Geologica Polonica*, **54**, 597-609.

Walter, S. 2000. *Palaeoenvironmental analysis of the upper Cenomanian and lower Turonian limestone beds in the Sergipe Basin, northeastern Brazil, based on microfacies analysis, micropalaeontology and stable isotopes*. Unpublished Ph.D. thesis, Ruprecht-Karls-Universtät Heidelberg. 107 pp.

Walter, S. & Bengtson, P. 1998. Biostratigraphy and microfacies analysis of the Cenomanian–Turonian boundary beds in the Laranjeiras and Itaporanga areas, Sergipe, northeastern Brazil. *In*: 16. Geowissenschaftliches Lateinamerika-Kolloquium, Zusammenfassungen der Tagungsbeiträge. *Terra Nostra* **98/5**, 170-171. Bayreuth.

Walter, S., Herrmann, A.D. & Bengtson, P. (in press). Stratigraphy and facies analysis of the Cenomanian–Turonian boundary succession in the Japaratuba area, Sergipe Basin, Brazil. *In*: P. Bengtson (Ed.), Mesozoic palaeontology and stratigraphy of South America and the South Atlantic, Part II. *Journal of South American Earth Sciences*.

White, C.A. 1887. Contribuições á Paleontologia do Brasil. *Archivos do Museu Nacional do Rio de Janeiro*, **7**, 1-273.

Whitfield, R.P. 1877. Preliminary report on the paleontology of the Black Hills, containing descriptions of new species of fossils from the Potsdam, Jurassic, and Cretaceous formations of the Black Hills of Dakota. *United States Geographical and Geological Survey of the Rocky Mountain Region*, 1-49. Washington, D.C.

Whitfield, R. P. 1880. Paleontology of the Black Hills of Dakota. *In*: Newton, H. & Jenney, W.P. Report on the geology and resources of the Black Hills of Dakota. *United States Geographical and Geological Survey of the Rocky Mountain Region*, 325-468.

Wiedmann, J. & Kauffman, E.G. 1978. Mid-Cretaceous stratigraphy of northern Spain. *Annales du Muséum d'Histoire Naturelle de Nice* **4** (3), 1-34. [for 1976]

Wiese, F. 1997. Das Turon und Unter-Coniac im Nordkantabrischen Becken (Provinz Kantabrien, Nordspanien): Faziesentwicklung, Bio-, Event- und Sequenzstratigraphie. *Berliner Geowissenschaftliche Abhandlungen, Reihe E*, **24**, 1-131.

Wiese, F. & Kröger, B. 1998. Evidence for a shallowing event in the Upper Turonian (Cretaceous) *Mytiloides scupini* Zone of northern Germany. *Acta Geologica Polonica*, **48**, 265-284.

Wiese, F. & Kaplan, U. 2001. The potential of the Lengerich section (Münster Basin, northern Germany) as a possible Stratotype Section and Point (GSSP) for the Middle/Upper Turonian boundary. *Cretaceous Research*, **22**, 549-563.

Wiese, F., Čech, S., Ekrt, B., Košt'ák, M., Mazuch, M. & Voigt, S. 2004. The Upper Turonian of the Bohemian Cretaceous Basin (Czech Republic) exemplified by the Úpohlavy working quarry: integrated stratigraphy and palaeoceanography of a gateway to the Tethys. *Cretaceous Research*, **25**, 329-352.

Wood, C.J., Walaszczyk, I., Mortimore, R.N. & Woods, M. 2004. New observations on the inoceramid biostratigraphy of the higher part of the upper Turonian and the Turonian–Coniacian boundary transition in Poland, Germany and the UK. *Acta Geologica Polonica*, **54**, 541-549.

Woods, H. 1911. A monograph of the Cretaceous Lamellibranchia of England. *Palaeontographical Society*, *Monographs*, **2** (Part 7), 261-284. [for 1910]

Woods, H. 1912. A monograph of the Cretaceous Lamellibranchia of England. *Palaeontographical Society*, *Monographs*, **2** (part 8), 285-340. [for 1911]

Plates

Plate 1

Figures 1–4: *Mytiloides puebloensis* Walaszczyk & Cobban, 2000 from Retiro 26.
1a–b, RT26.609; 1a, internal view of LV shell; 1b, plaster cast of LV; bed Z-49
2, RT26.02; internal view of LV shell; bed 1
3, RT26.66; internal mould RV; bed 49
4, RT26.143; internal mould RV; bed 85

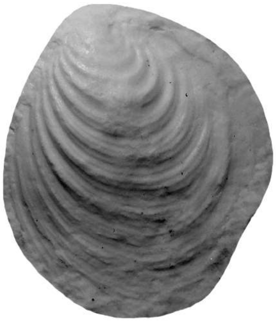
Figures 5–7: *Mytiloides kossmati* (Heinz, 1933) from Retiro 26.
5, RT26.65; internal mould RV; bed 49
6, RT26.89; internal mould LV; bed 51
7, RT26.118; internal mould LV; bed 58

Figures 8–11: *Mytiloides* cf. *hattini* Elder, 1991 from Retiro 26.
8, RT26.72; internal mould LV; bed 49
9, RT26.81; internal mould RV; bed 50
10, RT26.109; internal mould RV (anterior margin deformed); bed 56
11, RT26.91; internal mould RV bed 52

All figures are natural size

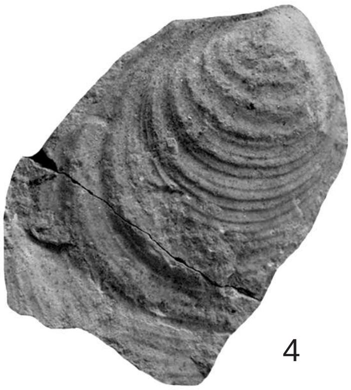
Plate 1


1a


1b

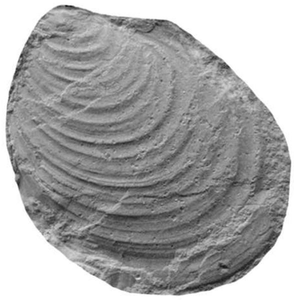

2


3


4


5


6


7


8


9


10


11

Plate 2

Figures 1–3: *Mytiloides goppelnensis* (Badillet & Sornay, 1980) from Retiro 26.
1, RT26.33; internal mould RV; bed 39
2, RT26.20; internal mould RV; bed 36
3, RT26.136; internal mould RV; bed 75

Figure 4: transitional morphotype between *Mytiloides goppelnensis* (Badillet & Sornay, 1980) and *Mytiloides ganuzaensis* (López, 1992) from Retiro 26.
4, RT26.186; internal mould RV; block (bed 270–280)

Figures 5–11: *Mytiloides mytiloides* (Mantell, 1822) from Retiro 26.
5, RT26.610; internal mould RV; bed 36
6, RT26.51; internal mould RV; bed 41
7, RT26.50; internal view of RV shell (hinge line and muscle tracks partially preserved); bed 41
8, RT26.138; internal mould LV; bed 79
9, RT26.410; internal mould RV; bed 291
10, RT26.193; internal mould LV; bed 280
11, RT26.189; internal view of RV shell (umbonal part damaged); bed 290;

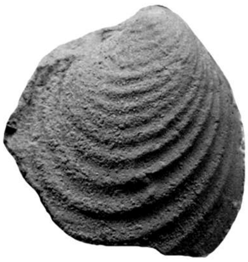
Figure 12: *Mytiloides mytiloides*? (Mantell, 1822) from Retiro 26.
12, RT26.167; internal mould RV (posterior auricle slightly damaged); bed 170

