The Jurassic-Cretaceous Boundary (Tithonian - Hauterivian) in the Andean Basin of Central Chile: Ammonites, Bio- and Sequence Stratigraphy and Palaeobiogeography

INAUGURAL DISSERTATION

Zur Erlangung der Doktorwürde
Der Naturwissenschaften-Mathematischen Gesamtfakultät
Der Rupecht-Karls-Universität
Heidelberg

vorgelegt von
Diplom-Geologe
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Heidelberg, im Oktober 2012

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Tag der mündlicher Prüfung: 14.12.2012.

Abstract

Five sections of the Baños del Flaco and Lo Valdés formations in the High Andean Cordillera of Central Chile have been analyzed with regard to sediment, bio- and sequence stratigraphy, ammonite assemblages and palaeobiogeography, in order to reveal the age and depositional facies of the sediment sequence, and to evaluate the age and important bioevents across the Jurassic-Cretaceous boundary.

The Baños del Flaco Formation was investigated at Rio Tinguiririca and in the Rio Maitenes valley, while sections of the Lo Valdés Formation were studied at Rio Volcán and in the Rio Maipo valley. The Baños del Flaco Formation is 369 m thick at Baños del Flaco section and 536 m thick at Rio Maitenes; lithologies consist of conglomerate, limestone, sandy limestone, calcareous sandstone, calcareous siltstone and siltstone. A lower and an upper member are distinguished by their lithological composition. The Lo Valdés Formation is here divided into two formations, based on the lithological composition. The lower part is assigned here as the Cathedral Formation, composed mainly of andesitic units and only restricted levels of sediment. This formation is 760 m thick and divided into two members (lower and upper); it is assigned to the Lower-Middle Tithonian. The Lo Valdés Formation as redefined here overlies the Catedral Formation; it is 539 m thick in the type locality, 582 m thick at Cajón del Morado and 150 m thick at Cruz de Piedra. Three members are differentiated by their predominant lithological composition, from base to top a sandstone, siltstone and limestone member.

The ammonite assemblage of the Baños del Flaco Formation is referred to 12 species and 10 genera. *Aulacosphinctes proximus*, *Micracanthoceras spinulosum* and *Corongoceras evolutum* are new records for this formation. *Pseudolissoceras* cf. *zitteli*, *Euvirgalithacoceras malarguense*, *Choicensisphinctes windhauseni*, *Catutosphinctes* cf. *americanensis*, *Virgatosphinctes scythicus* and *Micracanthoceras microcanthum* are registered for the first time in Chile. *Micracanthoceras spinulosum* shows strong ontogenetic changes not recorded previously. *Virgatosphinctes scythicus* is here considered a morphologically variable species and considered synonymous with classical South American taxa such as *Virgatosphinctes andesensis*, *V. mendozanus*, *V. mexicanus* and *V. leñaensis*. *Virgatosphinctes* aff. *pseudolictor*, *V.* cf. *raja* and *V. guadalupensis* are considered synonymous with *E. malarguense,* while *V. tenuilineatus* is synonymous with *C. windhauseni* and *Aulacosphinctes chilensis* with *A. proximus*. Other synonymies include *Micracanthoceras lamberti* and *M. tapiai,* with *M. microcanthum,* and *Corongoceras rigali* with *C. alternans*. A detailed biozonation of the Baños del Flaco Formation is here presented for the first time. The following biozones were assigned, from bottom to top: *Virgatosphinctes scyticus* /

Pseudolissoceras zitteli zone, *Windhauseniceras internispinosum* zone, *Micracanthoceras microcanthum* / *Corongoceras alternans* zone and *Substeueroceras koeneni* zone. Here we suggest that the Baños del Flaco Formation reaches from the lower part of the Middle Tithonian to the lowermost part of the Lower Berriasian.

39 species of ammonoids were differentiated in the Lo Valdés Formation and were referred to 22 genera. *Frenguelliceras magister* is a new record for the Lo Valdés Formation and central Chile. *Pterolytoceras exoticum*, *Aspidoceras rogoznicense*, *Micracanthoceras microcanthum*, *Micracanthoceras vetustum*, *Corongoceras lotenoense*, *Corongoceras mendozanum*, *Spiticeras acutum*, *Spiticeras pricei*, *Spiticeras spitiense*, *Groebericeras rocardi*, *Berriasella* (*Berriasella*) *jacobi*, *Malbosiceras malbosi*, *Chigaroceras bardensis*, *Tirnovella kayseri*, *Thurmaniceras thurmanni*, *Crioceratites perditum* and *Bochianites* sp. are first registers for Chile. *Lytohoplites paredesi* n.sp., *Lytohoplites zambranoi* n.sp., *Lytohoplites varelae* n.sp. and *Lytohoplites rauloi* n.sp. are new taxa. The neotype of *Substeueroceras* is designated here and corresponds to the lectotype of *Substeueroceras koeneni*. *Parodontoceras* is here considered to be a junior synonym of *Substeueroceras*. We also designate lectotypes of *Micracanthoceras spinulosum*, *Micracanthoceras vetustum*, *Spiticeras acutum*, *Substeueroceras calistoide*, *Argentiniceras fasciculatum*, *Tirnovella kayseri*, *Crioceratites andinum*, *Crioceratites diamantense* and *Crioceratites perditum*. *Spiticeras acutum* is considered here a morphologically variable species. *Berriasella fraudans* is considered to be a junior synonym of *B. jacobi*. Six biozones are here differentiated for the Lo Valdés Formation, from bottom to top: *Micracanthoceras microcanthum* / *Corongoceras alternans*, *Substeueroceras koeneni* (*Berriasella jacobi* and *Groebericeras rocardi* sub-zones), *Thurmaniceras thurmanni* / *Argentiniceras fasciculatum*, and *Crioceratites diamantense*. In consequence, the Lo Valdés Formation reaches from the upper part of the Upper Tithonian to the Upper Hauterivian.

Biozonations of the Baños del Flaco and the Lo Valdés formations are integrated and correlated, leading to the identification of 9 biozones reaching from Middle Tithonian to Upper Hauterivian times. According to the ecological index, major bioevents are recognized for the Upper Tithonian, with peak relative abundances and diversity, and for the Lower Berriasian, which is characterized by highest species richness. The turn-over analysis indicates that similarity (Jaccard index) is low between the Upper Tithonian and the Lower Berriasian. Species abundances and richness decrease in the Valanginian and even further, during the Hauterivian.

Taxa endemic to Central Chile and Tethyan species are the dominant ammonites during the Tithonian. During the Berriasian, Cosmopolitan and Indo-Pacific influences increase and these

taxa form the dominant group, while Tethyan and Endemic ammonites dominate during the Valanginian. During the Tithonian, the dominance of endemic taxa suggests that Central Chile may not have been well connected with the Tethyan region via the Hispanic Corridor, but that Indo-Pacific affinities result from an open Indo-Austral seaway. During the Berriasian, the dominance of Cosmopolitans and abundance of Indo-Pacific taxa suggests that new pathways opened between Antarctica and South America–Africa. These connections were likely established via the Indo-Austral seaway and a new connection through the Hispanic Corridor. Subsequently, during the Lower Valanginian, Tethyan, Indo-Pacific (Indo-Austral) and Boreal taxa are present in the Central Chilean fauna and Endemic ammonites are equally abundant. This may correspond to a similar grade of influence from the Hispanic Corridor and the Indo-Austral seaway.

The base of the Baños del Flaco Formation represents transgressive facies (sequence 1) during the lowermost Middle Tithonian, with a maximum depth during the uppermost Middle Tithonian. Upsection, sequence 2 represents a second cycle with transgressive facies during the Upper Tithonian and a regression in the Lower Berriasian.

In the Lo Valdés Formation, sequence 3 represents a retrogradational and progradational pattern, which results in transgression during the Upper Tithonian to Lower Valanginian and a regression during the Upper Valanginian to Upper Hauterivian.

Zusammenfassung

Im Rahmen der vorliegenden Dissertationsschrift wurden Sedimente, Bio-und Sequenzstratigraphie, Ammonitentaxonomie und Paläobiogeographie der Baños del Flaco und der Lo Valdés Formationen in den hohen Anden von Zentral-Chile untersucht, um das Alter und den Ablagerungsraum der Sedimenteinheiten zu dokumentieren und um wichtige Bioevents im Übergang zwischen Jura- und Kreidezeit abzuschätzen.

Die Baños del Flaco Formation wurde in Profilen an der Typuslokalität Baños del Flaco am Rio Tinguiririca und im Tal des Rio Maitenes untersucht. Profile der Lo Valdés Formation wurden am Rio Volcán und im Tal des Rio Maipo aufgenommen. Bei Baños del Flaco beträgt die Mächtigkeit der Baños del Flaco Formation 369 m und am Rio Maitenes 536 m. Die Einheit besteht aus Konglomerat, Kalkstein, Kalksandstein und Siltstein, wobei lithologisch ein unteres und ein oberes Member unterschieden werden. Die Lo Valdés Formation wurde neu definiert und dabei in zwei Formationen untergliedert. Die Catedral Formation bildet den unteren Teil der Abfolge und besteht vorrangig aus Andesit und nur untergeordnet aus geringmächtigen Sedimenteinheiten. Diese Einheit ist 760 m mächtig und wird dem unteren bis mittleren Tithonium zugeordnet. Die neu definierte Lo Valdés Formation überlagert die Catedral Formation. Die Mächtigkeit beträgt 539 m in der Typlokalität, 582 m im Cajón del Morado und 150 m bei Cruz de Piedra. Drei Member werden hinsichtlich ihrer lithologischen Zusammensetzung unterschieden, von der Basis zum Top das Sandstein-, Sltstein- und das Kalkstein-Member.

Die Ammoniten-Vergesellschaftung der Baños del Flaco Formation besteht aus 12 Arten, welche 10 Gattungen zugeordnet wurden. *Aulacosphinctes proximus*, *Micracanthoceras spinulosum* und *Corongoceras evolutum* sind Erstnachweise für diese Formation. *Pseudolissoceras* cf. *zitteli, Euvirgalithacoceras malarguense*, *Choicensisphinctes windhauseni*, *Catutosphinctes* cf. *americanensis*, *Virgatosphinctes scythicus* und *Micracanthoceras microcanthum* wurden erstmals in Chile registriert. *Micracanthoceras spinulosum* zeigt bisher nicht bekannte deutliche ontogenetische Veränderungen. *Virgatosphinctes scythicus* wird hier als eine morphologisch variable Art und als Homonym klassischer südamerikanischer Taxa wie *Virgatosphinctes andesensis, V. mendozanus, V. mexicanus* und *V. leñaensis* angesehen. *Virgatosphinctes* aff. *pseudolictor, V.* cf. *raja* und *V. guadalupensis* werden als Synonyme von *E. malarguense* betrachtet, wohingehend *V. tenuilineatus* ein Synonym zu *C. windhauseni* und *Aulacosphinctes*

chilensis ein Synonym zu *A. proximus* darstellt. Zusätzlich werden *Micracanthoceras lamberti* und *M. tapiai* als Synonyme von *M. microcanthum* und *Corongoceras rigali* als Synonym von *C. alternans* angesehen. Erstmals wird eine detaillierte Biozonierung der Baños del Flaco Formation vorgenommen. Die folgenden Biozonen werden vom Liegenden zum Hangenden untergliedert: *Virgatosphinctes scyticus / Pseudolissoceras zitteli* Zone, *Windhauseniceras internispinosum* Zone, *Micracanthoceras microcanthum / Corongoceras alternans* Zone und *Substeueroceras koeneni* Zone. Die Baños del Flaco Formation reicht damit vom unteren Mittel-Tithonium bis zum untersten Berriasium.

39 Ammonitenarten wurden in der Lo Valdés Formation 22 Gattungen zugeordnet. *Frenguelliceras magister* ist ein neuer Nachweis für die Lo Valdés Formation und für Zentral-Chile. *Pterolytoceras exoticum, Aspidoceras rogoznicense, Micracanthoceras microcanthum, Micracanthoceras vetustum, Corongoceras lotenoense, Corongoceras mendozanum, Spiticeras acutum, Spiticeras pricei, Spiticeras spitiense, Groebericeras rocardi, Berriasella (Berriasella) jacobi, Malbosiceras malbosi, Chigaroceras bardensis, Tirnovella kayseri, Thurmaniceras thurmanni, Crioceratites perditum* und *Bochianites* sp. sind Erst-Nachweise für Chile. *Lytohoplites paredesi* n. sp., *Lytohoplites zambranoi* n. sp., *Lytohoplites varelae* n. sp. und *Lytohoplites rauloi* n. sp. sind neue Arten. Der Neotypus der Gattung *Substeueroceras* wird definiert und entspricht dem Lectotypus von *Substeueroceras koeneni*. *Parodontoceras* wird hier als ein Synonym von *Substeueroceras* bezeichnet. Die Lectotypen von *Micracanthoceras spinulosum, Micracanthoceras vetustum, Spiticeras acutum, Substeueroceras calistoide, Argentiniceras fasciculatum, Tirnovella kayseri, Crioceratites andinum, Crioceratites diamantense* und *Crioceratites perditum* werden festgelegt. *Spiticeras acutum* wird hier als eine morphologisch variable Spezies angesehen. *Berriasella fraudans* ist ein Synonym von *B. jacobi*. Die Lo Valdés Formation wird in sechs Biozonen untergliedert, vom Liegenden zum Hangenden: *Micracanthoceras microcanthum / Corongoceras alternans, Substeueroceras koeneni (Berriasella jacobi* und *Groebericeras rocardi* Sub-Zonen), *Thurmaniceras thurmanni / Argentiniceras fasciculatum* und *Crioceratites diamantense*. Die Lo Valdés Formation reicht vom Oberen Tithonium bis zum Oberen Hauterivium.

Neun Biozonen der Baños del Flaco und der Lo Valdés Formation werden korreliert und reichen vom mittleren Tithonium bis zum oberen Hauterivium. Wichtige Bioevents werden an Hand der maximalen relativen Häufigkeit und Diversität abgeschätzt, wobei sich das untere Berriasium gefolgt vom Ober-Tithon durch besonderen Artenreichtum auszeichnet. Trotzdem zeigt die Turn-over-Analyse, dass die Ähnlichkeit der Faunen-Vergesellschaftung (Jaccard-Index) zwischen diesen beiden Stufen nur gering sind. Während des Valanginium und im Hauterivium nimmt die Diversität weiter ab.

Endemiten sowie Tethys-Arten sind die dominierenden Ammoniten zur Zeit des Tithonium. Während des Berriasium nehmen kosmoplitische und indo-pazifische Einflüsse zu. Im Valanginium dominieren dagegen tethyale und endemische Ammoniten. Die Dominanz endemischer Taxa im Tithonium belegt,womöglich dass Zentral Chile schlecht mit der Tethys verbunden und dass der hispanische Korridor noch geschlossen war. Demgegenüber indizieren die deutlichen indo-pazifischen Affinitäten vermutlich einen offenen indo-australischen Seeweg. Während des Berriasium bedeutet die Dominanz der Kosmopoliten und der Reichtum an indo-pazifischen Taxa, dass sich neue Verbindungswege zwischen der Antarktis und Südamerika und Afrika öffneten. Diese Verbindungen belegen einen indo-australischen Seeweg und eine neue Verbindung über den hispanischen Korridor. Danach treten während des unteren Valanginium tethyale, indo-pazifische (indo-australische) und boreale Taxa in der zentralchilenischen Fauna auf und auch endemische Ammoniten sind divers. Der hispanische Korridor und der indo-australische Seeweg scheinen in diesem Zeitraum einen ähnlichen bedeutenden Einfluss gehabt zu haben.

Die Basis der Baños del Flaco Formation belegt transgressive Fazies (Sequenz 1) während des untersten Mittel-Tithonium und maximale Wassertiefen im obersten Mittel-Tithonium. Darüber repräsentiert Sequenz 2 einen zweiten Zyklus mit transgressiver Fazies im oberen Tithonium gefolgt von einer Regression im unteren Berriasium.

In der Lo Valdés Formation belegt Sequenz 3 ein retrogradierendes und progradierendes Muster, welches im oberen Tithonium bis unterem Valanginium in einer Transgression und im oberen Valanginium bis oberen Hauterivianium in einer Regression resultiert.

Resumen

Cinco secciones de las formaciones Baños del Flaco y Lo Valdés de la Cordillera de los Andes en Chile Central, han sido analizadas, considerando su sedimentología, bio-estratigrafía secuencial, paleontología de ammonites y paleobiogeografía, con el fin de precisar la edad y facies de depositación de la secuencia sedimentaria, y para evaluar la edad e importantes bioeventos a través del límite Jurásico-Cretácico.

La Formación Baños del Flaco fue analizada en las secciones del Río Tinguiririca y en el valle del Río Maitenes, mientras que las secciones de la Formación Lo Valdés fueron estudiadas en el Río Volcán y en el valle del Río Maipo. La Formación Baños del Flaco tiene 369 m de espesor en la sección Baños del Flaco y 536 m de espesor en la sección de Río Maitenes, que consiste en conglomerados, calizas, calizas arenosas, areniscas calcáreas, lutitas y lutitas calcárea. Se diferencian dos miembros por su composición litológica, Superior e Inferior. La Formación Lo Valdés es dividida aquí en dos formaciones, basado en la composición litológica. La parte inferior se asigna aquí como la Formación Catedral, compuesta principalmente por unidades andesíticas y restringidos niveles sedimentarios. Esta formación tiene 760 m de espesor, y se divide en dos miembros (inferior y superior), asignada al Tithoniano Inferior-Medio. La Formación Lo Valdés aquí redefinida se superpone a la Formación Catedral, con 539 m de espesor en su localidad tipo; 582 m de espesor en la sección Cajón del Morado y 150 m de espesor en la sección Cruz de Piedra. Tres miembros se diferencian de acuerdo a su composición litológica, desde base a techo el miembro arenoso, lutítico y calcáreo.

La Formacion Baños del Flaco contiene 12 especies de amonoideos agrupados en 10 géneros. *Aulacosphinctes proximus*, *Micracanthoceras spinulosum* y *Corongoceras evolutum* son nuevos registros para esta formación. *Pseudolissoceras* cf. *zitteli*, *Euvirgalithacoceras malarguense*, *Choicensisphinctes windhauseni*, *Catutosphinctes* cf. *americanensis*, *Virgatosphinctes scythicus* y *Micracanthoceras microcanthum* son registrados por primera vez para Chile. *Micracanthoceras spinulosum* presenta fuertes cambios ontogenéticos, no registrados previamente. *Virgatosphinctes scythicus* es aquí considerado una especie morfológicamente variable y considerado sinonima con especies clásicas de Sur America, tales como *Virgatosphinctes andesensis*, *V. mendozanus*, *V. mexicanus* y *V. leñaensis*. *Virgatosphinctes* aff. *pseudolictor*, *V.* cf. *raja* y *V. guadalupensis,* son consideradas sinonimias con *E. malarguense*, mientras que *V. tenuilineatus* es sinonima con *C. windhauseni* y *Aulacosphinctes chilensis* con *A. proximus*. Otras sinonimias incluyen

Micracanthoceras lamberti y *M. tapiai,* con *M. microcanthum,* y *Corongoceras rigali* con *C. alternans*. Una detallada biozonación de la Formación Baños del Flaco es aquí presentada por primera vez. Las siguientes biozonas fueron asignadas, de base a techo: zona *Virgatosphinctes scyticus* / *Pseudolissoceras zitteli*, zona *Windhauseniceras internispinosum*, zona *Micracanthoceras microcanthum* / *Corongoceras alternans* y zona *Substeueroceras koeneni*. Aqui se sugiere que la Formacion Baños del Flaco alcanza desde la parte baja del Titoniano Medio a la parte mas baja del Berriasiano temprano.