Figure 13: *Mytiloides ganuzaensis* (López, 1992) from Retiro 26.
13, RT26.205; internal view of RV shell; bed 302

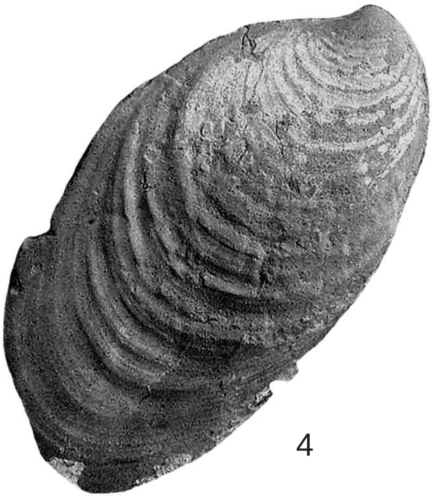
Figures are natural size, except figures 7, 10, 11 and 13 are x 0.75

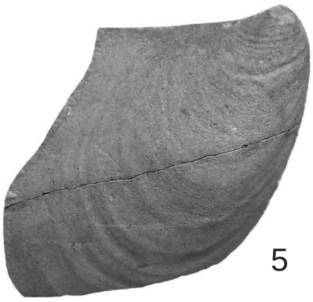
Plate 2


1

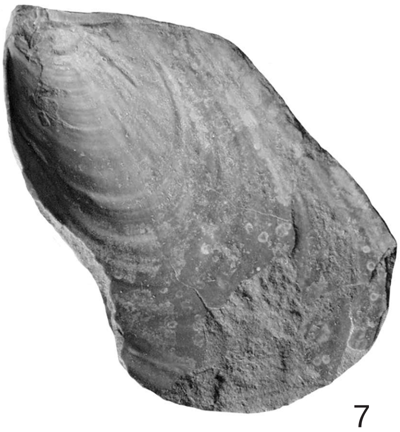

2


3

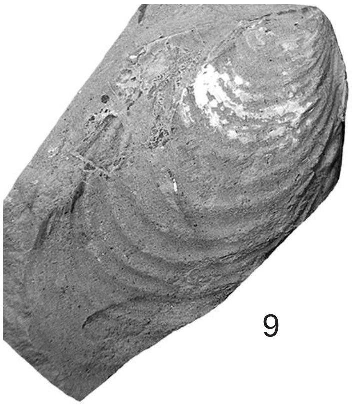

4


5


6

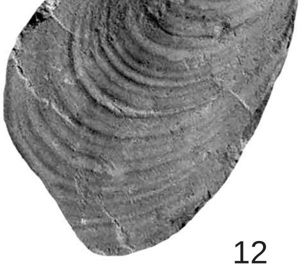

7


8


9


10


11


12


13

Plate 3

Figures 1–6: *Mytiloides mytiloides* (Mantell, 1822) from Retiro 26.
1a, b, RT26.190; a, internal mould LV; b, anterior view of LV; bed 290
2, RT26.185; internal mould LV; bed 297
3, RT26.187; internal mould RV; bed 309
4, RT26.415; internal mould RV; bed 294
5, RT26.406; internal mould LV; bed 299
6, RT26.560; internal mould LV; bed 502

Figures 7–13: *Mytiloides labiatus* (Schlotheim, 1813) from Retiro 26.
7, RT26.431; RV shell; bed 313
8, RT26.271; incomplete internal mould of RV with shell fragments; bed 362
9, RT26.420; internal mould of LV; bed 301
10, RT26.434; internal mould of RV with shell fragments (anterior margin damaged); bed 315
11, RT26.435; internal mould of LV; bed 315
12a, b, RT26.273; a, internal mould LV with shell fragments (slightly compressed laterally); b, anterior view of LV; bed 362
13, RT26.447; incomplete internal mould RV; bed 317

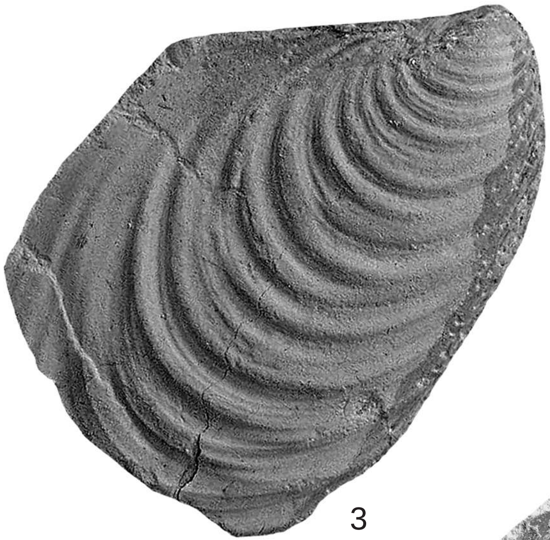
Except figure 1a, b, which is x 0.75, all other figures are natural size

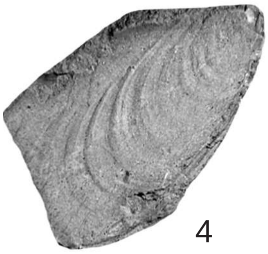
Plate 3


1a

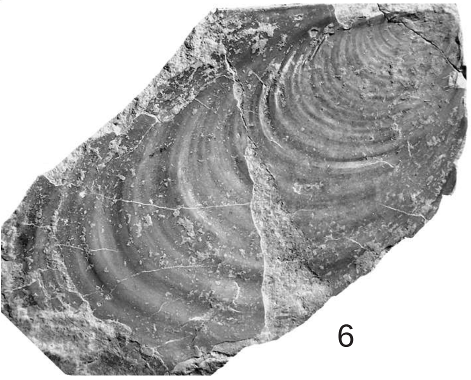

1b

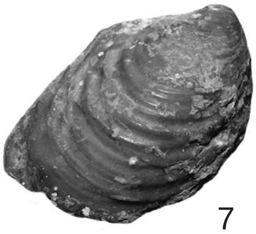

2


3


4


5


6

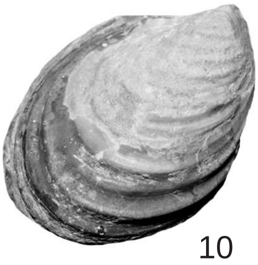

7


8


9


12a


13


10


11

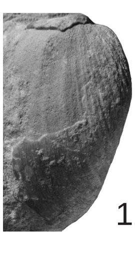

12b

Plate 4

Figure 1: *Rhyssomytiloides retirensis* Hessel, 1988 from Retiro 26.

1, RT26.459; internal mould of LV (beak and part of anterior margin slightly damaged); bed 319

Figures 2–3: *Rhyssomytiloides beurleni* Hessel, 1988 from Retiro 26.

2, RT26.460; internal mould of LV; bed 319

3, RT26.465; internal mould of LV with shell fragments; bed 320

Figures 4–6: *Rhyssomytiloides mauryae* (Hessel, 1986) from Retiro 26.

4a, RT26.248; internal view of LV shell; 4b plaster cast of LV; bed 323

5, RT26.640; internal mould of LV; block above bed 340

6, RT26.506; internal mould of LV, with shell fragment on posterior auricle. Anterior margin slightly damaged. Bed 342.

Figures 7–10: *Mytiloides subhercynicus* (Seitz, 1935) from Retiro 26.

7, RT26.332; internal view of LV shell; bed 546

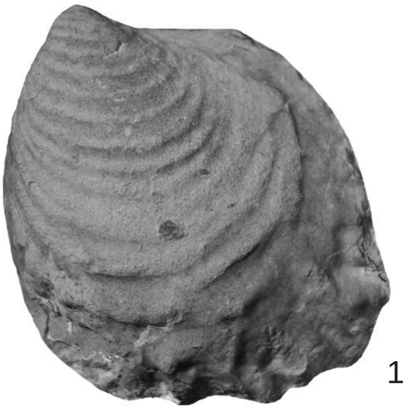
8, RT26.589; internal mould of RV; bed 663

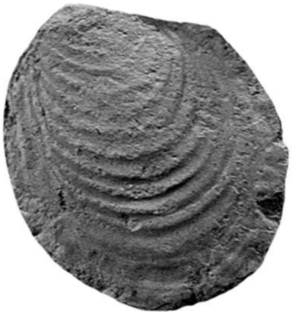
9, RT26.347; internal view of LV shell; bed 551

10, RT26.627; internal view of LV shell and incomplete internal mould; bed 650

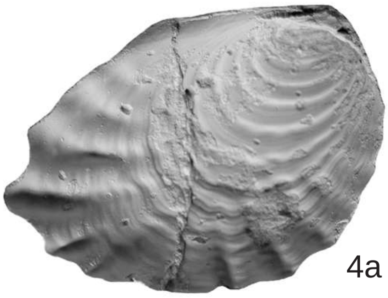
Except figure 10, which is x 0.7, all other figures are x 1.2

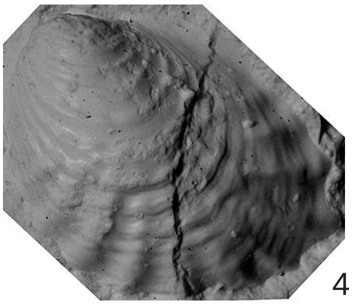
Plate 4


1


2

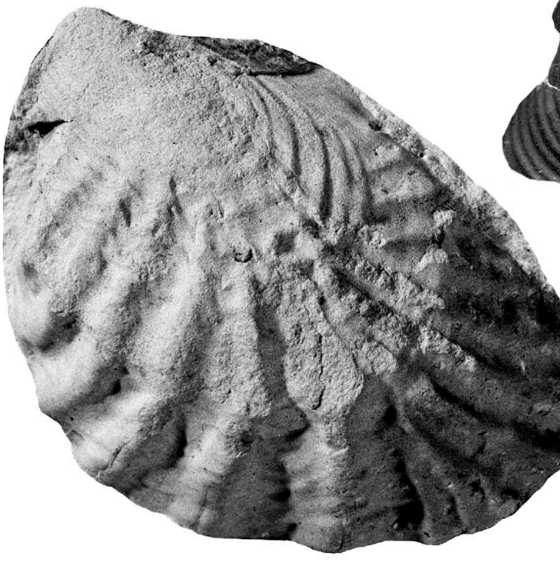

3

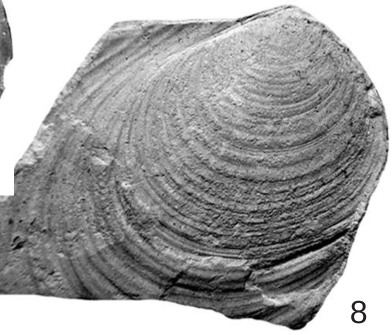

4a

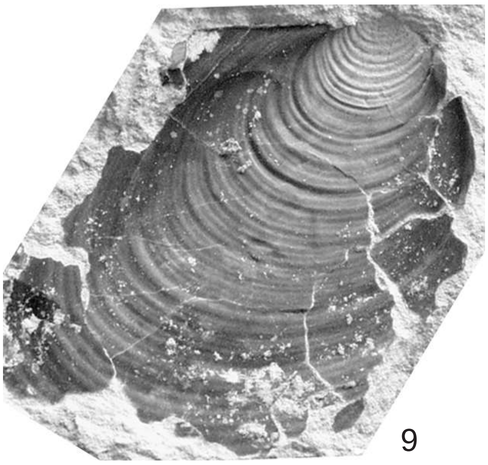

4b


5


7


6


8


9

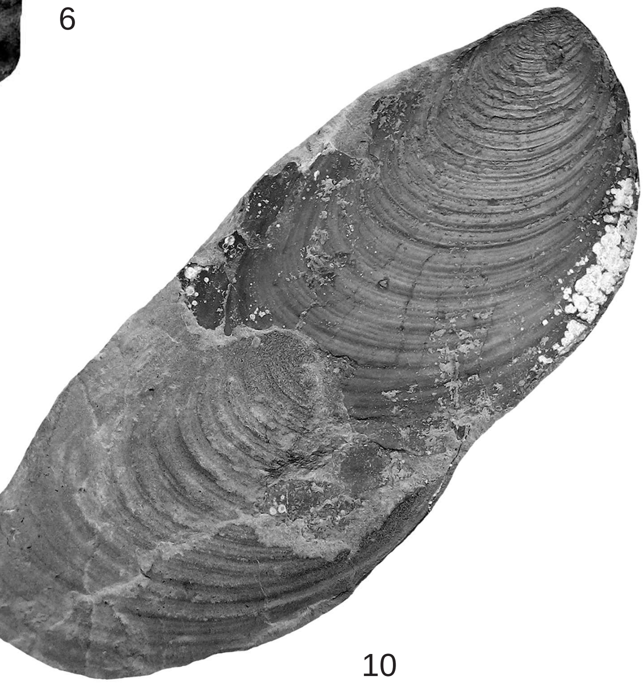

10

Plate 5

Figures 1–4, 7–10: *Mytiloides hercynicus* (Petrascheck, 1903) from Retiro 26 (except figure 1, from Muçuca 5).

1, MC5.01; internal mould of LV; bed B

2, RT26.377; internal mould of RV; bed 652

3, RT26.370; internal mould of RV; bed 649

4, PMU SA-208; internal mould of RV (Hessel, 1988, fig. 32f)

7, RT26.383; internal mould of RV; bed 653

8, RT26.363; internal view of RV shell; loose block above bed 640

9, RT26.626; internal view of LV shell; bed 700

10, RT26.624; incomplete internal mould of LV (slightly compressed laterally); bed760

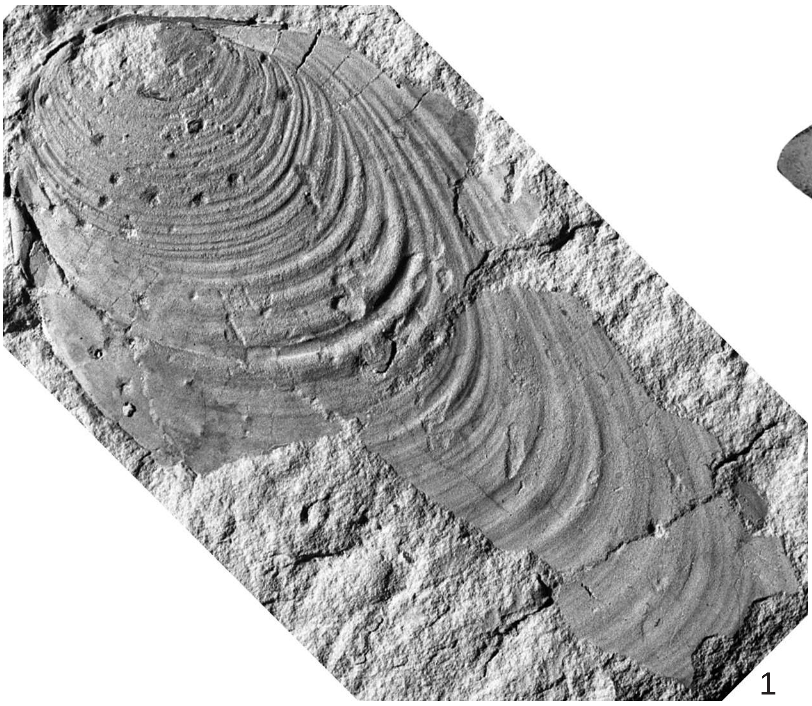
Figures 5–6: *Mytiloides hartti* (Hessel, 1988) from Retiro 26.