39 especies de ammonoideos fueron diferenciados en la Formacion Lo Valdés y referidos a 22 generos. *Frenguelliceras magister* es un nuevo registro para la Formación Lo Valdés y para Chile Central. *Pterolytoceras exoticum*, *Aspidoceras rogoznicense, Micracanthoceras microcanthum*, *Micracanthoceras vetustum*, *Corongoceras lotenoense*, *Corongoceras mendozanum*, *Spiticeras acutum*, *Spiticeras pricei*, *Spiticeras spitiense*, *Groebericeras rocardi*, *Berriasella* (*Berriasella*) *jacobi*, *Malbosiceras malbosi*, *Chigaroceras bardensis*, *Tirnovella kayseri*, *Thurmaniceras thurmanni*, *Crioceratites perditum* y *Bochianites* sp. son primeros registrados en Chile. *Lytohoplites* paredesi n. sp., *Lytohoplites zambranoi* n. sp., *Lytohoplites varelae* n. sp. y *Lytohoplites rauloi* n. sp. son nuevas especies. El Neotipo de *Substeueroceras* es aquí designado y corresponde al lectotipo de *Substeueroceras koeneni*. *Parodontoceras* es aquí considerado un sinonimo menor de *Substeueroceras*. También se designan los lectotipos de *Micracanthoceras spinulosum*, *Micracanthoceras vetustum*, *Spiticeras acutum*, *Substeueroceras calistoide*, *Argentiniceras fasciculatum*, *Tirnovella kayseri*, *Crioceratites andinum*, *Crioceratites diamantense* y *Crioceratites perditum*. *Spiticeras acutum* es aquí considerado una especie morfológicamente variable. *Berriasella fraudans* es considerado un sinonimo menor de *B. jacobi*. Seis biozonas son aquí diferenciadas para la Formación Lo Valdés, de base a techo: *Micracanthoceras microcanthum* / *Corongoceras alternans*, *Substeueroceras koeneni* (sub-zonas *Berriasella jacobi* y *Groebericeras rocardi*), *Thurmaniceras thurmanni* / *Argentiniceras fasciculatum*, y *Crioceratites diamantense.* En consecuencia, la Formación Lo Valdés representa la parte alta del Titoniano Superior al Hauteriviano Superior.

Las biozonaciones de las formaciones Baños del Flaco y Lo Valdés están integradas y correlacionadas, lo que lleva a la identificación de 9 biozonas que van desde el Titoniano Medio al Hauteriviano Superior. De acuerdo con los índices ecológicos, importantes bioeventos son reconocidos en el Tithoniano Superior, con máximos de abundancia relativa y diversidad, y para el Berriasiano Inferior, que se caracteriza por la más alta riqueza de especies. El análisis Turn-

over indica que la similitud (índice de Jaccard) es bajo entre el Titoniano Superior y el Berriasiano Inferior. La abundancia y riqueza de especies disminuye en el Valanginiano y más aún, durante el Hauteriviano.

Las especies endémicas de Chile Central y del Tethys son los amonoideos dominantes durante el Tithoniano. Durante el Berriasiano, la influencia aumenta de las especies con afinidades Cosmopolita e Indo-Pacífica, mientras que las especies endémicas y del Tethys dominan nuevamente durante el Valanginiano. Durante el Titoniano, el predominio de especies endémicas sugiere que la zona central de Chile no estaba bien conectada con la región del Tethys a través del Corredor Hispanico, mientras que las afinidades Indo-Pacíficas son el resultado de la apertura de una ruta Indo-Austral. Durante el Berriasiano, el predominio de especies Cosmopolitas y la abundancia de especies del Indo-Pacífico sugiere que nuevos rutas se abrieron entre la Antártida y América del Sur y África. Estas conexiones se establecieron probablemente a través de la vía marítima Indo-Austral y una nueva conexión a través del Corredor Hispánico. Posteriormente, durante el Valanginiano Inferior, las especies con afinidades del Tethys, Indo-Pacífico (Indo-Austral) y Boreal están presentes en la fauna de Chile Central y amonites endémicos son igualmente abundantes. Esto puede corresponder a un grado similar de influencia del Corredor Hispánico y la vía marítima Indo-Austral.

La base de la Formación Baños del Flaco esta representada por facies transgresivas (secuencia 1) durante la parte baja del Titoniano Medio, con su máxima profundidad durante la parte alta del Titoniano Medio. Sobre yaciendo, la secuencia 2 representa un segundo ciclo con facies transgresivas durante el Titoniano Superior y una regresión en el Berriasiano Inferior.

En la Formación Lo Valdés, la secuencia 3 representa un patrón retrogradacional y progradacional, lo que resulta de la transgresión durante el Titoniano Superior al Valanginiano Inferior, y una regresión durante el Valanginiano superior al Hauteriviano Superior.

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1. Introduction

1.1 Jurassic-Cretaceous (J/K) boundary

The Jurassic-Cretaceous (J/K) transition is characterized by a sea-level lowstand (Haq et al. 1987, 1988, Ziegler 1990, Hardenbol et al. 1998, Hallam 2001), resulting in a diversification and separation of depocenters and faunal provinces. The climatic history during this interval of time is well documented, suggesting an increase in humidity (Price 1999) and cooling during the Late Jurassic, followed by moderate warming into the Lower Cretaceous (Ruffell et al. 2002). Both $\partial^{13}C$ and $\partial^{18}O$ stable isotopic curves pass the J/K boundary without major excursions (Wiessert & Channell 1989, Weissert & Mohr 1996; Bartolini et al. 1999, Gröcke et al. 2003) and coeval Sr87/86 values only present a minor increase (Jones 1992, Howart & McArthur 1997, Gröcke et al. 2003). This absence in the J/K transition of characteristic isotopic events and other geochemical criteria hampers intercontinental correlation. New biostratigraphic approaches are needed to resolve the existing difficulties to correlate between faunal realms of the Pacific, the Atlantic Hispanic corridor and the Tethys.

Even though the position of the J/K boundary has been discussed over more than a century, no internationally valid definition has been agreed upon about its position or Global Stratotype Section and Point (GSSP) (Remane 1991). This complex situation results from the absence of a significant faunal change at the end of the Jurassic period, extreme faunal provincialism and endemism, and from the worldwide sea level regression during the "Purbeckian" (Upper Berriasian - early Lower Valanginian). Even today, the combination of these factors still complicates intercontinental correlation between Tethyan and Boreal sections of Tithonian and Berriasian age. It has been recommended during the "Colloque International sur la limite Jurassique-Cretacé, Lyon-Neuchâtel, 1973, that the boundary should best be placed at the base of the combined ammonite zone *Jacobi-Grandis* which is approximately equivalent to the base of the *Calpionella* Zone in terms of microfossils, but the base of the *Tirnovella occitanica* - Zone (lower *Calpionella* Zone near base of calpionellid Zone C) has also been proposed (Hoedemaker 1987, 1991). However, this classification has only been applied for the European Tethys whereas correlation with the western Atlantic Hispanic Corridor (e.g., Mexico), or even with the classical Pacific southern high latitude localities in Chile and Argentina, remained tentative, at most. Until a few years ago, no calpionellids were known from South America and ammonites were considered to be endemic on both sides of the Atlantic. In consequence, the stratigraphical ranges of many South and North American ammonite genera have long been controversially discussed in terms of European zones (e.g., Zeiss, 1983, 1984, 1986; Jeletzky, 1984, Cantu-Chapa, 1989, 1999, 2006) and it appeared likely that no direct oceanic connection existed then between Europe and America. Data on the J/K interval in Mexico, however, suggest that biostratigraphic correlation is possible between faunal realms of the western Pacific, the Hispanic Corridor and the western Tethys and that classical biostratigraphical research may bear the key to resolve decades of confusion in the calibration of faunal and environmental changes in the J/K interval of the western hemisphere (Adatte et al. 1994, Adatte et al. 1996).

1.2 The Jurassic/Cretaceous (J/K) boundary in southern South America (Chile and Argentina)

The Jurassic/Cretaceous (J/K) boundary in Chile and adjacent west central Argentina has been the subject of considerable attention since the turn of the XIXth century, beginning with the classic works made by German speaking scientists, such as Behrendsen (1891-92, 1922), Steuer (1897-1921), Bodenbender (1892), Burckhardt (1900a, 1900b, 1903), Haupt (1907), Krantz (1926-1928) and Gerth (1921-1925). It was A. F. Leanza (1945) who proposed the first modern zonation based on ammonites in the southern Mendoza province while Biro (1964) and Corvalán (1956, 1959) worked on the faunas in Central Chile. H. Leanza (1973, 1980, 1981a, 1981b) was also devoted to the J/K boundary, but in this case in the Neuquén province in Argentina. The author demonstrated the diachronic nature of the formational units in this region, independent of the J/K boundary. A similar diachrony likely occurs in Chile but has never been documented in detail. Nearly 40 years have passed since the original publications by Leanza and Biro, and the general and rapid improvement of knowledge as well as the development of new techniques (e.g., sequence stratigraphy), makes a revision quite necessary. Recently, Rawson (2007) discussed the global relationships of Argentinian Early Cretaceous ammonites and documented striking similarities between taxa from the Neuquén basin and species of the Boreal faunal realm. These new data therefore suggest that a faunal link and possibly a direct marine connection existed between the two regions.

The position of the J-K boundary, as defined in Europe, has not been convincingly located in the Eastern Pacific Province. Recent improvements by Rawson (2007) and Aguirre-Urreta et al. (2007) focus on the Early Cretaceous (Valanginian-Barremian) sequence and do not include the Jurassic-Cretaceous transition.

1.3. Location

The working area is located the central high Andes of Chile, between the Metropolitan and Maule regions (Figure 1.1). In this area three sections of the Lo Valdés Formation and two sections of the Baños del Flaco Formations were measured and sampled. Sections of the Lo Valdés Formation are located in the Cajón del Morado (CM), near Lo Valdés (LV) and at Cruz de Piedra (CP) (Figure 1.1). Sections covering Baños del Flaco Formations were measured at Baños del Flaco (BF) and at Rio Maitenes (RM) (figure 1.1). For details of each section see chapter 3.

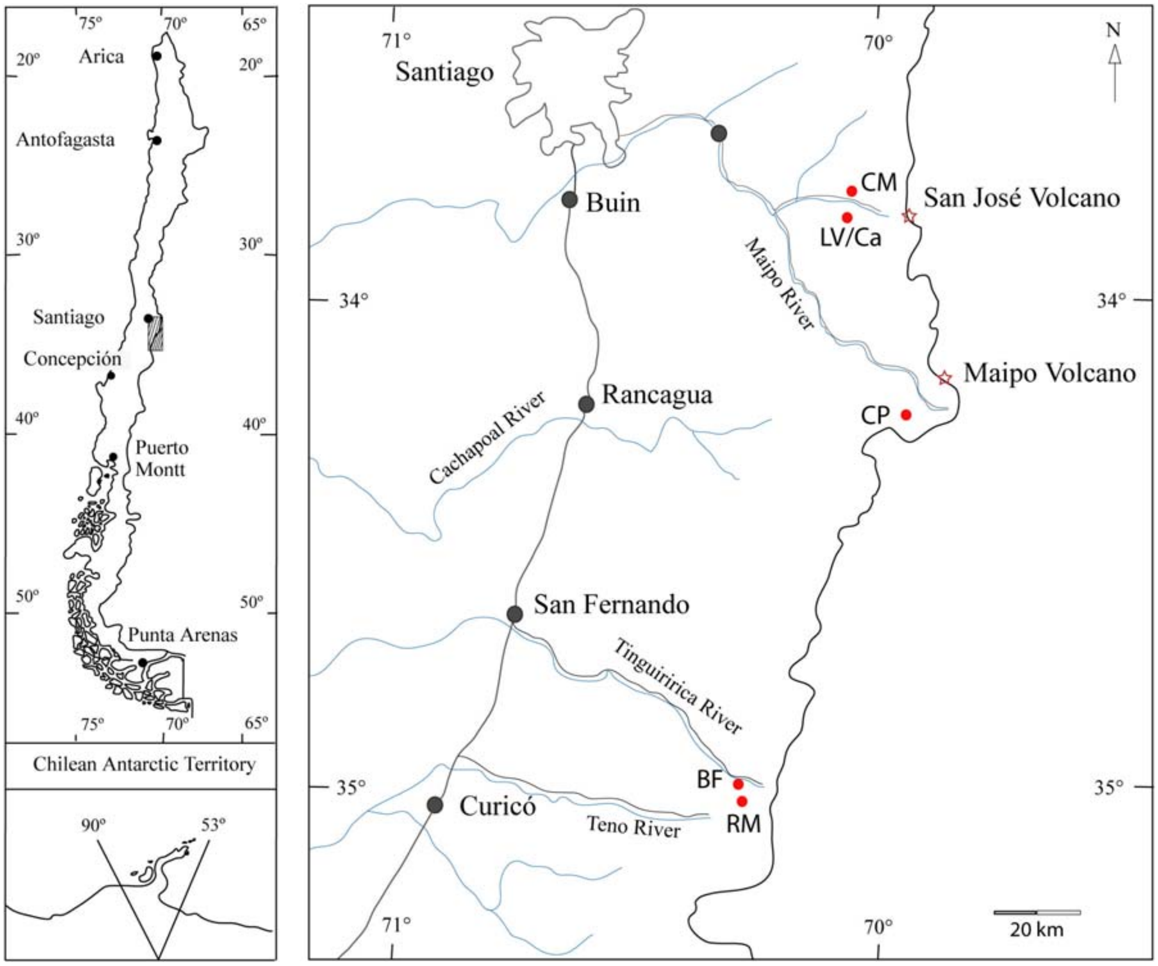


Figure 1.1. Map of Chile showing the location of outcrops of the Baños del Flaco and Lo Valdés Formations. CM: Cajón del Morado; LV: Lo Valdés; CP: Cruz de Piedra; Baños del Flaco and RM: Rio Maitenes.

1.4. Geological Setting

The geology of Central Chile is characterized by the ongoing subduction of the oceanic plate under continental South American plate, a process with continues since early Jurassic times. As a consequence to these process, geological settings in the region include a dynamic volcanic arc as well as fore arc, intra arc and back arc basin (Mpodozis & Ramos 1989).

In Chile, the backarc basin related to this subduction system is traceable without interruption along the eastern side of the magmatic arc from at least southern Perú to southern Chile (Charrier et al. 2007). The Central Chilean segment (30°S to 39°S) is considerably wider than further to the north and is known as the Mendoza-Neuquén Basin. It extends eastwards into Argentina and shows a general southeastward bend (Charrier et al. 2007).

The area of research forms part of the central Chilean subduction system (figure 1.1 - 1.2) and thus presents a sequence of volcanics rocks and intercalated sediments from Jurassic to present ages. The sequence was folded from the Upper Cretaceous to present as part of the Andean orogeny. Tectonic orientations are North-South (figure 1.2) and thus follow the regional trend. In addition, laccoliths and batholiths of granitic composition intruded during the Miocene (Klohn 1960, Thiele 1980, Charrier 1981a).

Two depositional areas are recognized in the for the marine deposits accumulated during the Late Jurassic to Early Cretaceous time, one in the Coastal Cordillera and the second in the High Cordillera, and mostly on its eastern side (A and C, figure 1.3) (Charrier et al. 2007). The two basins are separated from each other by a volcanic Arc. It is therefore possible to identify three palaeogeographic domains, from west to east: the Lo Prado Forearc Basin, the Lo Prado-Pelambres Volcanic arc, and the Mendoza-Neuquén Backarc Basin (figure 1.3) (Charrier et al. 2007).

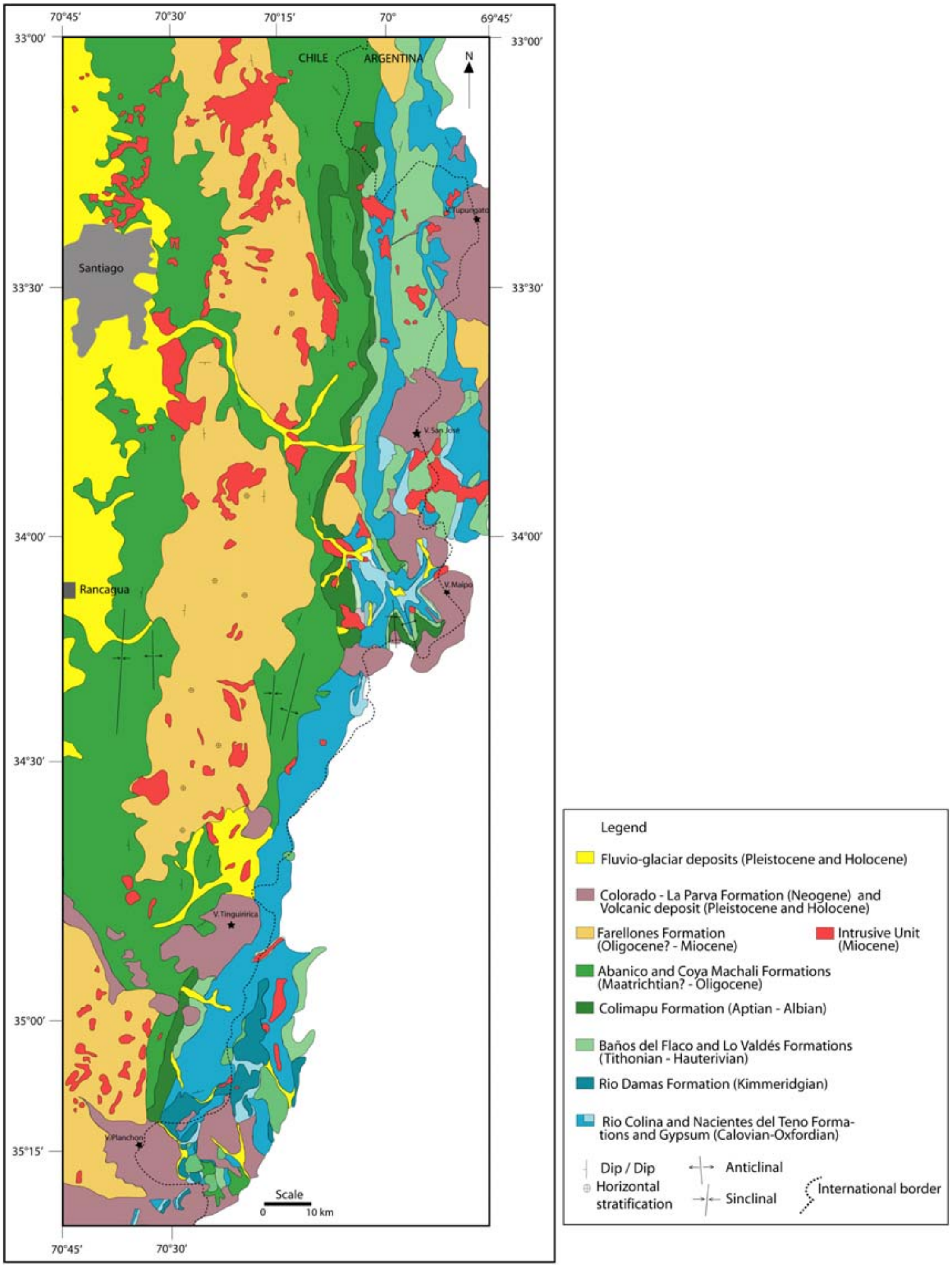


Figure 1.2. Geological map of Central Andes of Chile. This figure is based on the Geological maps "Hoja Santiago" (Thiele 1980) and "Geologia de la Cordillera de los Andes de Chile Central" (Klohn 1960). The geological map correlated the formations and unites present in both areas. Lo Valdés and Baños del Flaco Formations are show as the same color. Lo Valdés Formation is distributed to the north of latitude 34°30` S, and Baños del Flaco Formation is distributed to the south of latitude 34°30`S.