5, holotype of *Sergipia hartti* (see Hessel, 1988, fig. 32d); internal mould of LV.

6, RT26.606; internal view of RV shell; bed 763

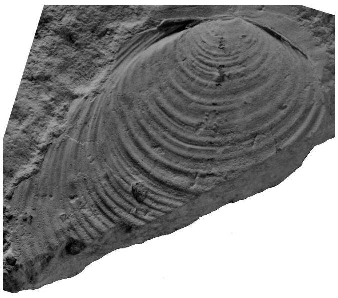
All figures are natural size

Plate 5


1


2

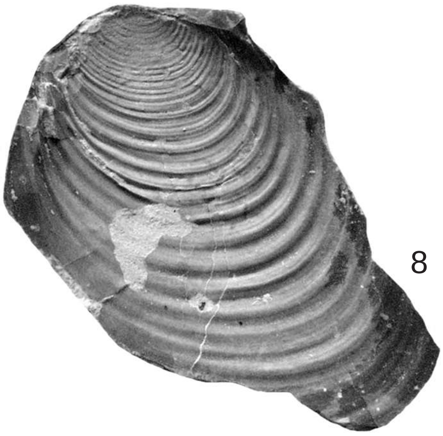

3

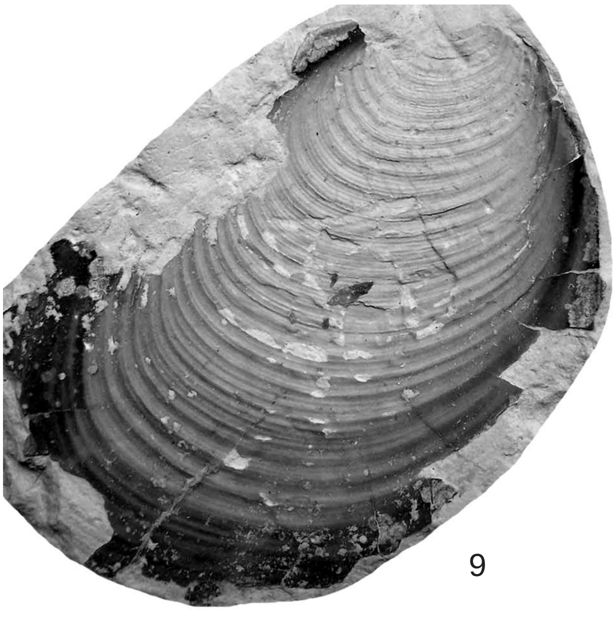

4


5


6


7


8


9


10

Plate 6

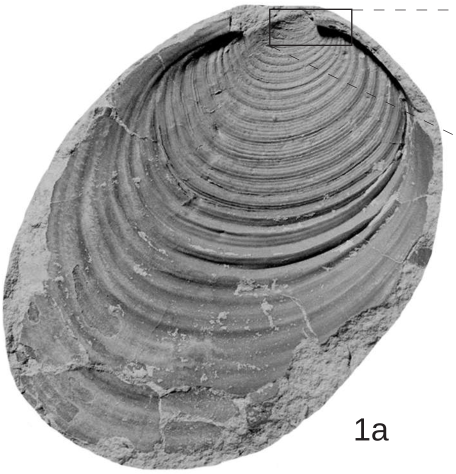
Figure 1: transitional morphotype between *Mytiloides hercynicus* (Petrascheck, 1903) and *Didymotis*? form.
1a,b, MC5.03; 1a, internal view of LV shell; 1b, enlargement of the anterior ligamental plate x 4.5, as indicated by box on Fig. 1a; from locality Muçuca 5.

Figures 2–8: "*Didymotis*" aff. *posidonomyaformis* (Maury, 1925) from Retiro 26.
2–4: specimens described by Hessel (1988, figs 32a–c) as *Sergipia* aff. *posidonomyaformis* (Maury)
2, PMU SA-217 (Hessel, fig. 32c); internal view of LV shell
3, PMU SA-210 (Hessel, fig. 32b); internal view of LV shell
4, PMU SA-221 (Hessel, fig. 32a); internal mould of LV with RV shell
5, RT26.375; internal view of RV shell; bed 651
6, RT26.314; a, internal view of incomplete double-valve shell; b, enlargement of the anterior ligamental plate (x 3.0) as indicated by box on figure 6a
7, RT26.381; internal view of LV shell; bed 654
8, RT26.608; internal view of LV shell; bed 763

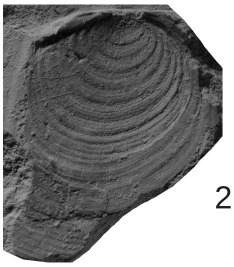
Figures 10–12: *Mytiloides* cf. *tourtenayensis* (Badillet & Sornay, 1980)
9, holotype of the *Inoceramus goppelnensis tourtenayensis* Sornay (see Sornay, 1982, pl. 7, fig. 3); internal mould of LV
10, RT26.389 internal mould of RV; bed 655
11, RT26.587 internal view of LV shell and rest internal mould; bed 661
12a, b, RT26.625 a, internal mould of RV; b, anterior view of RV; bed 760

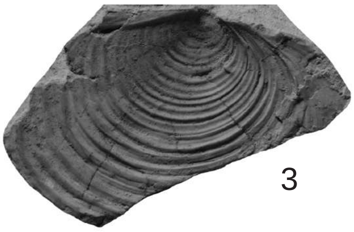
Figures 2–6a: are x 1.2
Figures 1a, 7–12 are natural size

Plate 6

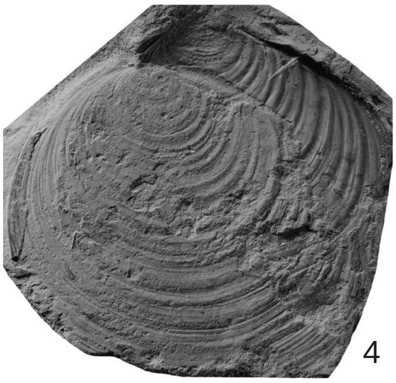

1a

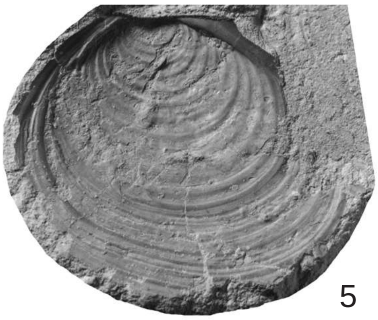

1b

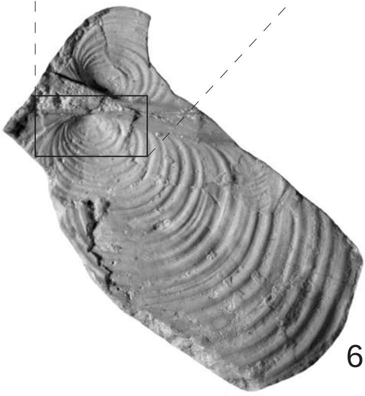

2

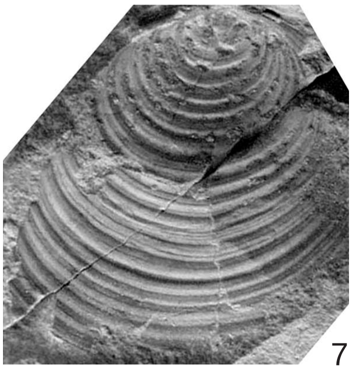

3


6b

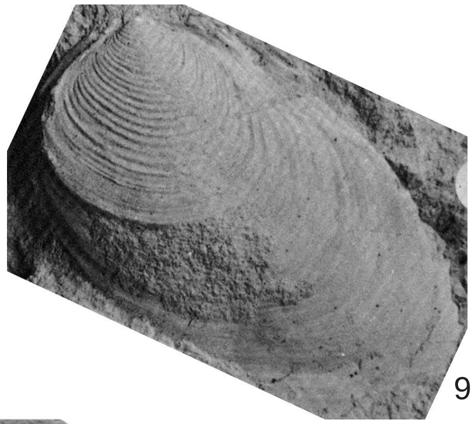

4

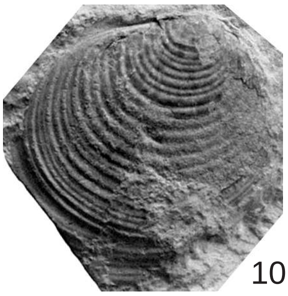

5

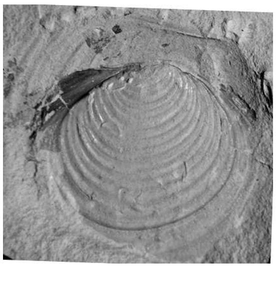

6a

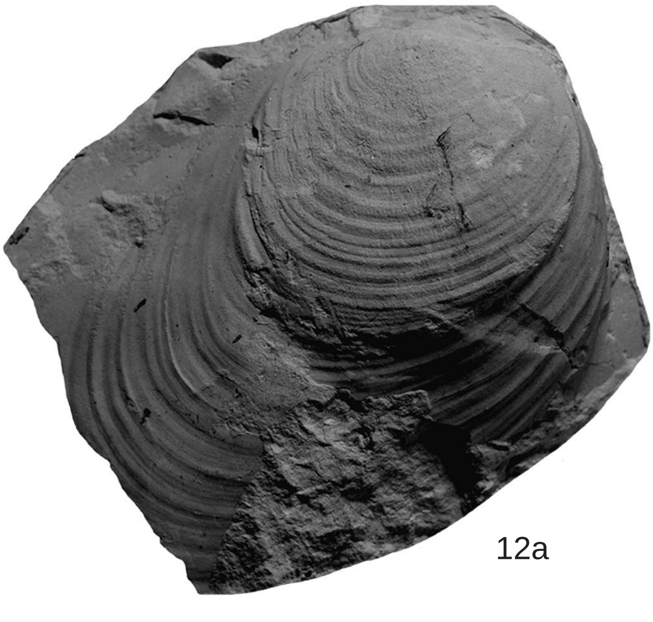

7


8


9


10


11


12a


12b

Plate 7

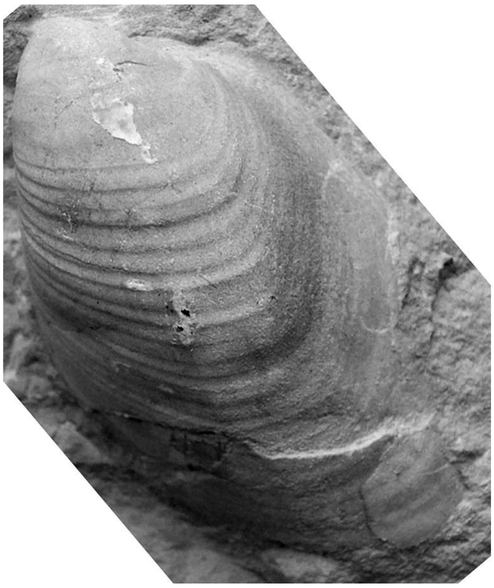
Figures 1–3: *Mytiloides striatoconcentricus* (Gümbel, 1868) from Mata 11.
1, MT11.374; internal mould LV; bed 8
2a, b, MT11.132; a, internal mould LV; b, anterior view of LV; bed 16
3, MT11.35; internal mould RV; bed 12a

Figures 4–7: *Mytiloides incertus* (Jimbo, 1984) from Mata 11.
4, MT11.33; incomplete internal mould LV; bed 10b
5, MT11.32; internal mould RV; bed 10b
6, MT11.28; internal view of LV shell; bed 10b
7, MT11.221; internal mould LV; bed 39a

Figures 8–9: *Mytiloides turonicus* Walaszczyk, 1992 from Mata 11.
8, MT11.27; internal mould RV; bed 10
9, MT11.144; internal mould LV; bed 16

Figure 10: *Mytiloides labiatoidiformis* (Tröger, 1967) from Mata 11.
10, MT11.50; internal mould RV (juvenile specimen); bed 16b

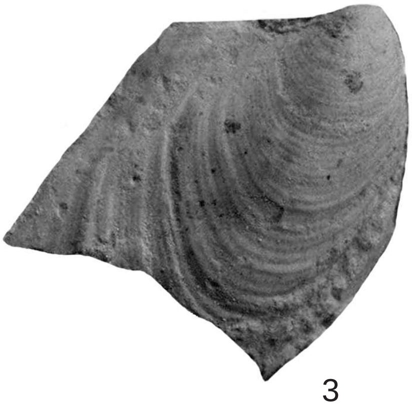
Except figure 3, which is x 1.2 and 7, is x 1.5, all other figures are natural size



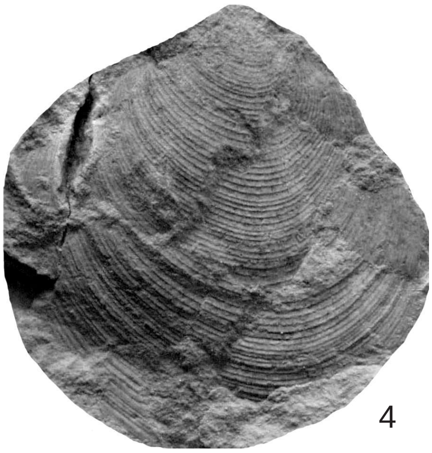
1

2a

2b



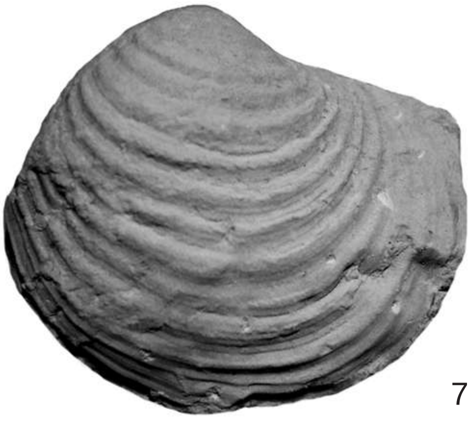
3



4

5

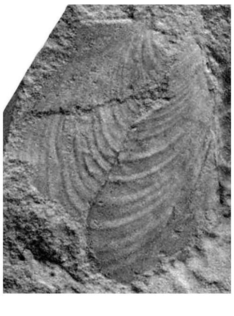
6



7

8

9



10

Plate 8

Figures 1–4: *Mytiloides labiatoidiformis* (Tröger, 1967) from Mata 11.