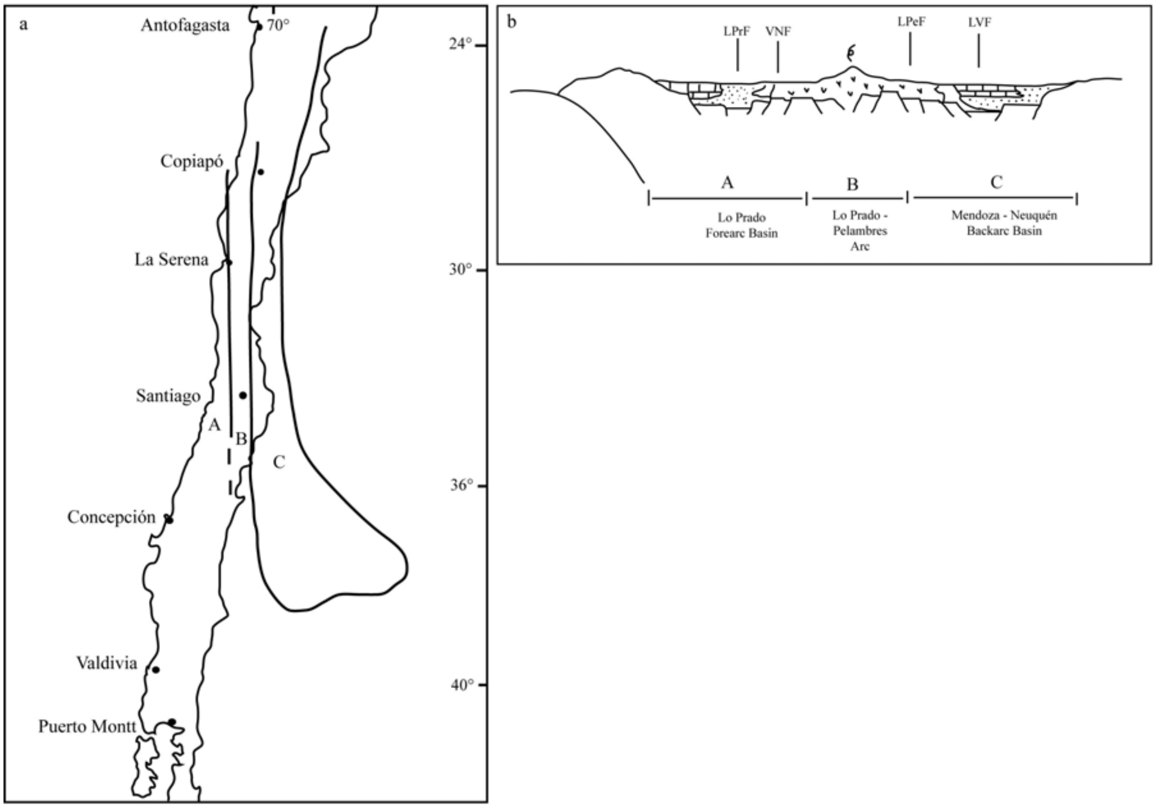


Figure 1.3. Late Jurassic-Early Cretaceous palaeogeographic distribution in central Chile.
a) The forearc and backarc basin separated from each other by the Pelambres arc in central Chile. A, Lo Prado Forearc Basin; B, Lo Prado-Pelambres Volcanic Arc; C, Mendoza-Neuquén Basin.
b) Schematic palaeogeographic cross section of Andean evolution in central Chile between 32°S and 33°S. A, Lo Prado Forearc Basin; B, Lo Prado-Pelambres Volcanic Arc; C, Mendoza-Neuquén Basin. LPrF, Lo Prado Formation; VNF, Veta Negra Formation; LPeF, Los Pelambres Formation; LVF, Lo Valdés Formation (Charrier et al. 2007).

1.4.1. Andean Basin: The Late Jurassic-Early Cretaceous sequence

East of Santiago, in the western part of Andean Basin, the Late Jurassic-Early Cretaceous (Neocomian) transgression-regression cycle resulted in the deposition of a thick succession of neritic to shallow marine (external platform) and predominantly calcareous sediments, known as the San José (Aguirre 1960), Lo Valdés (González1963; Hallam et al 1986) and Baños del Flaco formations (Klohn 1960; González & Vergara 1962; Covacevich et al. 1976; Charrier 1981a, b; Arcos 1987, and Charrier et al. 2007).

In the segment of Santiago-Curicó (figure 1.1 - 1.2), the upper Jurassic and lower Cretaceous sediment sequence is differentiated in the Río Colina, Nacientes del Teno, Rio Damas, Leñas-

Espinoza, Baños del Flaco and Lo Valdés formations. Río Colina Formation consists of limestone, calcareous siltstone, siltstone and gypsum and was deposited in a shallow marine setting during the Upper Oxfordian (Thiele 1980) or Callovian-Oxfordian (Alvarez et al. 1997). The Nacientes del Teno Formation is a penecontemporaneous equivalent (Bajocian? to Oxfordian; Klohn 1960) of the Rio Colina Formation and composed of conglomerate, sandstone, siltstone, limestone, marl, gypsum and pyroclastic rocks. These units underlie the Rio Damas Formation, a continental unit of Kimmeridgian age, composed by siliciclastic sediments and andesite (Klohn 1960, Thiele 1980). The Leñas-Espinoza Formation encompasses sandstone and limestone which were deposited during the Tithonian under shallow marine conditions. Originally this unit was thought to represent the Tithonian (Klohn 1960), while Charrier (1982) assigned this formation to the lower part of the Baños del Flaco Formation. The Lo Valdés Formation is composed of andesite, sandstone, siltstone and limestone, assigned to the Tithonian-Hauterivian or Barremian? Age (González 1963; Biro 1964; see chapter 3).

1.4.2. Baños del Flaco Formation

This unit was defined by Klohn (1960) as a sequence of marine fossil-bearing grey limestone, sandy limestone and calcareous sandstones, and minor conglomerate, glauconitic sandstone and siltstone (e.g., Corvalán 1956, Klohn 1960, Covacevich et al., 1976). The unit is well developed in the area of Baños del Flaco, located in the valley of the Río Tinguiririca, O`Higgins Region of Chile; and along the Río Maitenes, tributary of Río Teno, Curicó, Maule Region of Chile (figure 1.1, 1.2).

Ammonites collected in the Baños del Flaco Formation by Corvalán (1956 and 1959) and Klohn (1960) on the southern side of Tinguiririca River y and along the Maitenes river in the Curicó province have been assigned to the late Tithonian, the Berriasian, early and late Valanginian, and to the Hauterivian. In addition to ammonites, sediments also contain sponges, corals, bivalves, gastropods, nautiloids and echinoids.

1.4.3. Lo Valdés Formation

This unit is located east of the Chilean capital of Santiago in the high Andes (figure 1.1, 1.2). The Lo Valdés Formation was defined by González (1963) and the type locality placed at Lo Valdés, a village located to 5 km (figure 1.1). The only detailed study on the biostratigraphy and lithology of the section was by Biro (1964). At Lo Valdés, the Lo Valdés Formation consists of a 750 m thick sequence of limestone, calcareous siltstone and calcareous sandstones, conglomerates and breccias as well as >600 m of andesite in the lower part of the section. Biro (1964) divided the formation in three members which are predominantly volcanic (spilite member, at base unit), siliciclastic (sandstone member, middle part of unit) and calcareous (calcareous member, at top of unit). The faunal assemblage was determined by Biro (1964) and consists of abundant ammonites as well as nautiloids, bivalves and gastropods. Biro (1964 and 1980a) and Hallam et al. (1986) assigned the Lo Valdés Formation to the early? Tithonian to Hauterivian based on ammonites. The latter authors also presented a biostratigraphic profile in which they differentiated 8 faunal associations.

2. Objectives and Methods

2.1 Objectives

The main objective of this dissertation is to re-evaluate the Jurassic/Cretaceous (J/K) boundary in the classical localities of central Chile using new techniques and data, to clarify the paleogeographic setting of this region, and to improve the stratigraphic correlation of these sections with localities of the Tethys and elsewhere. The present research includes sequence stratigraphical, micro- and macrofacies and faunal analyses, principally of ammonites and bivalves. Biostratigraphical and palaeobiogeographical analyses will be based on ammonites. This multistratigraphical approach will allow us to verify sea level fluctuations across the J/K boundary, including main flooding episodes, as well as the identification of systems tracts. Biostratigraphy is based on ammonite assemblages and will lead to a high resolution of events across this transition. This new data set will allow us to manage modern fine stratigraphic correlation at a global perspective, thus allowing to correlate the Chilean J/K boundary sequences with those of the other regions within South America and the Northern Hemisphere Tethyan Realm, including the Boreal and European Mediterranean region.

2.2 Methods

The Geological maps “Hoja Santiago” (sheet N°39, scale 1:250 000, Thiele 1980) and “Geología de la Cordillera de los Andes de Chile Central” (boletin N°8, scale 1:150 000, Klohn) of the “Servicio Nacional de Geología y Minería” (SERNAGEOMIN) were used for orientation in search the outcrops (figure 1.2).

Field work campaigns to the region were executed in 2006, 2007 and 2008, usually during the summer months of January and February. A total of five months were spent in the field searching and measuring and drawing sections as well as collecting fossils and rocks samples.

Five sections were measured and sampled at Cajón del Morado, Lo Valdés, Cruz de Piedra, Baños del Flaco and Rio Maitenes. Samples were taken every 10 m of section and in 1 m distances across the Jurassic-Cretaceous boundary transition.

Lithology: The description of carbonate microfacies is based on the classification of Wright (1992), who revised the classification of Dunham (1962) and Embry & Klovan (1971) and expanded it to diagenetically of Dunham. Siliciclastic sediments are subdivided by grain size.

Differentiation of conglomerate, sandstone and siltstone followed rules according to British Geological Survey (BGS) grain size scheme proposed by Wentworth (1922) and Folk (1968).

Thin sections: The microfacies of siliciclastic and carbonate rocks were analyzed with a petrographical microscope, based on small-sized thin sections (4.5 cm x 4.5 cm).

Facies and sequence stratigraphy: The terminology used here was proposed by Coe (2003) and Nichols (2009), who summarized the vast numbers of articles on facies and sequences stratigraphy published within the past years. The terminology on facies and sequence stratigraphy terms used in the present research is presented in the chapters 4 and 6.

Fossils and Taxonomy: Fossils samples were collected during field campaigns in every section. The fossils from Rio Maitenes section were collected by Lajos Biró Bagoszky from the Universidad de Concepción in the early 1960ies. He only published a single article on an echinoid of this assemblage (Larraín & Biro 1985). His field book, rock samples and his collection of ammonites is available for this research.

Fossils were prepared in the Palaeontological laboratory of the Institut für Geowissenschaften (Heidelberg University, Germany), with the “air pen” methodology.

The taxonomic citations are only used in the faunal lists. Taxa described in open nomenclature are assumed to represent indeed the species given in the systematic part of this research. The paleontological systematic terms and abbreviations used in this research are given in the chapter 4.

Explanation and abbreviations to symbols used in the figures are given in figure 2.1. Unless figures contain separate explanations, this legend is valid for all figure of the present research.

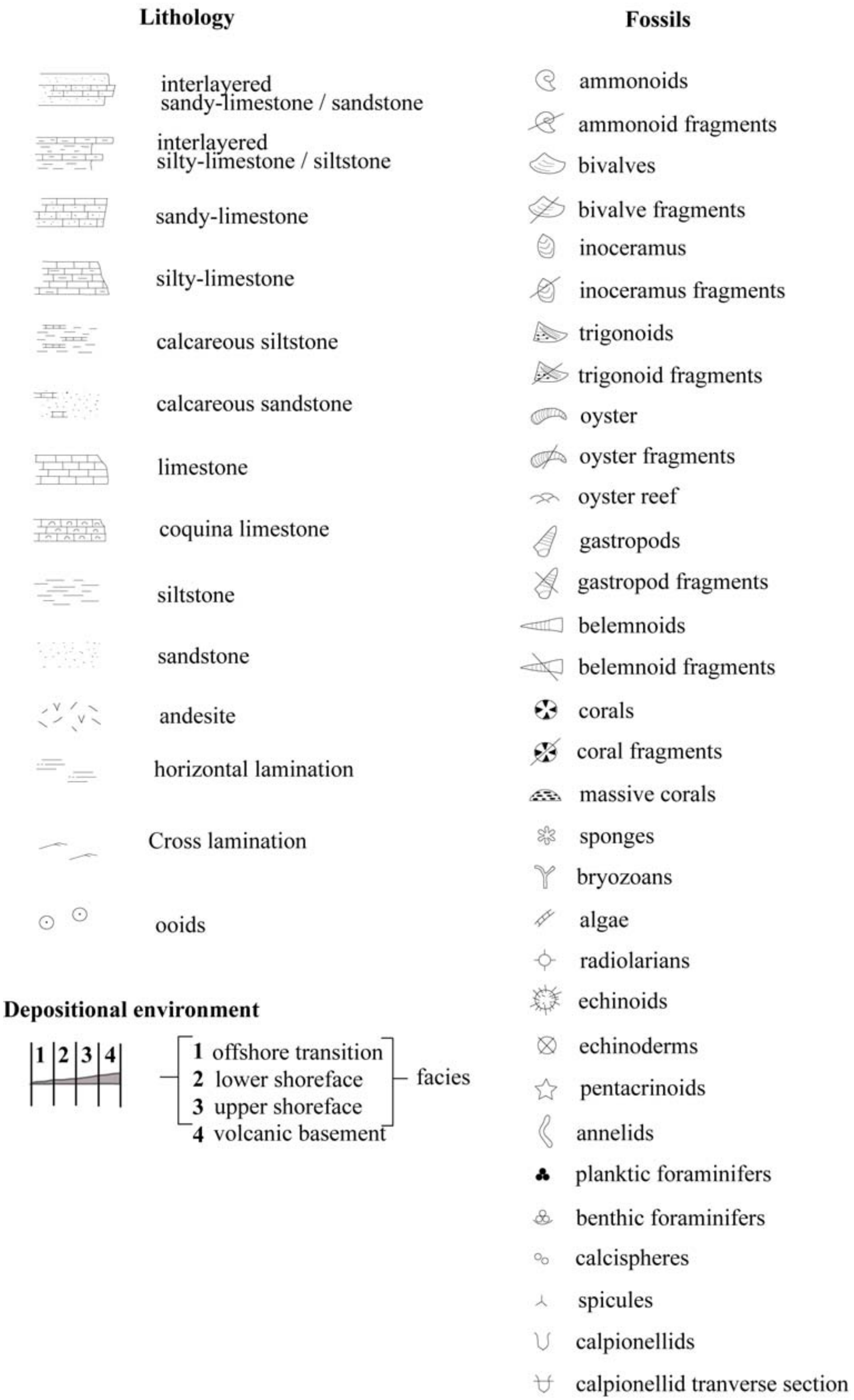


Figure 2.1. Key to symbols and abbreviations used in the stratigraphic columns.

3. Sections

The Lo Valdés Formation is well exposed in the high Andes of Central Chile, East and Southeast of Santiago (figure 1.1). The type locality of the Lo Valdés Formation is situated on the southern side of the Rio Volcán valley, located between Cerro Catedral and Quebrada Lo Valdés. The thickness was measured by González (1963) to reach 1635 m, whereas Biro (1964) suggests a thickness of 1456 m at the type locality.

For the present research, we measured 5 sections of the Lo Valdés and Baños del Flaco formations in a North-South transect, from Cajón del Morado in the North to Rio Maitenes in the South (Figure 1.1). The thickness of the Lo Valdés Formation varies from 1460 m at Lo Valdés to 1173 m at Cajón del Morado and only 150 m at Cruz de Piedra. In all five sections measured, we detected andesite, conglomerate, sandstone, siltstone, limestone and volcanoclastic rocks. The Baños del Flaco Formation is 369 m thick at Baños del Flaco and 536 m thick at Rio Maitenes and consists of conglomerate, sandstone, siltstone and limestone.

Lo Valdés Formation is located east of the Chilean capital of Santiago in the high Andes (figure 1.1) and was originally defined by Gonzalez (1963). This author placed the type locality at Lo Valdés (figure 1.1) and described a 1635 meters thick marine sediment sequence rich in fossils, which conformously overlies continental red-beds of the Rio Damas Formation of Kimmeridgian age and underlies continental sediments of the Colimapu Formation of Aptian-Albian age.

To date, Biro (1964) is the only author to present a detailed documentation on the biostratigraphy and lithology at the type locality. Biro (1964) re-measured the section which he regarded 1456 meters thick, and assigned a Lower-Middle Tithonian to Hauterivian-Barremian? age to the sequence (Biro 1964 and Hallam et al. 1986). He also divided the unit in three members (Biro 1964), from bottom to top:

1) “Spilítas”, or spilite lower member, 762 meters thick, dominated by prophyric andesite (“spilite”) and volcanic breccia, and restricted layers of sandstone, limestone and siltstone. He assigned this member to the Lower-Middle and lower part of the Upper Tithonian.
2) “Arenáceo”, or sandstone middle member, 72 meters thick, mainly composed of sandstone and minor conglomerate and breccia. Biro (op. cit.) assigned this member to the middle part of the Upper Tithonian.

3) “Calcáreo”, or calcareous upper member, 622 meters thick, consisting of limestone, siltstone and calcareous sandstone; this unit also contains a 20 meters thick andesite. This upper member was assigned to the uppermost Tithonian to Hauterivian-Barremian?.

The regional distribution of the Lo Valdés Formation is illustrated in the geological map of Santiago (Carta Geológica de Chile N° 39; Thiele 1980, figure 1.2). The “Spilítas” lower member is restricted to the Metropolitan region, reaching from a few kilometers north of “Cajón del Morado” to “Río Barroso” in the south (figure 1.1). According to the original description of this member, the predominantly volcanic composition differs from other members of the Lo Valdés Formation which consist of sediments. For this reason we propose to separate the spilite-dominated unit overlying the Rio Damas red beds from the sediment-dominated Lo Valdés Formation overlying the volcanic rock sequence, and suggest the name Catedral Formation for this unit.

3.1 Catedral Formation

3.1.1. Definition

The Catedral Formation is here proposed for the “Spilitas” Member of the Lo Valdés Formation, as denominated by Biro (1964). Salazar & Stinnesbeck (submitted) explain in detail the argument for this new Formation. It is defined as a predominantly volcanic unit of andesite porphyry. Occasional sedimentary units are thin, only a few tens of meters thick, and consist of coarse to medium sized siliciclastic rocks. The type locality corresponds to the “Catedral” mountain on the south side of Volcán River, 70°02`57``W and 33°49`41``S (Ca locality, figure 1.1). This Formation overlies the Rio Damas Formation and underlies the Lo Valdés Formation. Both contacts are sharp but conformous (figure 3.1).

3.1.2. Lithology and thickness

In the type locality at Catedral hill, the unit is 760 m thick (figure 3). At the base, overlying the Rio Damas Formation, a 15 m thick silty limestone is present with scare fragments of bivalves and rare ammonoids.

Upsection, between 15 m and 87.5 m, a 10 m thick unit of andesite porphyry is characterised by 15 mm long phenocrystals of plagioclase. It underlies a 1 m thick silty limestone with scare fragments of bivalves, a 5 m thick unit of andesite porphyry, a 5 m thick silty limestone with

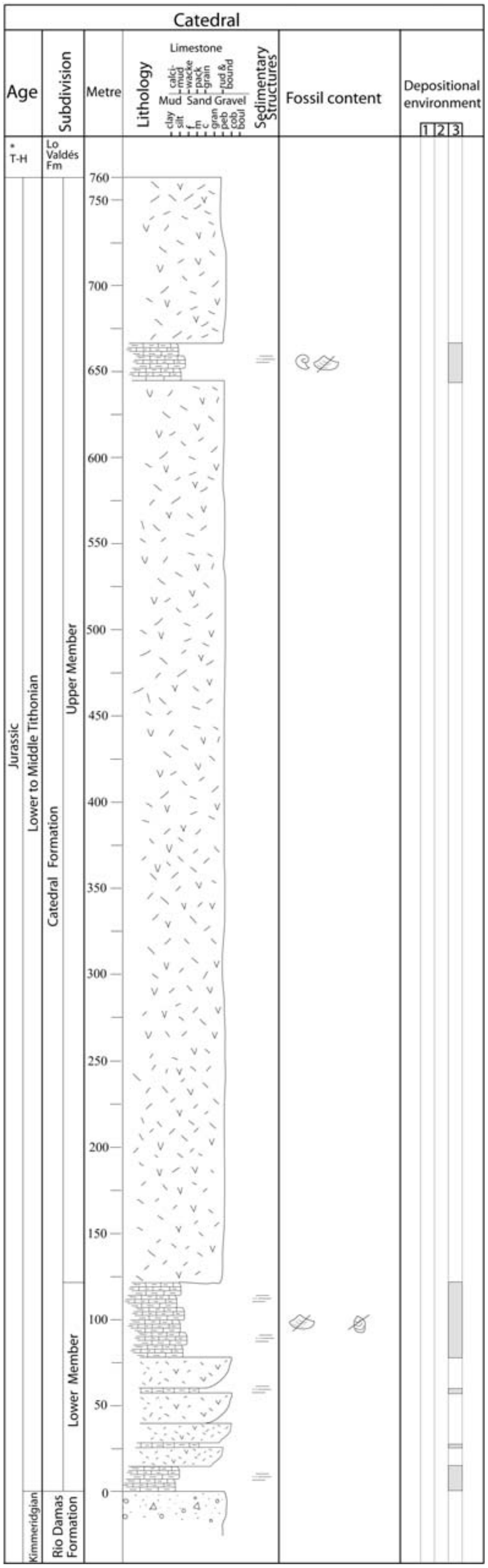


Figure 3.1. Cross section of the Catedral Formation at Cerro Catedral, with differentiation of lithological Members. * T-H: Upper Tithonian to Hauterivian.

fragments of bivalves, 30 m of andesite porphyry, 1.5 m of silty limestone with horizontal lamination and a 20 m thick andesite porphyry with phenocrystals of plagioclase and a chloritized matrix (Figure 3.1).