1, MT11.09 internal mould RV (crushed specimen); bed 19

2, MT11.06; internal mould RV; bed 20

3, MT11.126; internal view of LV shell; bed 40

4, MT11.08; internal mould RV (auricle well separated from disc); bed 19

Figures 5–10: *Mytiloides herbichi* (Atabekjan, 1968) from Mata 11.

5, MT11.11; internal mould LV; bed 19

6, MT11.10; internal mould LV, with shell fragment attached in the auricle; bed 19

7, MT11.12; internal mould LV, with shell fragment attached; bed 20

8, MT11.169; internal mould RV, bed 22

9, MT11.66; incomplete internal mould LV (crashed specimen); bed 20

10, MT11.127; internal view of LV shell; bed 20b

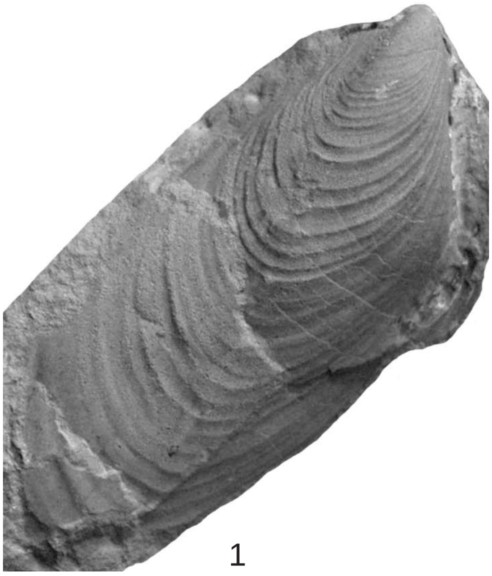
Figures 11–12: *Inoceramus longealatus* Tröger, 1967 from Mata 11.

11, MT11.14; internal mould LV; bed 20

12, MT11.161; internal mould LV; bed 20

All figures are natural size

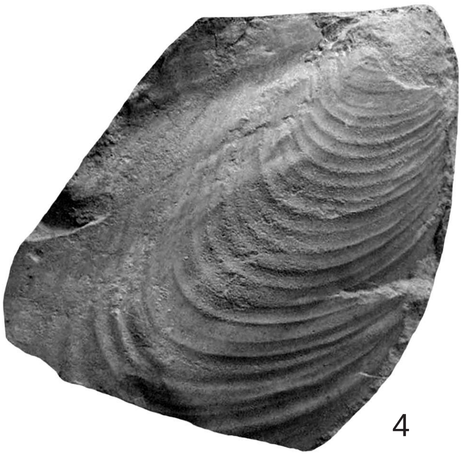
Plate 8



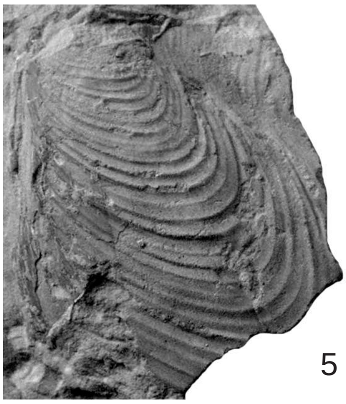
1

2

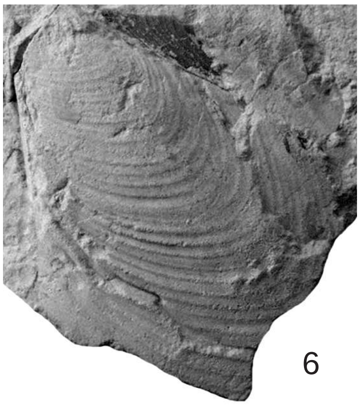
3



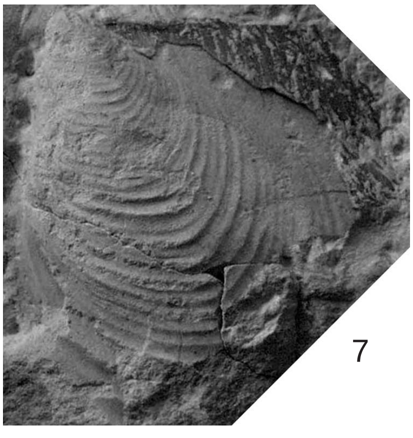
4



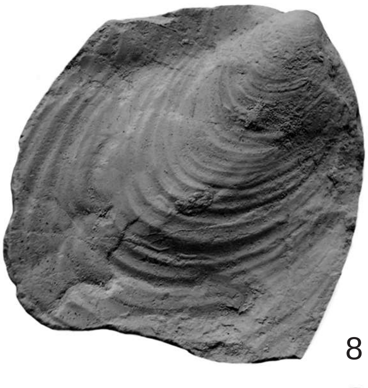
5



6



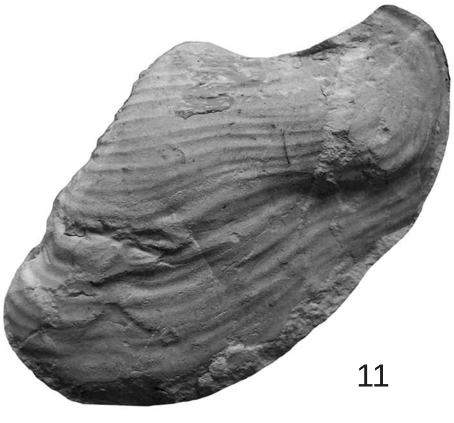
7



8

9

10



11

12

Plate 9

Figures 1–2: *Inoceramus* cf. *perplexus* Whitfield, 1877 from Mata 11.

1, MT11.162; internal mould LV; bed 20

2, MT11.164; incomplete internal mould LV; bed 20

Figures 3–5; 7–8: *Mytiloides scupini* (Heinz, 1930) from Mata 11.

3, MT11.92; incomplete internal mould LV; bed 36

4, MT11.07; internal mould RV and rest LV shell; bed 20–22(?)

5, MT11.196; incomplete internal mould RV; bed 34

7, MT11.15; internal mould RV (juvenile specimen?); bed 40

8, MT11.04; incomplete internal mould LV; bed 34

Figure 9: *Mytiloides mytiloidiformis* (Tröger, 1967) from Mata 11.

9, MT11.380; internal mould RV; bed 40

Figures 6, 10–11: *Cremnoceramus walterdorfensis walterdorfensis* (Andert, 1911)

6, DNPM 4800; LV shell of holotype of *Inoceramus wanderley* Santos (see Santos, 1963, fig. 1); compressed specimen. From locality Socorro 14.

10, DNPM 4818; incomplete RV shell; holotype of *Inoceramus remoratus* Santos (see Santos, 1963, fig. 2); from Socorro 14.

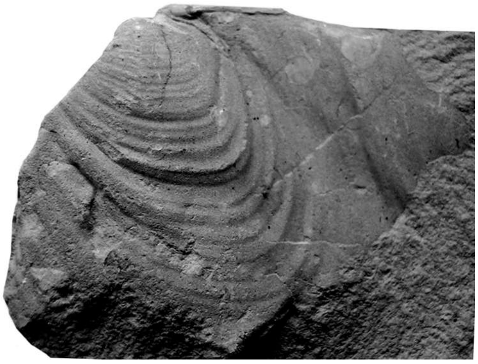
11, MT11.263; internal mould LV; bed 42; from Mata 11.

Except figures 6 and 10, which are x 0.75, all other figures are natural size

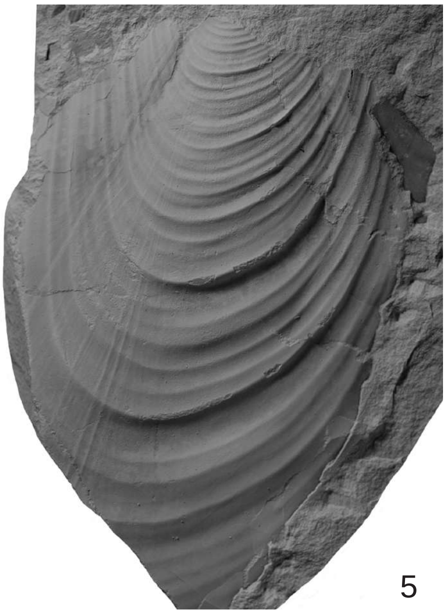
Plate 9

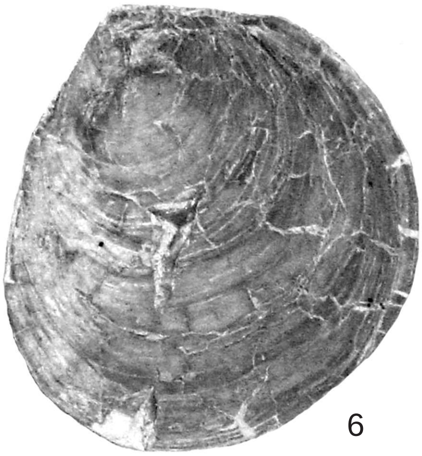

1


2

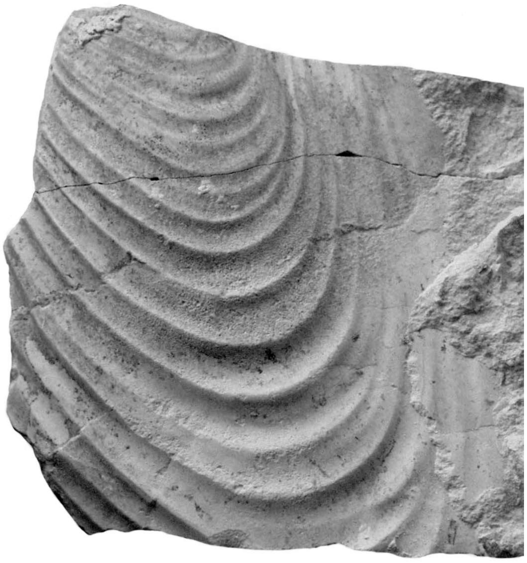

3


4


5


6


7


8


9


10


11

Plate 10

Figures 1–11: *Didymotis posidonomyaformis* (Maury, 1925) from Sapucari 1.
1–7: Original material of Maury (1925, 1937)

1, Illustration of *Inoceramus* (*Sergipia*) *posidonomyaformis* Maury (See Maury, 1937, pl. 8, fig. 15)
2, DNPM 3019; incomplete internal mould of RV
3, DNPM 3022; incomplete internal mould of RV and rest shell fragments
4, DNPM 3021; incomplete internal mould of RV
5, DNPM 3017; incomplete internal mould of RV
6, DNPM 3018; incomplete internal mould of RV
7, DNPM 3020; internal mould of LV

8a, b, SP1.14; a, internal view of incomplete double-valve shell; b, incomplete internal

9, SP1.13; shell fragment with radial striae.
10, GPIH-BR C494.24; internal mould of LV
11, PMU AF-404; Nigerian specimen illustrated by Offodile & Reyment (1978, fig. 15) as *Sergipia* aff. *posidonomyaformis* Maury; internal mould of LV

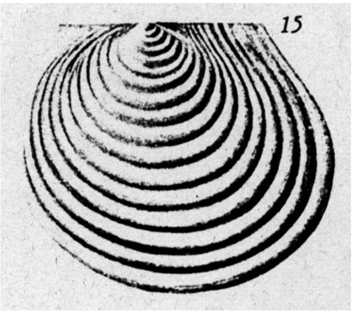
Figures 12: *Didymotis posidonomyaformis* (Maury, 1925) from Mata 11.
12, MT11.206; incomplete internal mould of LV with articulated fragment of RV

Figure 13: *Didymotis* sp. indet. from Mata 11.
13, MT11.214; internal view of LV shell.

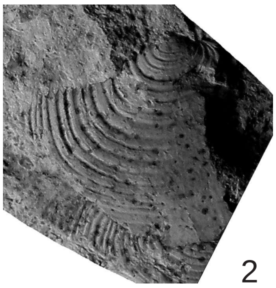
Figure 14: *Didymotis costatus* (Frič, 1893) from Ilhas 2.
14, GPIH-BR-C608.3; internal mould of RV