Upsection, between 87.5 m and 117 m, a silty limestone (biomicritic wackestone) contains fragments of inoceramids and other bivalves, as well as abundant calcispheres (figure 3.1). Between 117.5 to 418.5, is a unit of andesite porphyry with up to 2.4 mm long phenocrystals of plagioclase and a chloritized matrix; the unit present pillow and ellipsoidal structures that have diameters between 0.10 – 0.50 m. The unit underlies andesite porphyry with up to 5 mm long phenocrystals of plagioclase and a chloritized matrix, from 418.5 m to 637.5 m (figure 3.1 - 3.2).

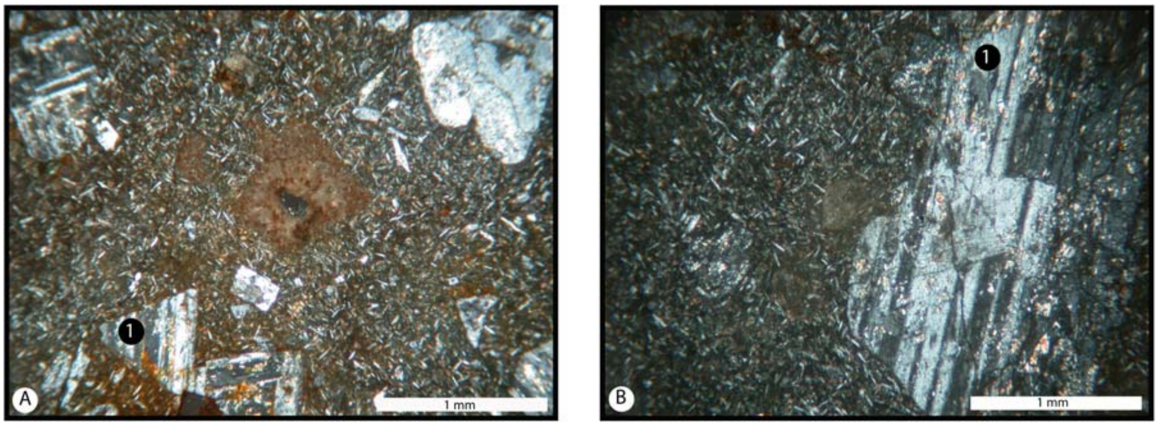


Figure 3.2 Andesite from Catedral Formation. **A**: Andesite with phenocrystals of plagioclase with chloritic matrix. **B**: Andesite with large phenocrystals of plagioclase.

Between 637.5 m and 653.25 m of the section. From base to top we detected a 0.7 m thick microconglomerate, a 0.8 m thick calcareous sandstone, 0.1 thick m of silty limestone, a 0.9 m thick calcareous sandstone, 0.15 m of silty limestone, a 2.1 m thick sandy limestone with fragments of echinoderms, and an 11 m thick unit of silty limestone (figure 3.1). Biro (1964) described ammonoids, inoceramids, oysters, trigoniids and other bivalves from these layers.

At 653.25 m, a 107 m thick unit of andesite with plagioclase phenocrystals and a chloritized matrix forms the top of this member (figure 3.2).

The Catedral Formation at Cajón del Morado (70°01`00``W and 33°46`24``S) is 591 m thick (figures 1.1 - 3.3) and overlies the Rio Damas Formation conformably. The base is formed by a 30 m thick unit of calcareous siltstone with planar lamination. Upsection, between 30 m and 81 m, 8 m of andesite underlie 15 m of calcareous sandstone with horizontal lamination, few ooids

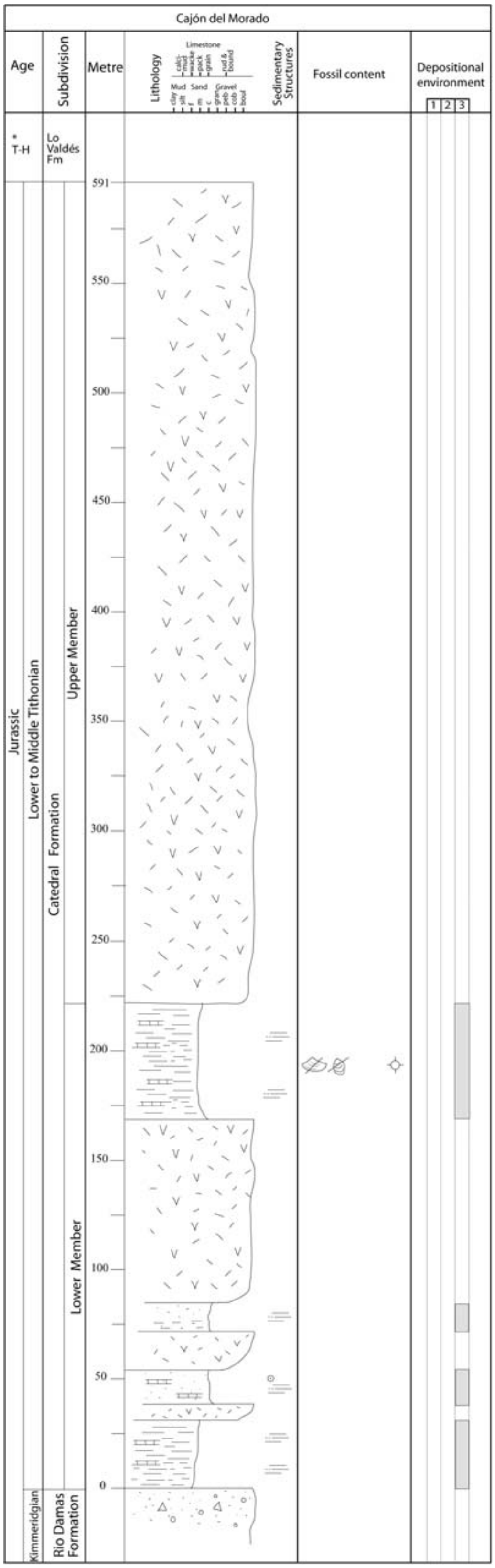


Figure 3.3. Cross section of the Catedral Formation at Cajón del Morado, with differentiation of lithological Members. * T-H: Upper Tithonian to Hauterivian.

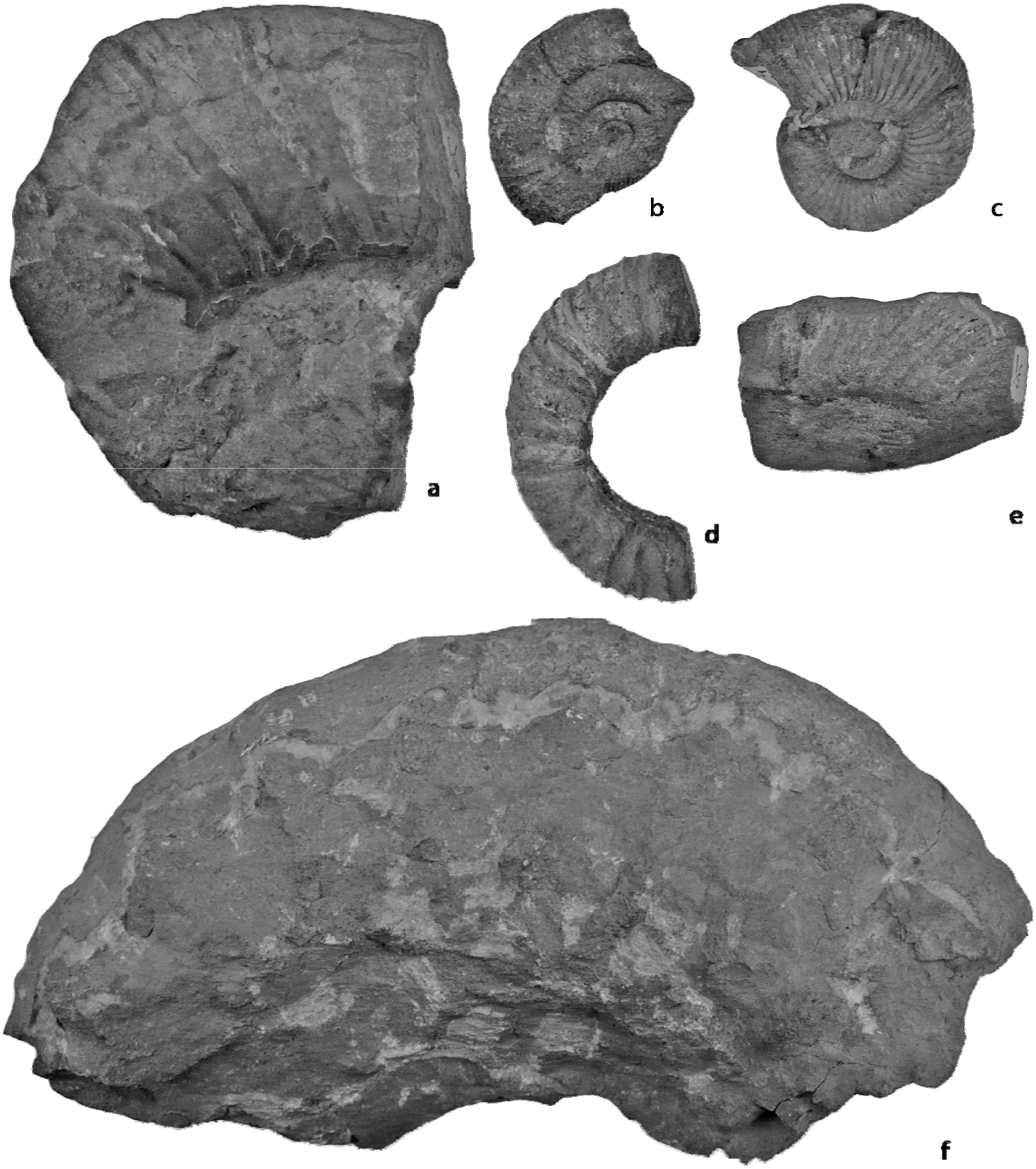


Figure 3.4. Ammonoids from sediments interlayered between volcanic rocks in the Catedral Formation. **a, e:** *Virgatosphinctes* cf. *andesensis*, CPUC/LV/I-4 and CPUC/LV/I-5. **b:** *Wichmanniceras* aff. *mirum* CPUC/LV/II-2. **c:** *Paraulacosphinctes striolatus* CPUC/LV/I-4. **d:** *Aulacosphinctes windhauseni* CPUC/LV/I-2.. **f:** *Windhauseniceras humphreyi* CPUC/LV/II-1. All figures are x1. These fossils were collected and determinated by Biro (1964).

and disseminated pyrite. This unit underlies 17 m of andesite, 6 m of calcareous siltstone and 5 m of calcareous sandstone, both with horizontal lamination and disseminated pyrite (figure 3.3).

Upsection, an 89 m thick unit of andesite with phenocrystals of plagioclase overlies these sediments of which the matrix is chloritized. The unit underlies a 50 m thick calcareous siltstone with horizontal lamination, which is rich in organic matter and disseminated pyrite. The siltstone contains radiolarians, fragments of inoceramids and other bivalves. Between 371 m to 591 m, a thick unit is composed by andesite with plagioclase phenocrystals, sericitic alteration and a chloritized matrix. It also contains restricted levels of volcanic breccias (figure 3.3).

3.1.3. Fauna and age

To date, the only detailed paleontological research on the Catedral formation (the former *Spilitas* member of the La Valdés Formation) was done by Biro (1964). Here we re-study this ammonite assemblage and identify *Aulacosphinctes windhauseni*, *Torquatisphinctes* cf. *proximus*, *Virgatosphinctes* cf. *andesensis*, *Windhauseniceras humphreyi*, *Wichmanniceras* aff. *mirum* and *Paraulacosphinctes striolatus* (Figure 3.4). In Argentina, a similar assemblage was considered to represent the Lower to Middle Tithonian (Leanza 1980).

3.2 Lo Valdés Formation

The Lo Valdés Formation is defined here as a sediment sequence divided into three members, from base to top a Sandstone, Siltstone and a Limestone member. The type locality corresponds to the site determined by Gonzalez (1963). He defined the Lo Valdés Formation along the south side of the El Volcán River at Catedral hill, 70°02`52`` W and 39°49`50`` S (Lo Valdés section, figure 1.1). The Lo Valdés Formation conformously overlies the Catedral Formation and underlies an undefined volcanic unit (see below). The Lo Valdés Formation is divided in three members: Sandstone member, Siltstone member and Limestone member.

3.2.1 Lo Valdés Section (Type locality).

In the type locality, the total thickness of the Lo Valdés Formation is 539 meters (Figure 3.5-3.9).

Sandstone Member

The sandstone member is approximately 73 m thick (figure 3.6). The lowermost unit, is 6 meter thick, consists of fine-grained calcareous sandstone intercalated with centimetre-thick layers of coarse calcareous sandstone and a 0.3 m thick layer of sandy limestone. The fauna comprises ammonoids, fragments of bivalves and gastropods.

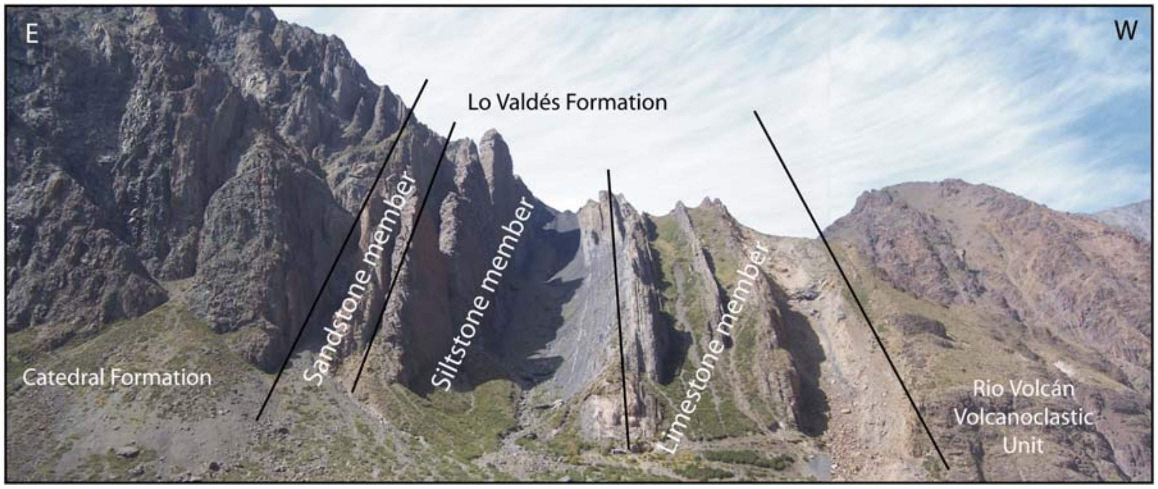


Figure 3.5. Cross section of the Lo Valdés Formation at Lo Valdés (Type Locality).

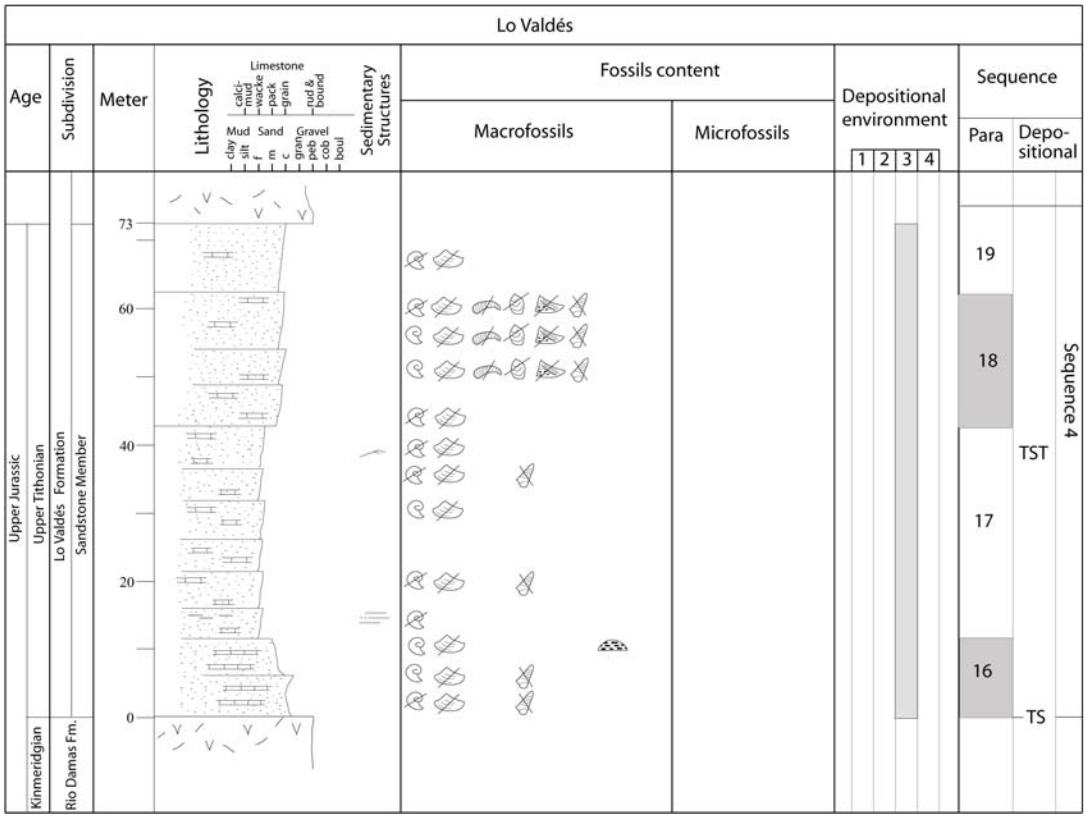


Figure 3.6. Detail of Sandstone member of Lo Valdés Formation at Lo Valdés section.

From 6 m to 12.4 m, coarse calcareous sandstone gradually changes to medium calcareous sandstone with fragments of ammonoids, bivalves and corals (*Actinastrea scyphoidea*).

Upsection (12.4 m to 43 m) follow 30.6 m of fine to medium-grained calcareous sandstone (figure 3.6). The lowermost unit consists of 7.6 m of fine calcareous sandstone with horizontal lamination and fragments of ammonoids, bivalves and rare gastropods. At 20 m, a 10 m thick fine to medium-grained calcareous sandstone contains centimetre-thick layers of coarse calcareous sandstone and ammonoids, fragments of bivalves and rare gastropods. A 13 m thick medium-sized calcareous sandstone is scare in fossils but contains fragments of ammonoids and bivalves.

At 43 m, a 20 m thick unit of medium to coarse calcareous sandstone is present and contains scare ammonoids, fragments of bivalves, inoceramids, oysters, trigoniids and gastropods.

The topmost unit of the sandstone member (63 m to 73 m) is formed by a 20 m thick unit of unfossiliferous fine calcareous sandstone (figure 3.6).

Siltstone Member

The siltstone member is 214 m thick and consists of siltstone, calcareous siltstone, silty limestone and andesite (figure 3.7).

The lowermost unit, between 833 m to 854 m, is 21 m thick and consists of green andesite.

Between 94 m to 193 m, a 99 m thick unit of rhythmically bedded siltstone and calcareous siltstone contains ammonoids, oysters, inoceramids, other bivalves and scare gastropods, and high concentrations of organic matter (figure 3.7). This unit initiates with 13 m of siltstone and calcareous siltstone with parallel lamination. Layers of siltstone are 0.20 m thick and calcareous siltstone forms layers of 0.25 m thickness. Fauna is scare and only consists of a few fragments of ammonoids.