Except figures 6 and 9, which are x 1.5, all other figures are natural size

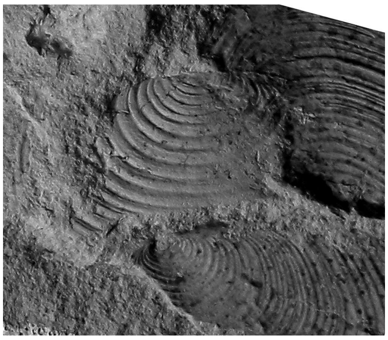
Plate 10



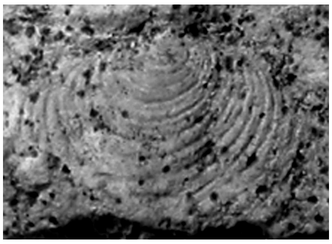
1



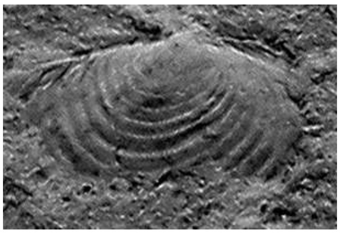
2



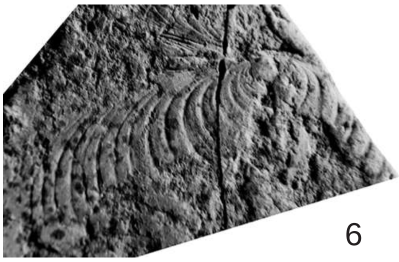
3



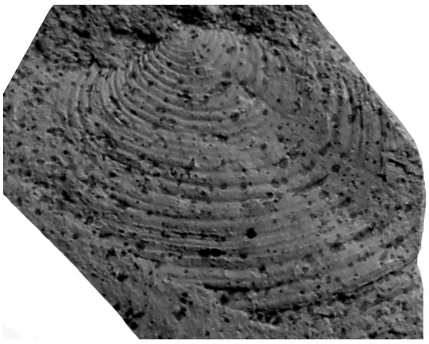
4



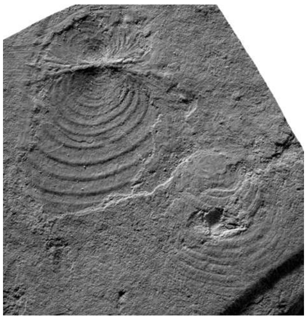
5



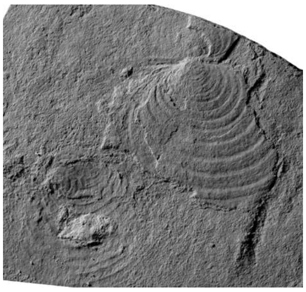
6



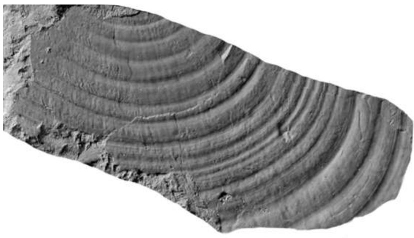
7



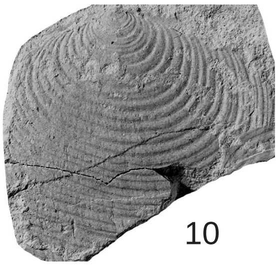
8a



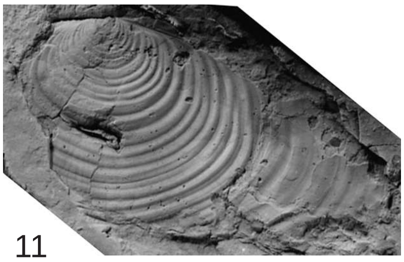
8b



9

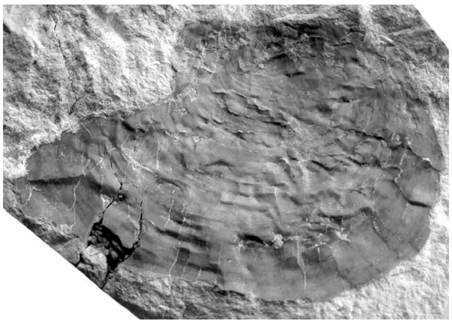


10



11

12



13

14

Plate 11

Selected ammonites from Retiro 26 (Votorantim quarry), Sergipe.

Figure 1: *Mammites nodosoides* (Schlüter, 1871); RT26.650; lateral view; x 0.5

Figure 2: *Hoplitoides* sp.; RT26.652; lateral view; x 0.5

Figure 3: *Kamerunoceras turoniense* (d'Orbigny, 1850); RT26.615; lateral view; x 0.5

Figure 4: *Kamerunoceras* sp. A from Retiro 26; RT26.01; lateral view; x 0.5

Figure 5: *Romaniceras kallesi* (Zázvorka, 1958) from Retiro 26; RT26.400; plaster of internal mould; lateral view; x 1.0

Figure 6: *Benueites* cf. *spinosus* Reyment, 1954; RT26.341; lateral view; x 1.0

Figure 7: *Puebloites* sp.; RT26.361; lateral view; x 1.0

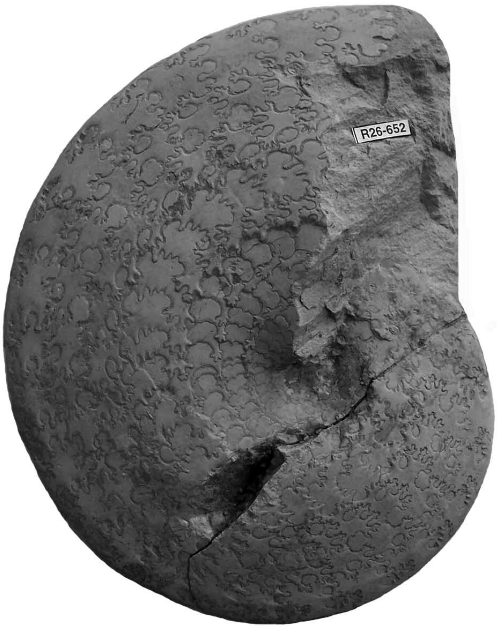
Figure 8: *Watinoceras* sp. A; RT26.334; lateral view; x 1.0

Figure 9: *Watinoceras* sp. B; RT26.553; lateral view; x 0.5

Figure 10: *Coilopoceras* sp.; RT26.663; lateral view; x 0.25

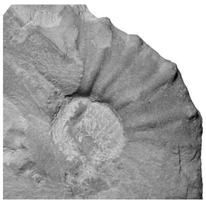
Plate 11


1



2


3


4


5


6


7


8


9


10

Plate 12

Selected ammonites from Mata 11 (Nassau quarry), Sergipe.

Figure 1: *Subprionocyclus neptuni* (Geinitz, 1849); MT11.352; lateral view; x 1.0

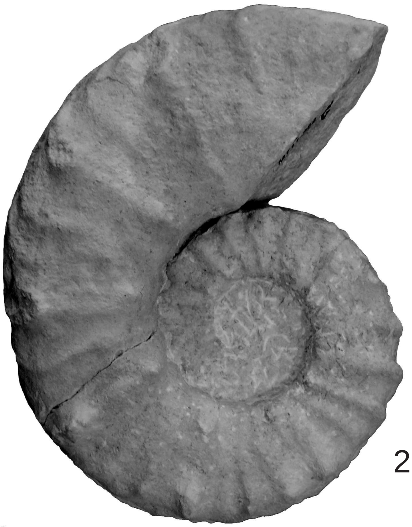
Figure 2a,b: *Prionocyclus germari* (Reuss, 1845); MT11.362; a. lateral view; b. ventral view; x 0.5

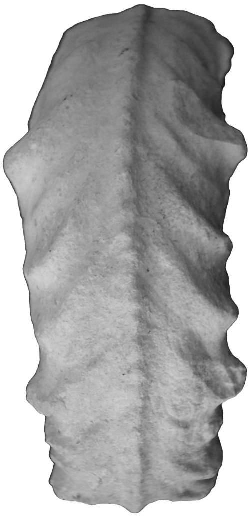
Figure 3a,b: *Gaudryceras* sp.; MT11.358; a. lateral view; b. ventral view; x 0.4

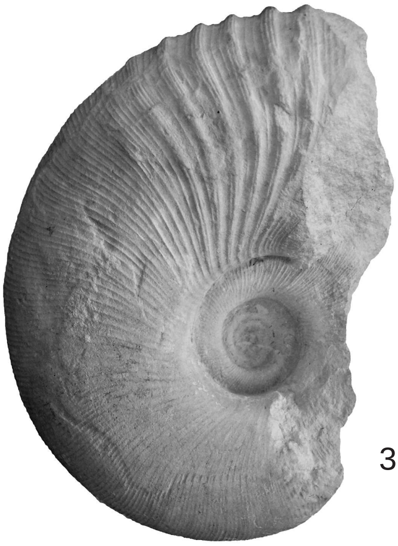
Figure 4a,b: *Forresteria brancoi* (Solger, 1904); MT11.371; a. lateral view; b. ventral view; x 0.5

Plate 12


1


2a


2b


3a


3b


4a


4b