From 867 m to 878 m, layers of 0.5 m thickness of horizontally laminated siltstone alternate by layers of 1 m thickness of calcareous siltstone; disseminated pyrite is common and ammonoids, calcispheres and rare radiolarians are typical faunal elements.

Between 107 m and 139 m, a 21 m thick unit of siltstone and calcareous siltstone shows horizontal lamination and also contains disseminated pyrite (figure 3.7). The siltstone layers reach 0.4 m thickness and layers of calcareous siltstone are 0.5 m thick. The fauna is scare, comprises ammonoids, fragments of bivalves, oysters, gastropods, calcispheres and rare benthic foraminifers.

At 139 m, a 10 m thick unit of siltstone and calcareous siltstone interlayered, are horizontally laminated and contains disseminated pyrite. Siltstone layers reach 0.4 m to 1 m and calcareous siltstone layers 0.1 m to 0.3 m thickness. Ammonoids are abundant faunal elements.

Rhythmically bedded siltstone and calcareous siltstone is present between 149 m to 181 m section. The sediment is horizontally laminated, contains disseminated pyrite, organic matter

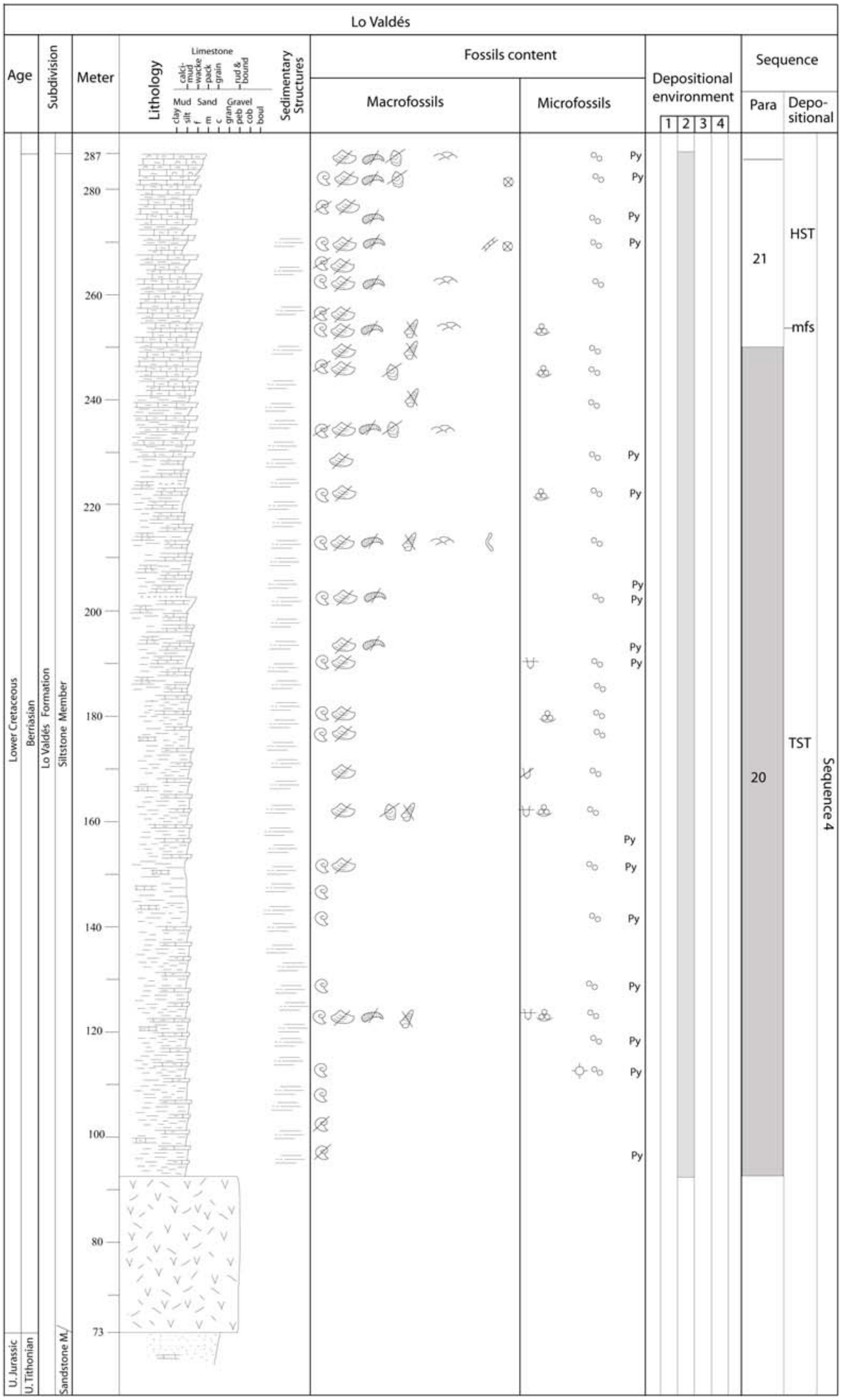


Figure 3.7. Detail of Siltstone member of Lo Valdés Formation at Lo Valdés section.

(figure 3.7) and scarce fossils, principally ammonoids, inoceramids and other bivalves, gastropods, calcispheres and benthic foraminifers.

Upsection (193 m to 242 m), calcareous siltstone and silty limestone form a 49 m thick rhythmic unit with horizontal lamination, disseminated pyrite and organic matter. The calcareous siltstone layers reach between 0.75 m and 0.85 m thickness (figure 3.7). The silty limestone (biomicrite calci-mudstone), forms layers between 0.9 m to 1 m thickness. The fauna consists of ammonoids, fragments of bivalves, calcispheres and scare annelids. Oyster reefs are present at 213 m, with 1.2 m thickness, at 216 m with 0.5 thickness and at 234 m with 0.4 m thickness; oysters are small with a maximum height of 3 cm.

Between 242 m and 251 m, a 9 m thick unit with horizontal lamination consists of rhythmically bedded calcareous siltstone with layers of up to 0.5 m thickness, and interlayers of silty-limestone (biomicritic, calci-mudstone to wackestone) forming 1 m thick beds. These layers contain ammonoids, bivalves, gastropods, calcispheres and rare foraminifers.

From 251 m to 287 m, a 36 m thick unit of silty limestone and calcareous siltstone forms the topmost unit of the siltstone member. Silty limestone layers are 2 m to 3 m thick and calcareous siltstone (biomicrite, wackestone to calci-mudstone) forms layers of 0.3 m to 0.5 m thickness. Sediments contain disseminated pyrite and organic matter (figure 3.7). The faunal contents increases upsection and comprises ammonoids, fragments of oysters, inoceramids and other bivalves, calcispheres, scare fragments of echinoderms and algae. Layers rich in oyster are present at 253 m, 262 m and 286 m.

Limestone Member

The Limestone Member is 252 m thick and consists of sandy and silty limestone and calcareous siltstone (figure 3.8).

The lowermost part of the limestone member, from 287 m to 390 m, is a 103 m thick unit of sandy limestone (intra- and biomicrite wackestone) (figure 3.8). Some layers present increased amounts of disseminated pyrite. Fossils are rare in the first 34 metres, consisting ammonoids and bivalves. Between 321 m to 372 m, faunal content increases and ammonoids, oysters, inoceramids, other bivalves and echinoderms are present. A 0.9 m thick a layer rich in oyster is present at 321 m.

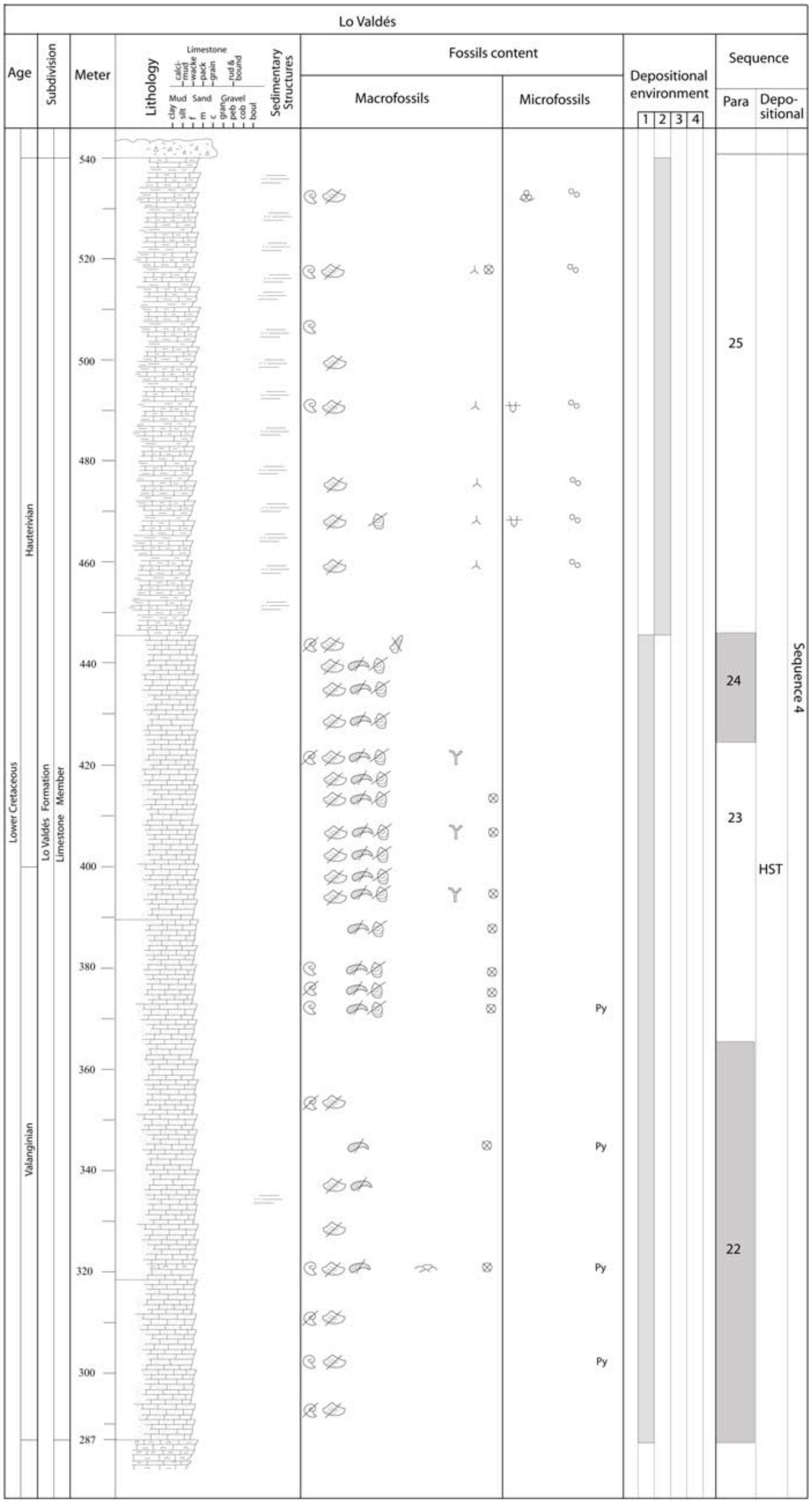


Figure 3.8. Detail of Limestone member of Lo Valdés Formation at Lo Valdés section.

Upsection, from 390 m to 446 m, a 56 m thick unit of sandy limestone (biomicrite wackestone) is highly fossiliferous (figure 3.8); we identified abundant oysters, inoceramids and other bivalves, and rare ammonoids, gastropods, fragments of bryozoans and echinoderms.

Between 446 m and 539 m, sandy limestone (biomicrite wackestone) is intercalated with calcareous siltstone (figure 3.8). The sandy limestone layers are 2 m to 3 m thick, while calcareous siltstone forms layers from 0.1 m to 0.5 m thickness. From 446 m to 490 m, fauna is scare and consist of bivalves, sponge spicules, calcispheres and possible calpionellids. Upsection, between 490 m and 539 m, ammonoids and fragments of bivalves are more abundant and accompanied by scare sponge spicules, fragments of echinoderms, calcispheres and rare foraminifers.

An unfossiliferous volcanic breccia with angular clasts of silty limestone overlies the Lo Valdés Formation with a visible thickness of 100 m (figure 3.5 - 3.8). This unit was previously defined as part of the Lo Valdés Formation (Gonzalez 1963, Biro 1964), but is here considered a separate lithological unit, independent from the Lo Valdés Formation, It is here referred to as the “Rio Volcán Volcanoclastic Unit”.

In the Figure 3.9, is the column complete of Lo valdés Formation is the Type Locality with the three members integrated, structure, fossil content and the contact relationship with the lower and upper unit that is in contact.

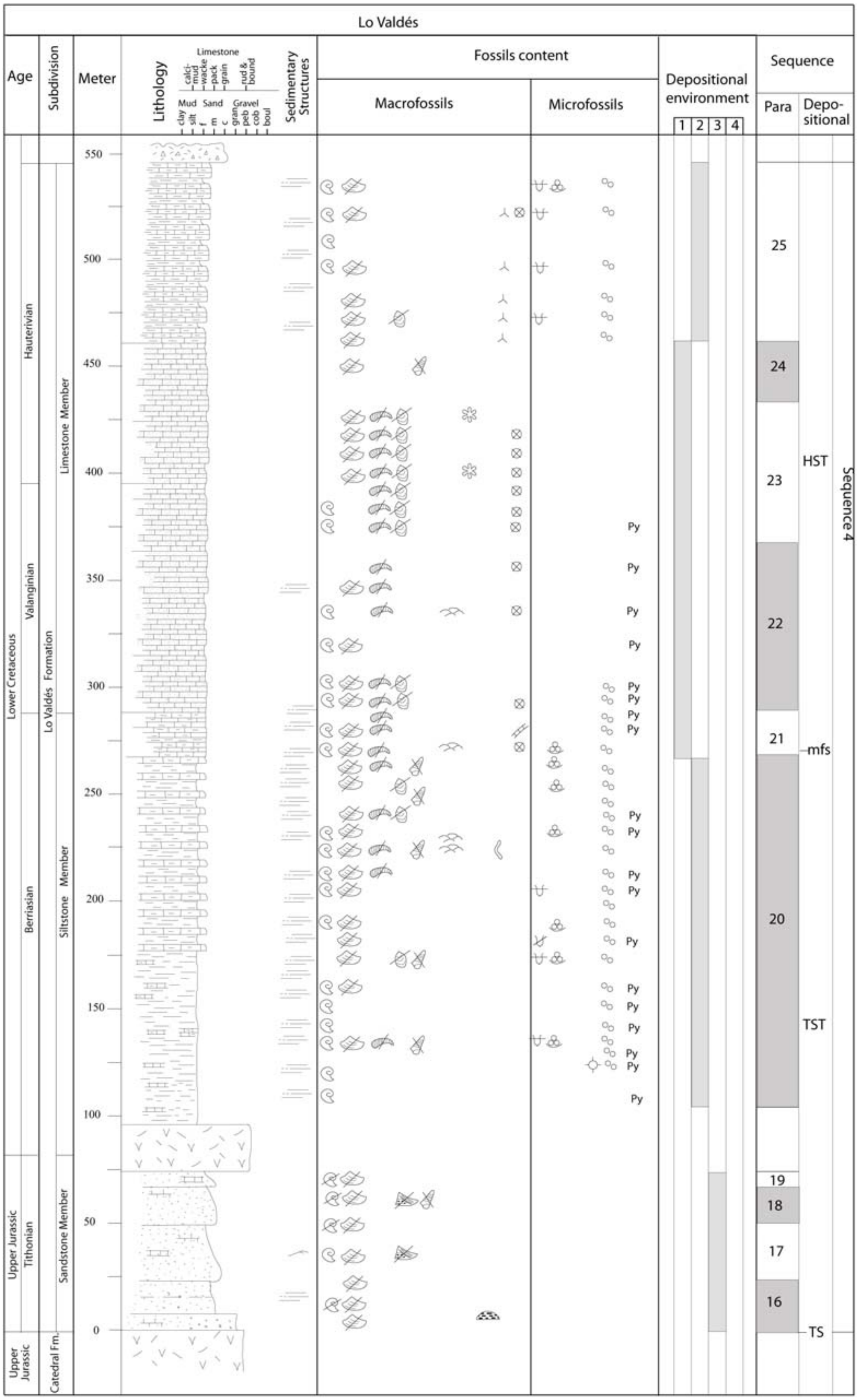


Figure 3.9. Column of the Lo Valdés Formation at Lo Valdés (Type Locality), with differentiation of lithological members. V.U.: Volcanic Unit.

3.2.2 Cajón del Morado section

At Cajón del Morado, the Lo Valdés formation is exposed on the eastern hillside of the Cajón del Morado valley, approximately 6 km North of the village of Baños Morales (figure 1.1). A section in the Cajón del Morado Valley (70°01`50``W and 33°46`39``S) is here proposed as a paratype locality of the Lo Valdés Formation. It is 582 meters thick. Here are distinguished three units (from base to top): Sandstone Member, Siltstone Member and Limestone Member (figure 3.10 - 3.14).

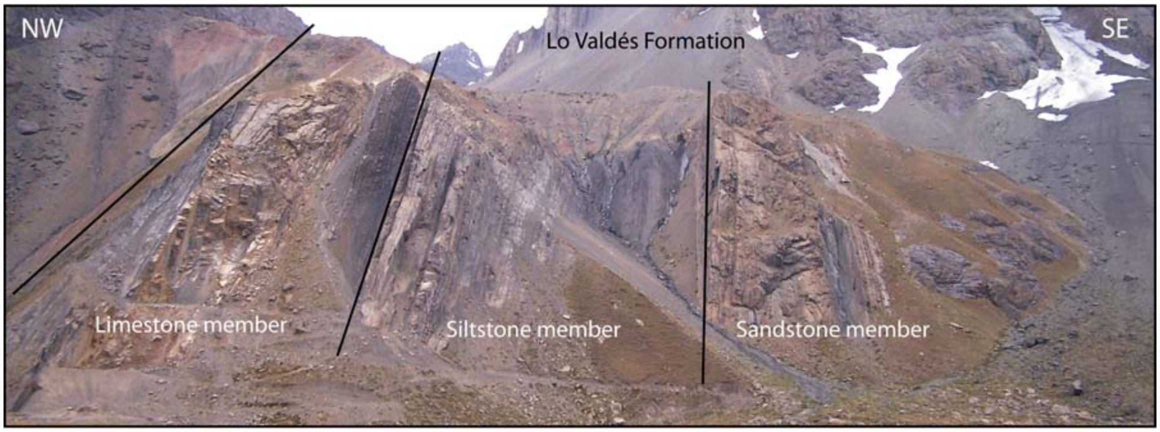


Figure 3.10. Cross section of the Lo Valdés Formation at Cajón del Morado.

Sandstone Member

The Sandstone Member is 160 m thick and overlies the Andesite member with a sharp and possibly disconformous contact. The lowermost unit, is 10.6 m thick, consists of cross-laminated calcareous sandstone with fragments of bivalves and gastropods. At 6 m, a 2.5 m thick sandy limestone (biomicritic wackestone) contains abundant fragments of oysters and other bivalves as well as gastropods (figure 3.11).

Upsection, between 10.6 m and 35 m of section, sandy limestone and calcareous sandstone are present. The lower part of the unit, between 10.6 m and 18 m, consists of rhythmically bedded sandy limestone (biomicritic wackestone) forming layers of 0.7 m thickness and calcareous sandstone of 0.3 m thickness. These sediments contain some fragments of bivalves and gastropods, scare algae, sponges and corals (Faceloide, family Placocoeniidae). At 18 m, a 2 m thick coarse-grained calcareous sandstone is intercalated. Above this sandstone, a 0.8 m thick limestone is present that contains abundant corals identified as *Cladophyllia qiebulaensis* (Liao 1982). Upsection, between 20.8 m to 35 m, a 5.2 m-thick sandy limestone (biomicritic packstone) contain scare ooids. It underlies 4 m of calcareous sandstone and 6 m of sandy limestone (biomicritic wackestone) with abundant ammonoids, bivalve fragments and scare algae (figure 3.11).

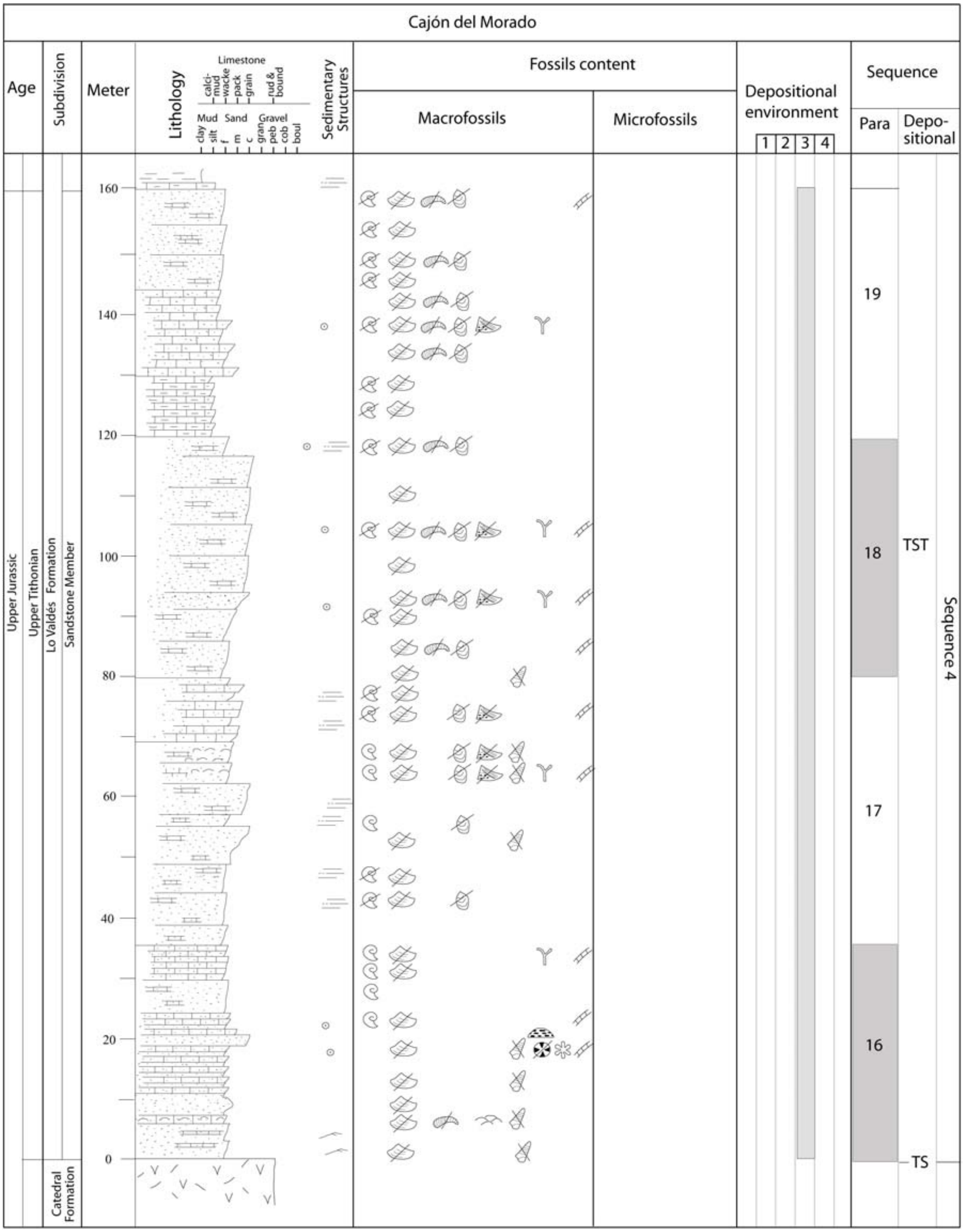


Figure 3.11 Detail of Sandstone member of Lo Valdés Formation at Cajón del Morado section.

Between 35 m and 61.5 m of the section, horizontally laminated calcareous sandstone contains ammonoids, inoceramids and other bivalves as well as rare gastropods (figure 3.11).

At 61.5 m, a 6.5 m thick calcareous sandstone is interlayered with three fossiliferous levels, each 15 cm thick with abundant ammonoids, inoceramids and other bivalves, scare gastropods, bryozoans and algae.

From 68 m to 84 m, sandy limestone (biomicritic packstone) with horizontal lamination contains ammonoids, fragments of inoceramids, trigoniids and other bivalves as well as algae (figure 3.11).

A 36 m thick unit of calcareous sandstone is present between 84 m and 120 m section. In the lower part (86 m to 109 m) we determinated fragments of ammonoids, oysters, inoceramids, trigoniids and other bivalves, as well as rare bryozoans and algae. Occasional ooids are also present. The upper 10 m of the unit, between 110 m and 120 m, is characterized by horizontal lamination. It contains ooids, fragments of ammonoids, oysters, inoceramids and others bivalves (figure 3.11).

At 120 m, a 9 m thick unit of silty limestone (biomicrite calci-mudstone) contains scare fragments of ammonoids and bivalves.

Between 129 m and 144 m section, a 15 m thick interval of sandy limestone (oomicritic packstone and biomicritic wackestone) forms 0.1 m to 0.2 m thick layers. This unit contains scare ammonoids, rare fragments of oysters, inoceramids, trigoniids, other bivalves and bryozoans (e.g. at 138 m).

The uppermost unit of the sandstone member, between 144 m and 160 m section, is 16 m thick and consists of calcareous sandstone. The fauna consists of scare fragments of ammonoids, oysters, inoceramids and other bivalves. Rare fragments of algae are registered in the topmost layers (figure 3.11).

Siltstone Member

The siltstone member is 217 m thick (160 to 376 m of section) and composed of siltstone, calcareous siltstone and silty limestone (figure 3.12).

The lowermost unit, between 160 m and 174 m of section, is 14 m thick and consists of calcareous siltstone and silty limestone (biomicrite of wackestone and packstone) with a high content in organic matter. It forms layers of 0.3 m to 0.7 m thickness and contains scare ammonoids, oysters and other bivalves, rare fragments of gastropods and echinoderms (figure 3.12).

Upsection, from 174 m and 273 m of section, a 99 m thick unit consists of rhythmically bedded layers of siltstone and calcareous siltstone, with abundant content of organic matter (figure 3.12). The lower 82 m of this unit, between 174 m to 256 m of section, consist of rhythmically layered siltstone and calcareous siltstone with predominantly horizontal lamination. Individual layers of siltstone are between 1.5 m and 2 m thick, whereas interlayered calcareous siltstone forms beds of 0.05 m to 0.08 m thickness (figure 3.12). The interval between 174 m and 214 m of section is relatively rich in ammonoids and calcispheres, and also contains scare fragments of inoceramids and other bivalves, as well as rare gastropods, algae and benthic foraminifers. Several layers contain disseminated pyrite. From 214 m to 235 m, we detected abundant ammonoids and calcispheres, some fragments of oysters and other bivalves, rare sponge spicules, radiolarians, foraminifers and rare possible calpionellids (figure 3.12). Between 235 m and 256 m of section, the fauna consists in scare fragments of inoceramids, other bivalves, abundant calcispheres, rare foraminifers and possible calpionellids. Between 256 m and 263 m, the content of calcareous siltstone gradually increases and ammonoids are dominant faunal elements, accompanied by common inoceramids and other bivalves. In addition, a two centimetre-thick level with abundant oysters was identified at 257 m of section. Upsection, between 263 m to 273 m section, a 9 m thick calcareous siltstone is present with interlayered thin-bedded (0.03 m to 0.15 m) siltstone which contains bivalves and calcispheres (figure 3.12).

Between 273 m and 281 m, an 8 metre thick unit of silty limestone (biomicrite, calci-mudstone and wackstone) contains abundant ammonoids, oysters, and other bivalves as well as rare radiolarians and annelids in the upper part. The unit also contains two layers rich in oyster of 4 m (between 274 m and 278) and 1 m (between 280 m and 281 m) thickness.

From 281 m to 286 m section, a 5 m thick unit of alternating silty limestone and calcareous siltstone consists of layers, each between 0.9 m and 1.2 m thick with horizontal lamination and an increased content in organic matter. Ammonoids are abundant, oysters and other bivalves are scare.

The unit underlies 11 m of calcareous siltstone, between 286 and 297 m of section, with a 2 m thick horizontally laminated limestone (biomicrite-wackestone) interlayered between 290 m and 292 m. The faunal assemblage consists in ammonoids, scare fragments of oysters, inoceramids,

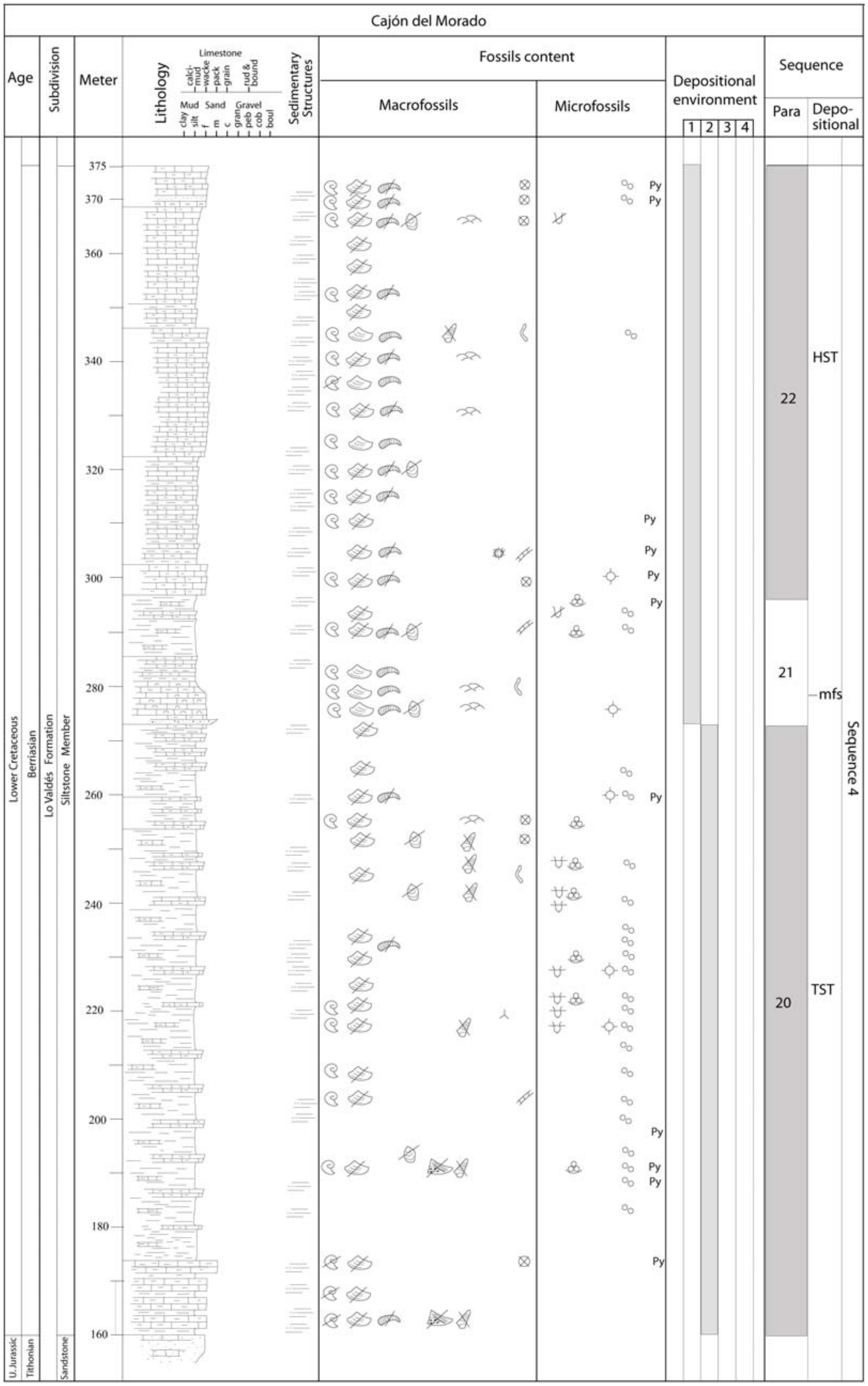


Figure 3.12. Detail of Siltstone member of Lo Valdés Formation at Cajón del Morado section.

rare algae, foraminifers and possible calpionellids. The unit also contains abundant calcispheres, disseminated pyrite and organic matter (figure 3.12).

Silty limestone (biomicritic wackestone) with horizontal lamination is present between 297 m and 301.9 m section. It is interlayered with 0.1 m to 0.15 m thick layers of calcareous siltstone with disseminated pyrite and organic matter, as well as ammonoids; fragments of oysters, rare echinoderms and radiolarians.

Between 301.9 m and 305 m, a 3.1 m thick unit of silty limestone (biomicrite, calci-mudstone) and calcareous siltstone consists of rhythmically bedded 0.1 m to 0.2 m thick layers with horizontal lamination. The fauna consists of scare fragments of bivalves, and rare algae (figure 3.12).

Upsection, between 305 m and 323 m section, silty limestone (biomicrite, calci-mudstone) interlayers with calcareous siltstone. Thickness of individual layers reaches 0.4 m in the silty limestone and 0.08 m in the calcareous siltstone. Horizontal lamination, disseminated pyrite and organic matter are common and the faunal assemblage includes abundant ammonoids, scare fragments of oysters and other bivalves. Between 317 m and 319.5 m, a 2.5 m thick limestone (biomicrite, calci-mudstone) is present (figure 3.12).

Between 323 m and 345 m, a 22 m thick silty-limestone (biomicrite wackestone) interlayers with calcareous siltstone. Two limestone intervals (biomicrite, wackestone) are present within this unit from 331 m to 333.7 m (2.7 m thick) and from 341 m to 343.5 m (2.5 m thick). A 0.2 m thick layer of calcareous siltstone is present between 333.2 m and 333.4 m (figure 3.12) and contains some ammonoids, scare fragments of oysters and other bivalves. In the uppermost metres of the unit (341 m to 345 m), ammonoids and bivalves (e.g. oysters) increase in abundance and diversity but annelids and calcispheres are also present. Layers rich in oyster were detected at 330.7 m (0.15 m thick) and at 341 m (0.5 m thick).

Between 345 m to 376 m section, silty limestone (biomicrite calci-mudstone) forms layers of 1.5 m to 2 m thickness and is intercalated with 0.4 m to 0.5 m thick beds of calcareous siltstone and calcareous sandstone (figure 3.12). From 345 m to 353 m, an 8 m thick unit of silty limestone (biomicrite calci-mudstone) and calcareous siltstone present rhythmically bedding and layers of 0.4 m to 0.5 m thickness; these sediments contain some fragments of bivalves. From 353 m to 369 m, a 16 m thick silty limestone (biomicrite calci-mudstone) is horizontally laminated and contains rare fragments of bivalves. A 2m thick limestone is intercalated at 361 m. Between 367 m to 368 m faunal abundance and diversity increase. We detected abundant ammonoids, oysters and inoceramids, scare fragments of echinoderms and possible calpionellids. At 369 m, a 1 m thick layer rich in oyster is interlayered in silty limestone (biomicrite wackestone) with abundant ammonoids; it overlies a 1 m thick unfossiliferous calcareous sandstone (figure 3.12).

The top of the member is characterised by a 5 m thick (371 m and 376 m) horizontally laminated silty limestone (biomicrite wackestone) with disseminated pyrite and organic matter, abundant calcispheres, scare fragments of ammonoids, oysters and rare fragments of echinoderms (figure 3.12).

The contact between the Siltstone Member and overlying Limestone Member is gradual, and characterized by an increase in carbonate content.

Limestone Member

Between 376 m and 582 m, the section predominantly consists of limestone (calci-mudstone and wackestone) interlayered with silty limestone and calcareous siltstone. This unit of 206 m thickness is described here as the Limestone Member (figure 3.13).

The base of the unit, between 376 m and 394 m section, is characterised by a rhythmically-bedded sequence of silty limestone (biomicrite, calci-mudstone) forming 1.5 m thick layers and calcareous siltstone forming 0.5 m thick beds (figure 3.13). This interval contains ammonoids, common fragments of oysters and other bivalves and rare annelids, echinoderms and pentacrinoids.

Between 394 m and 412 m section, silty limestone of varying thickness is interlayered with calcareous siltstone (figure 3.13). From 394 m to 396 m section, a 2 m thick silty limestone (biomicritic wackestone) with horizontal lamination contains disseminated pyrite as well as ammonoids and oysters. A 2 m thick oyster biostrome overlies this silty limestone from 396 m to 398 m. Between 398 m to 406 m, silty limestone (biomicritic wackestone) forms layers of 0.9 m to 1.2 m thickness and interlayers with horizontally laminated calcareous siltstone with rare bivalves. From 406 m to 408 m, a 2 m thick oyster-rich unit also contains ammonoids, rare annelids and disseminated pyrite. Between 408 m and 412 m section, a 4 m thick silty limestone (biomicritic wackestone) is intercalated with three layers of calcareous siltstone forming layers of 0.3 m to 0.4 m thickness. The faunal assemblage consists of rare ammonoids, bivalves and echinoderms.

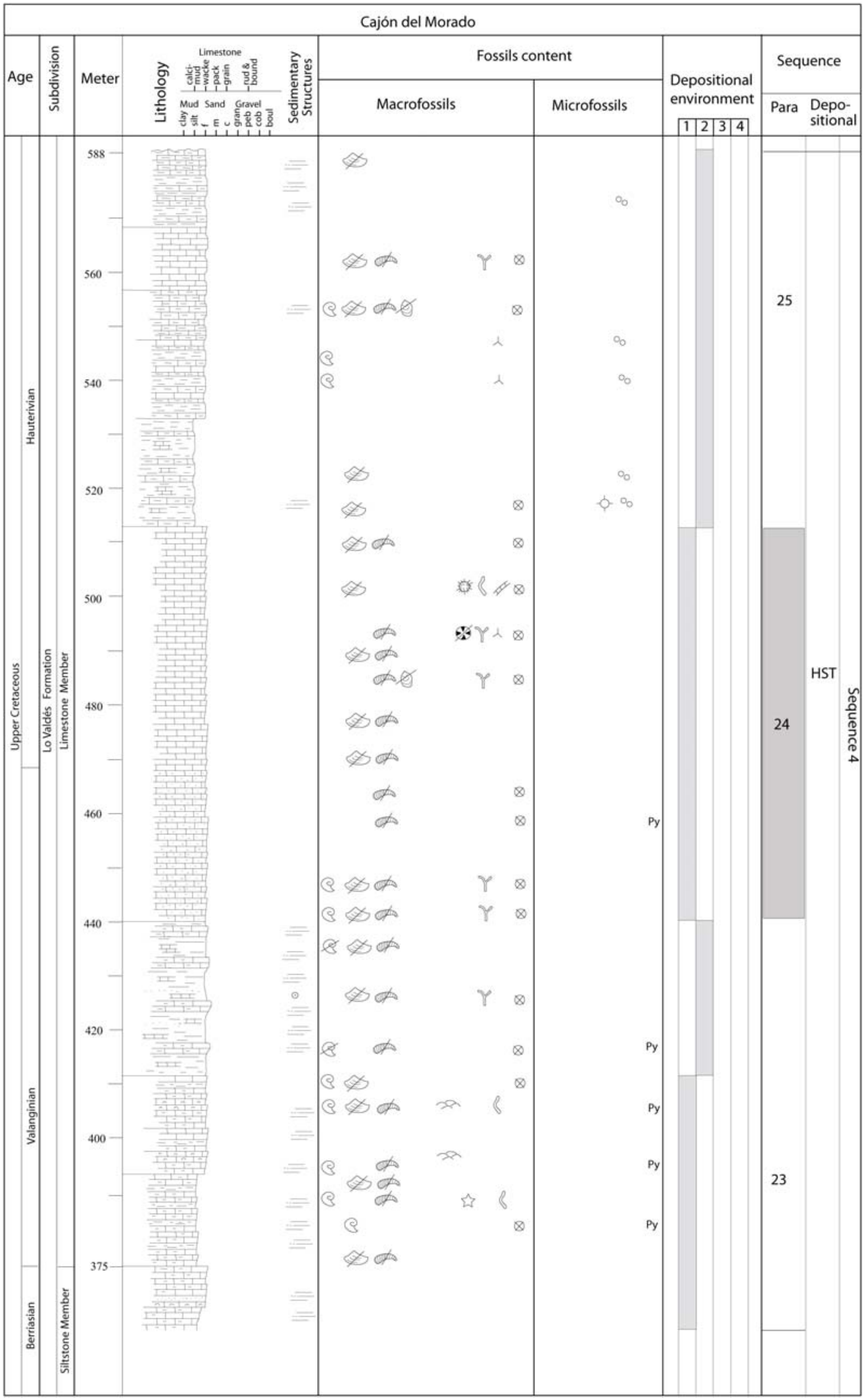


Figure 3.13. Detail of Limestone member of Lo Valdés Formation at Cajón del Morado section.

The interval between 412 m and 441 m is not well exposed. It consists of calcareous sandstone of variable thickness and interlayers of silty limestone (wackestone, bio-intramicrite, bio-intrasparite and biomicrite) and centimetre-thick calcareous sandstone (figure 3.13). The fauna consists of scare ammonoids, bivalves, oysters, rare bryozoans and echinoderms.

Upsection (441 m to 513 m), a 72 m thick monotonous limestone unit is present (wackstone, bio-intrasparite, biosparite, biomicrite, and bio-intramicrite; figure 3.13). In the lower part of the unit (441 m to 454 m), the fauna consists of scare ammonoids, scare fragments of oysters, rare echinoderms and bryozoans. Faunal abundance decreases in the middle part of the unit (454 m to 483 m). We detected rare oysters and echinoderms; disseminated pyrite is also present. Faunal abundance increases in the upper part of the unit (483 m to 513 m). Fragments of oysters and inoceramids are present, as well as a few layers with abundant corals, echinoids, bryozoans, annelids, algae and sponge spicules (figure 3.13).

From 513 m to 547 m, calcareous siltstone of varying thickness interlayers with silty limestone and limestone (figure 3.13). The lower 20 m, from 513 m to 533 m are characterised by calcareous siltstone forming layers from 2 m to 4 m thickness. They are interlayered with silty limestone (biomicrite calci-mudstone) forming layers between 0.9 m to 1.1 m thick. The interval between 513 m and 523 m contains rare fragments of bivalves, echinoderms, calcispheres and radiolarians. Sediment between 523 m and 533 m is unfossiliferous. Upsection, between 533 m and 547 m, a 14 m thick monotonous unit consists of alternating 1 m to 2.5 m thick calcareous siltstone and silty limestone (biomicritic wackestone) and rare layers of limestone (biomicrite, wackestone). Layers of silty limestone and limestone are between 0.5 m and 1 m thick. The faunal assemblage consists of ammonoids, abundant sponge spicules and calcispheres.

From 547 m to 557 m, a horizontally laminated silty limestone (bio-intramicritic wackestone) contains ammonoids, fragments of oysters, inoceramids, other bivalves and echinoderms (fgure 3.13). From 557 m to 568.5 m, an 11.5 m thick limestone (biomicritic wackestone) presents a fossil assemblage of low diversity, principally oysters, scare fragments of bryozoans and echinoderms. Between 568.5 m and 582 m, silty limestone interlayers with calcareous siltstone forming units of 1 m to 2.5 m thickness (figure 3.13). Layers of silty limestone increase in thickness upsection and reach individual thicknesses of 1 m to 5 m; fossils are scare in this interval and only consist of bivalves. The contact with the overlying unit is not exposed.

In the figure 3.14, show in the general column of Cajón del Morado section with the three members, sedimentary structure, fossil content and contact relation in the bottom and top of the column.

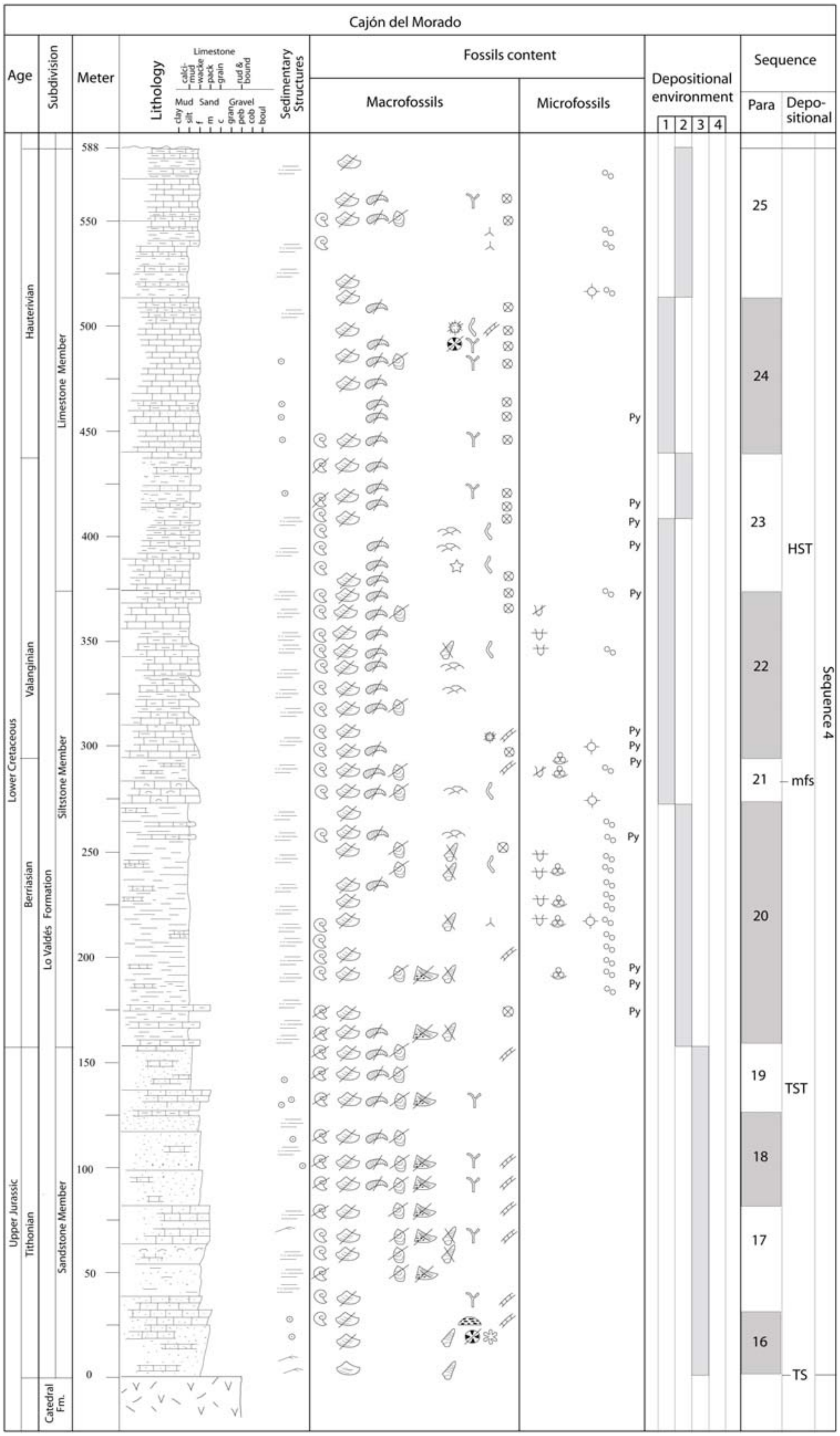


Figure 3.14. Column of the Lo Valdés Formation at Cajón del Morado, with the lithological members.

3.2.3 Cruz de Piedra section

Sections in the Cruz de Piedra area were first documented by Corvalán (1956) as Tithonian to Neocomian in age. Klohn (1960) and Charrier (1981a) assigned them to the Baños del Flaco Formation, based on the predominantly siliciclastic character of the sequence and the faunal assemblage. However, our survey on the Jurassic-Cretaceous sediment sequence in Central Chile leads us to conclude that these sediments rather correspond to lithologies known as the Lo Valdés Formation (see below).

The Cruz de Piedra section is 150 m thick and located in the Cruz de Piedra creek (69°56`25``W and 34°14`40``S), approximately 9 km southeast of the Chilean Police Border Station “Avanzada Cruz de Piedra” (figure 1.1). The section encompasses the Sandstone and Siltstone members of the Lo Valdés Formation (figure 3.15-3.16).

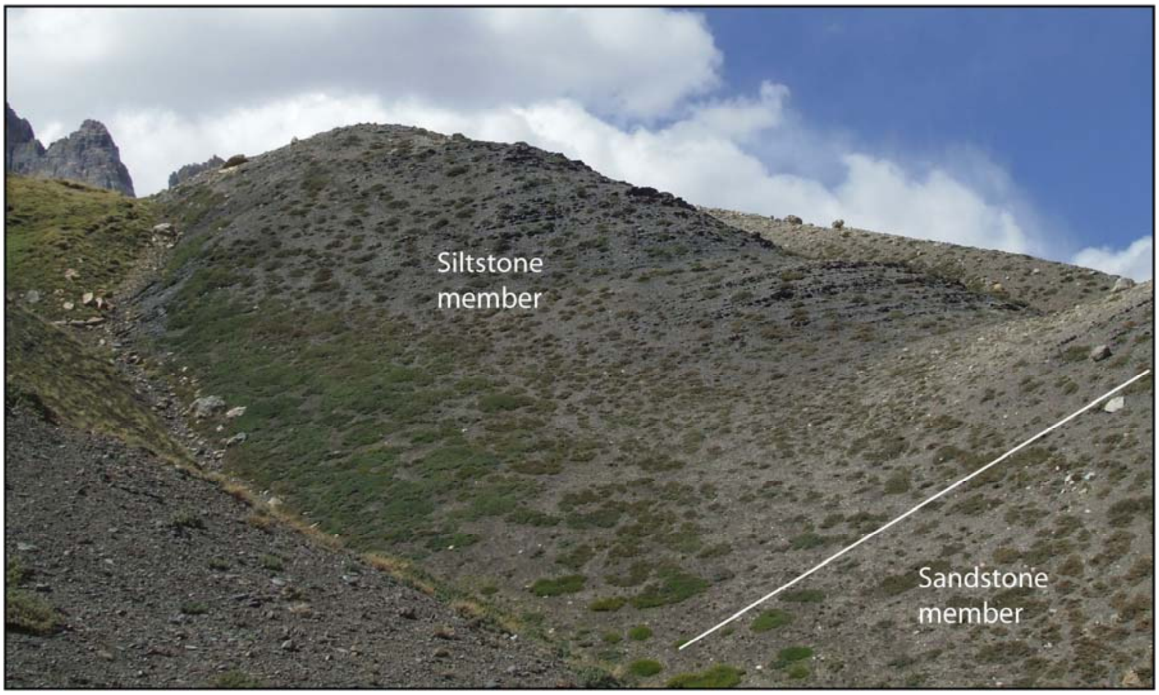


Figure 3.15. Cross section of the Lo Valdés Formation at Cruz de Piedra section.

Sandstone Member

The sandstone member is 50 m thick; its lower contact is conformous with the Rio Damas Formation; no andesite is present. The Sandstone Member consists of monotonous fine-grained calcareous sandstone with a few centimetre thick layers of coarse calcareous sandstone (figure 3.15 - 3.16). The unit is unfossiliferous.

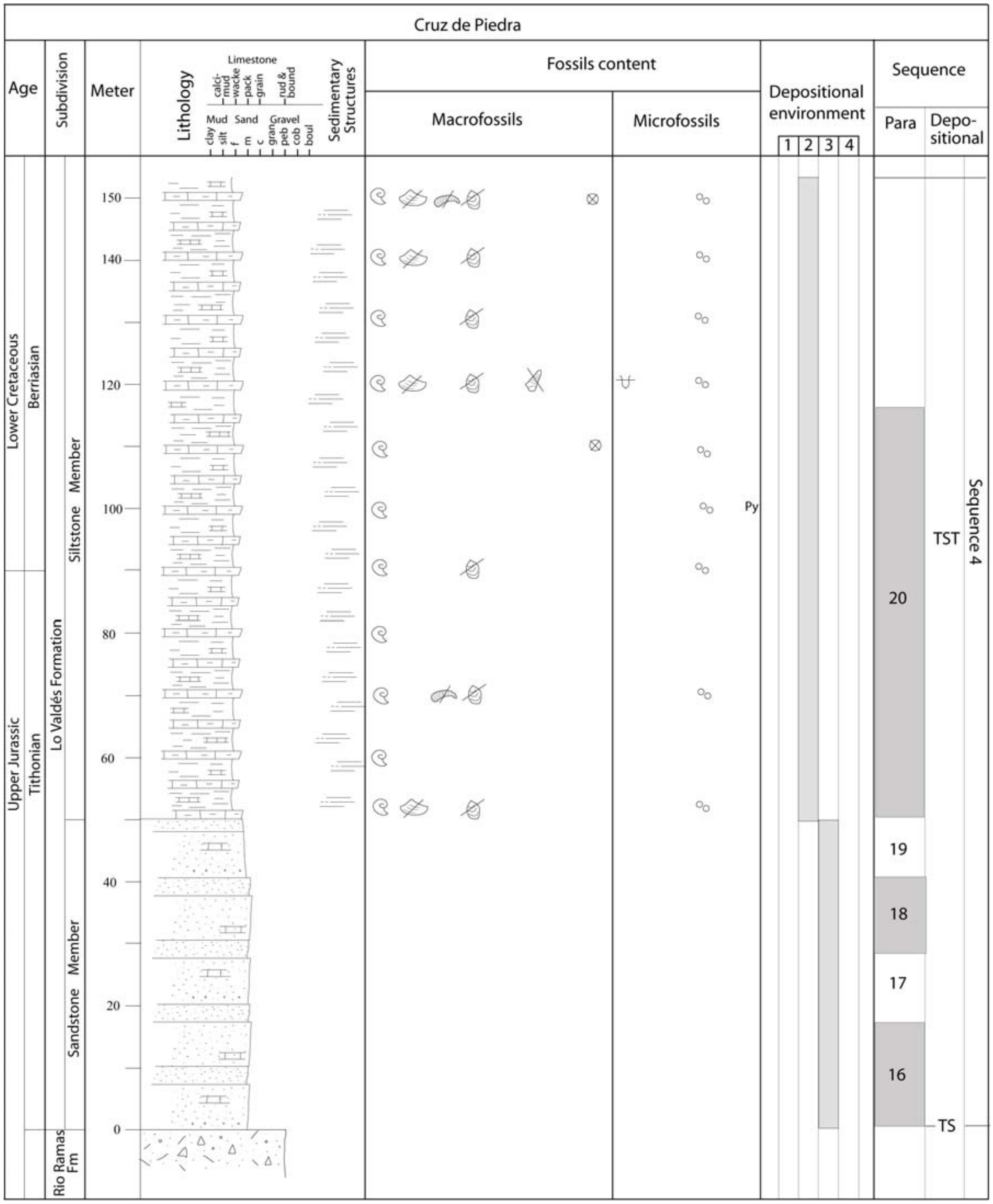


Figure 3.16. Column of the Lo Valdés Formation at Cruz de Piedra section, with differentiation of lithological members.

Siltstone Member

The visible thickness of the siltstone member is approximately 100 m. It consists of rhythmically bedded layers of calcareous siltstone and silty limestone with horizontal lamination and high concentrations in organic matter (figure 3.15-3.16). Individual layers of calcareous siltstone are between 3 m and 4 m thick, whereas silty limestone (biomicrite wackestone) is interlayered forming beds of 1 m to 2 m thickness. Ammonoids and calcispheres are abundant, but oysters, inoceramids and other bivalves, gastropods and echinoderms and radiolarians are also present. The upper limit of this member is not exposed due to overlying Holocene sediments.

3.3 Baños del Flaco Formation

3.3.1 Baños del Flaco section

The Baños del Flaco section is 369 m thick and located on the southern hillside of the Tinguiririca Valley close the Baños del Flaco village (figure 1.1).

The lower member of the Baños del Flaco Formation is 191 m thick and consists of conglomerate, limestone and calcareous sandstone. The upper member is 178 m thick and consists of siltstone, calcareous sandstone and sandy limestone (figure 3.17-3.20).

Figure 3.17. Cross section of the Baños del Flaco Formation at Baños del Flaco (Type Locality).

Lower Member

The lower contact of this member is conformous with the Rio Damas Formation. The basal 50 m is an unfossiliferous conglomerate (figure 3.18). Clasts consist of volcanic rocks, feldspars and

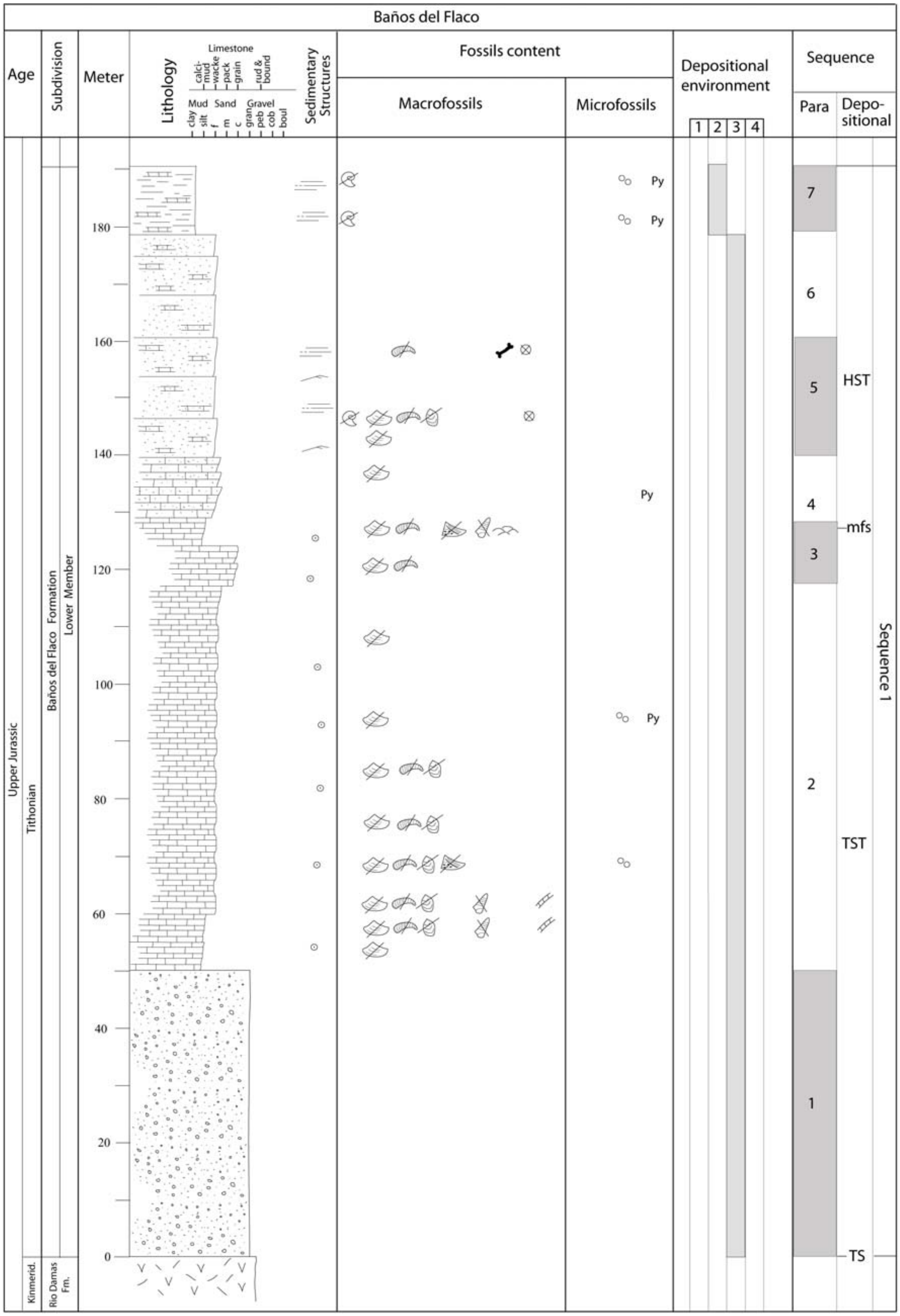


Figure 3.18. Detail of Lower member of Baños del Flaco Formation at Baños del Flaco section.

quartz; they are between 2 mm and 4 cm in diameter and well sorted, subangular to subrounded. The matrix is fine-grained and contains glauconite.

Upsection, from 50 m to 60 m, calci-mudstone (biomicrite) contains occasional ooids as well as oysters, inoceramids and other bivalves, algae and calcispheres.

Upsection, a wackestone (biomicrite) unit is present between 60 m and 118 m, and contains disseminated pyrite and occasionally ooids as well as fragments of oysters, inoceramids, scare trigoniids and other bivalves, gastropods, echinoderms and calcispheres (figure 3.18). Faunal contents decreases to the top of the unit and only a few bivalves were identified in these layers.

At 118 m, this unit underlies a 6 m thick grainstone with occasional ooids, fragments of oysters and other bivalves.

From 124 m to 129 m, calci-mudstone (biosparite) is present and contains occasionally ooids, scare oysters, trigoniids and other bivalves as well as, gastropods. Several layers are rich in oysters (consist of oyster biostromes) (figure 3.18).

Upsection, between 129 m to 140 m, an 11 m thick unit of sandy wackestone contains few fragments of bivalves and disseminated pyrite.

The uppermost unit, from 140 m to 179 m, consists of calcareous sandstone (figure 3.18). The lower 20 m of this unit are cross- and horizontally laminated and contain fragments of ammonoids and bivalves, scare fragments of oysters, inoceramids, other bivalves and echinoderms. At 158 m, vertebrate fragments were recovered from a cm-thick layer. An unfossiliferous calcareous sandstone unit is present between 160 m and 179 m. The upper part of the unit is 12 m thick and consists of horizontally laminated siltstone with disseminated pyrite and rare ammonoids and calcispheres (figure 3.18).

Upper Member

The Upper Member of the Baños del Flaco section is 178 m thick (figure 3.19). The basal unit, between 191 m to 255 m, is 64 m thick, consists of calcareous sandstone and also contains calcareous sandstone concretions (figure 3.19). Fossils are rare in the lower part of the unit, between 191 m and 225 m, and only a few fragmented bivalves were identified. Upsection, from 225 m to 255 m section, fossils increase in abundance and oysters, inoceramids and other bivalves, as well as algae are present and the sediment also contains disseminated pyrite.

At 255 m, an 11 m thick unit of calcareous siltstone contains scare inoceramids, other bivalves, algae and calcispheres (figure 3.19).

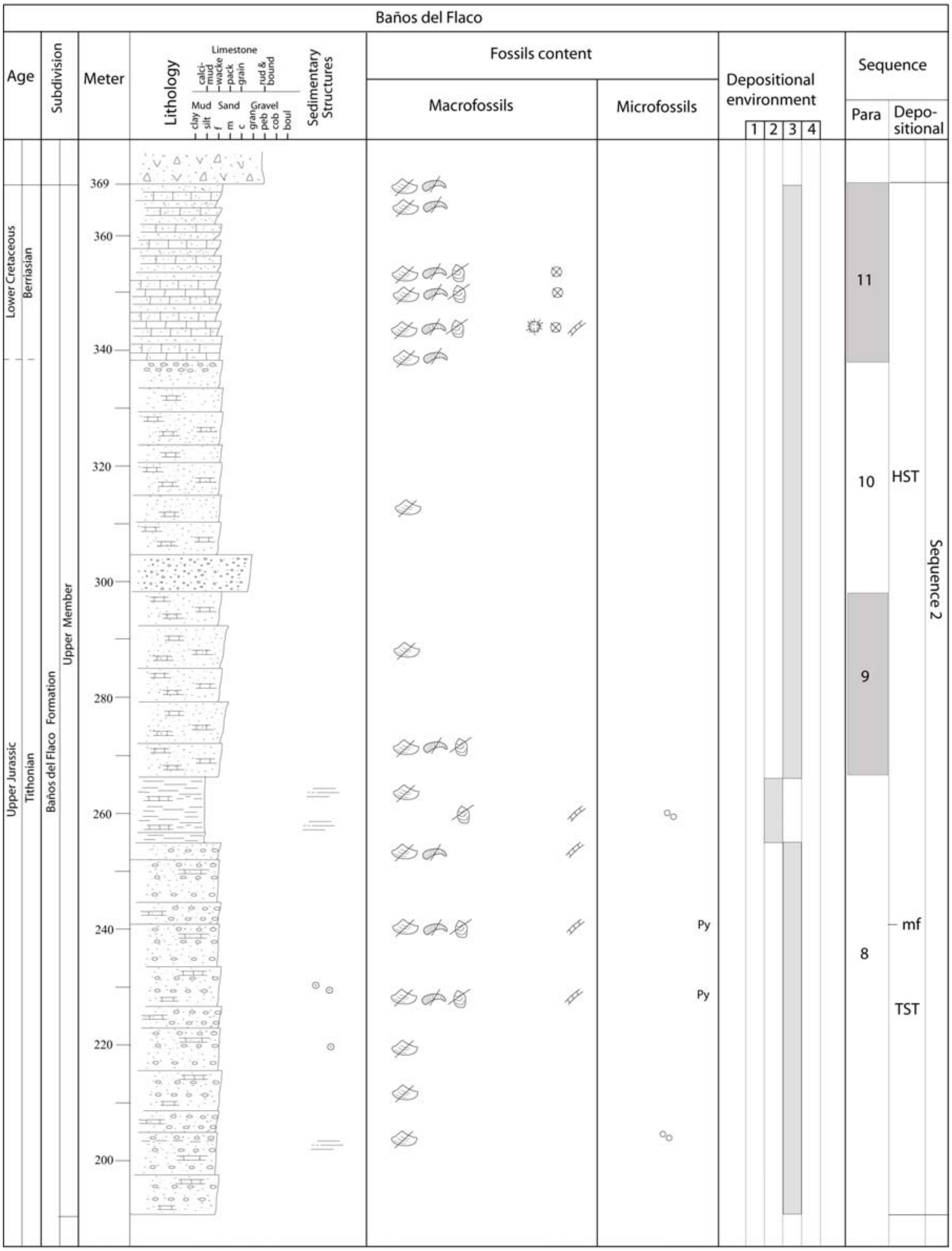


Figure 3.19. Detail of Upper member of Baños del Flaco Formation at Baños del Flaco section.

From 266 m to 338 m, a 72 m unit of calcareous sandstone is intercalated by 6 m of microconglomerate (299 m). The interval between 298 m and 303 m contains scare oysters, inoceramids and other bivalves. Sediments between 303 m to 338 m are unfossiliferous (figure 3.19).

Upsection, from 338 m to 354 m, calcareous sandstone and sandstone form 0.3 m to 1.8 m thick layers which contain oysters, inoceramids, other bivalves, scare echinoids and algae (figure 3.19).

Between 354 m and 369 m, interlayered calcareous sandstone and sandy limestone forms the uppermost unit of the Upper Member. These sediments only contain oysters and other bivalves (figure 3.19).

An abrupt and disconformous contact separates the Upper Member from a volcanoclastic sequence (e.g. sandstone, ash layers and conglomerate with abundant volcanics rock clasts) known as “Brownish-red Clastic Unit – BRCU” (Charrier et al. 1996).

The figure 3.20, show the general column of Baños del Flaco Formation at Baños del Flaco section, with the two member, sedimentary structure, fossil content and contact relationship.

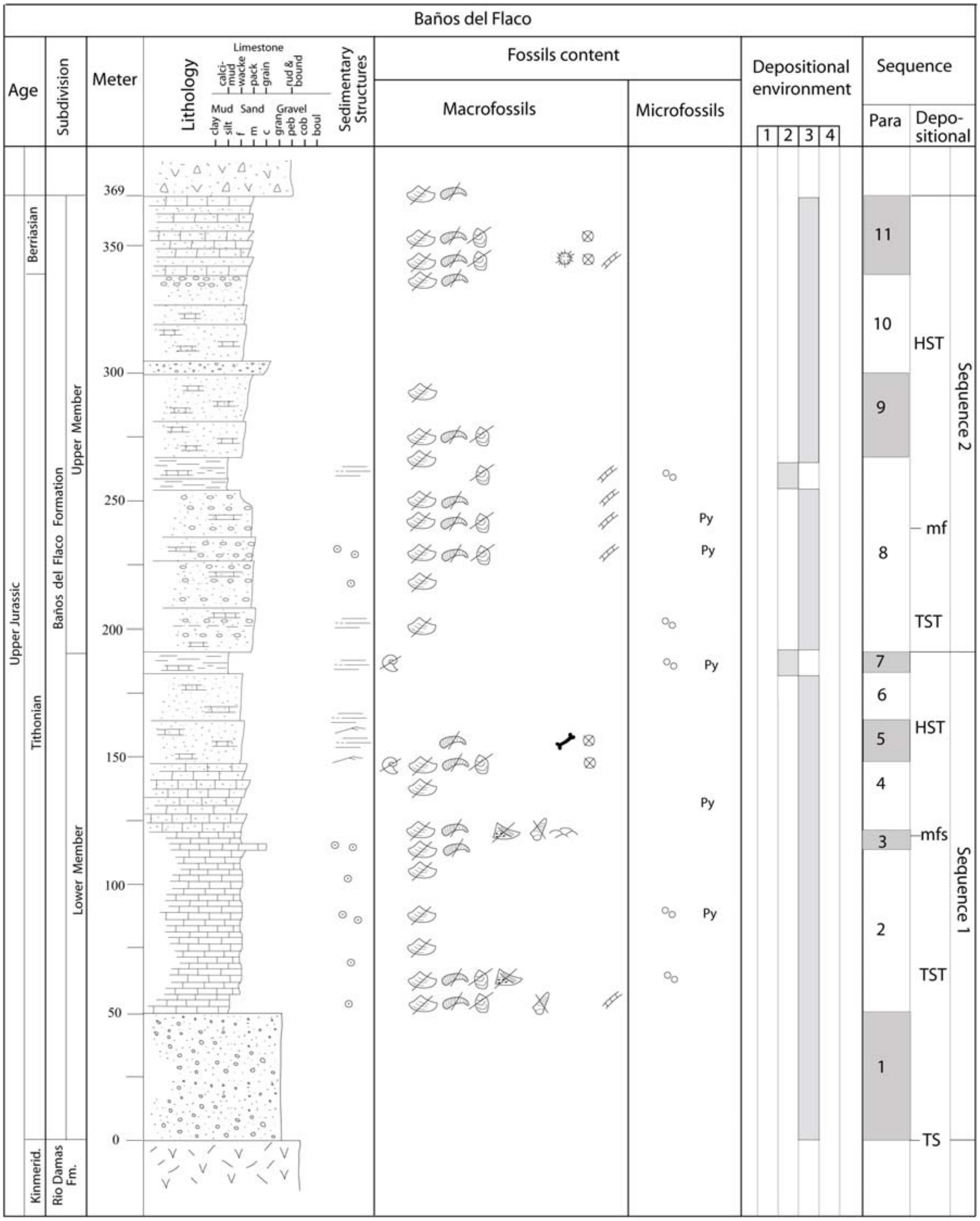


Figure 3.20. Column of the Baños del Flaco Formation at Baños del Flaco (Type Locality), with differentiation of lithological members.

3.3.2 Rio Maitenes section

The Rio Maitenes section located approximately 30 km east of Los Queñes village, is exposed along the northern hillside of the Rio Teno Valley, between Maitenes River and Portezuelo el Fierro, at the Mina del Fierro (figure 1.1). The thickness of the Baños del Flaco Formation is 536 m thick and consists of two members (figure 3.21 - 3.24). The lower member is 344 m thick and consists of conglomerate, limestone and calcareous sandstone. The upper member is 192 m thick and composed of siltstone, calcareous sandstone and sandy limestone.

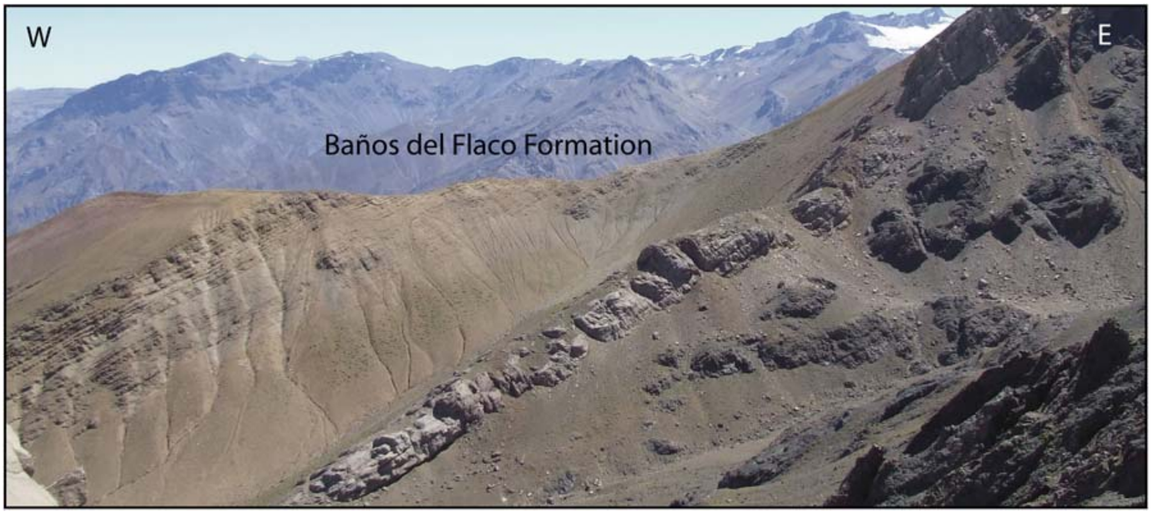


Figure 3.21. Cross section of the Baños del Flaco Formation at Rio Maitenes.

Lower Member

The contact with the underlying Rio Damas Formation is conformous. The base is formed by a 50 m thick unit of unfossiliferous conglomerate (figure 3.22), containing clasts of volcanics rocks, feldspars and quartz. They are up to 4 cm in diameter and subangular to subrounded and well sorted. The matrix is fine-grained and contains glauconite.

Upsection, between 50 m to 103 m of section, calcareous sandstone and sandy limestone are interlayered (figure 3.22). Between 50 m to 73 m, layers are between 0.15 m and 2.7 m thick and contain ammonoids, scare oysters, trigoniids and others bivalves, gastropods and corals. At 73 m, a 15 m thick coarse-grained calcareous sandstone is intercalated by two layers of 0.3 m and 2 m thickness of sandy limestone (wackestone) with oysters, inoceramids, trigoniids and others bivalves as well as gastropods (figure 3.22). Between 88 m and 103 m, the sediment sequence consists of 4 m of coarse calcareous sandstone, 6.2 m of fossiliferous limestone (wackestone), 2.3

m of medium-grained calcareous sandstone, 1.4 m of fossiliferous limestone (wackestone) and 0.7 m of coarse-grained calcareous sandstone (figure 3.22). The unit contains oysters, inoceramids, trigonids, others bivalves and gastropods.

A 21 m thick unit of limestone (grainstone) is present between 103 m and 124 m section and contains oysters, inoceramids, trigoniids, others bivalves and gastropods (figure 3.22).

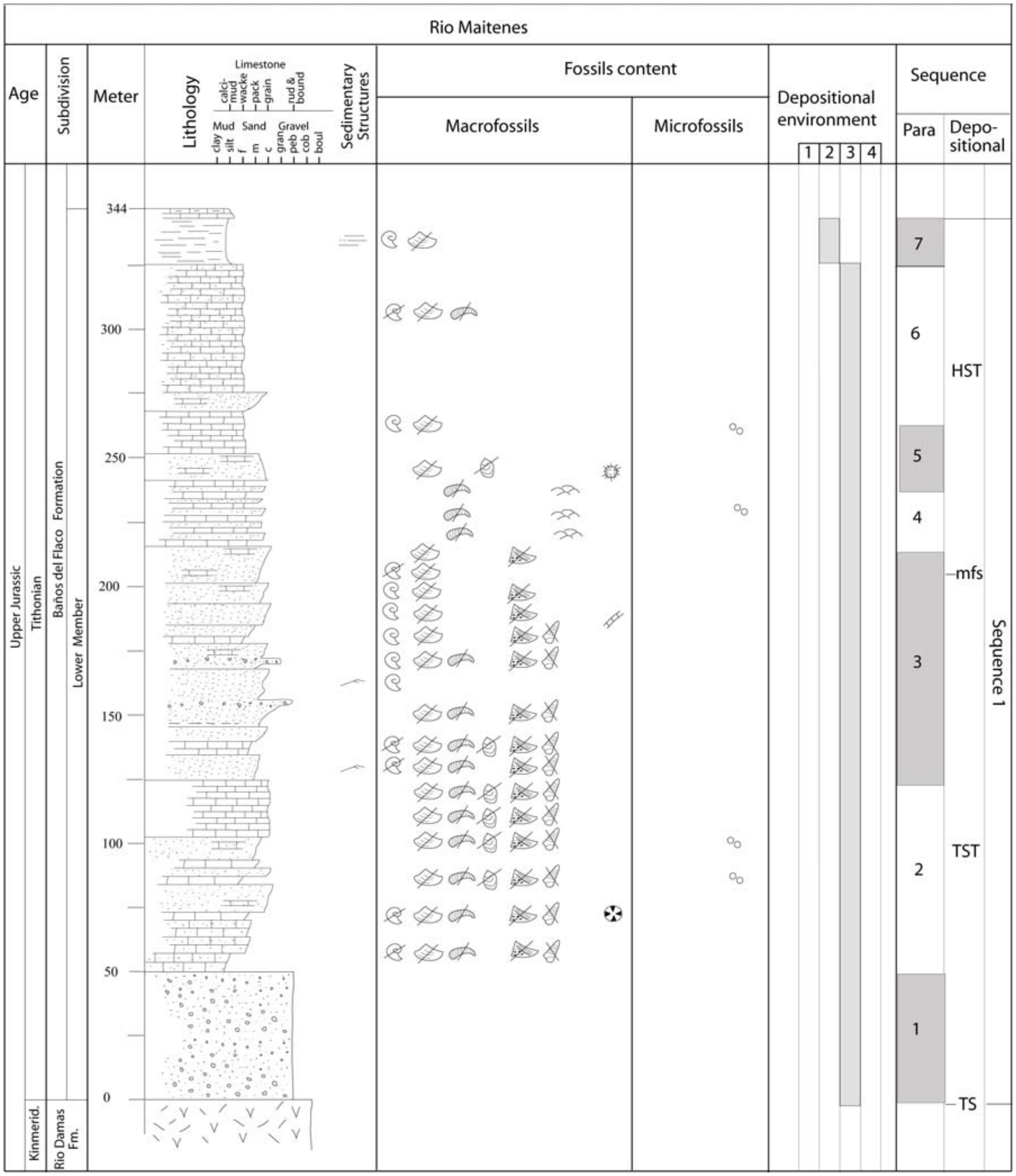


Figure 3.22. Detail of Lower member of Baños del Flaco Formation at at Rio Maitenes section.

From 124 m to 215 m, sandstone and calcareous sandstone is interlayered by occasional layers of limestone and conglomerate. At 124 m, an 11 m thick unit of medium- to fine-grained sandstone contains fragments of ammonoids, oysters, trigoniids, others bivalves, and rare gastropods. From 135 m to 138 m, a 3 m thick unit of limestone (biomicritic wackestone) is intercalated by centimetre-thick layers of fine sandstone. The fauna comprises fragments of ammonoids, oysters, inoceramids, trigonids, others bivalves and rare gastropods. From 138 m to 178.5 m, a 40.5 m thick sandstone is intercalated by occasional centimetre-thick layers of fine conglomerate and sandy limestone (wackestone biomicrite) and contains abundant ammonoids, oysters, trigoniids, other bivalves and rare gastropods (figure 3.22). At 178.5 m, a 3.4 m thick unfossiliferous limestone (calci-mudstone) is present. Between 181.9 and 215 m, a 33.1 m thick unit of calcareous sandstone contains ammonoids, scare fragments of trigoniids, oysters, others bivalves, gastropods and rare algae (figure 3.22).

Upsection, from 215 m to 241 m of section, a 26 m thick unit with rhythmically bedded layers of calcareous coarse sandstone and limestone (biomicritic wackestone) is present (figure 3.22). Individual layers of limestone (biomicritic wackestone) are between 0.35 m and 2.45 m thick, whereas calcareous coarse-grained sandstone is interlayered forming beds of 0.04 m to 1.3 m thickness. The faunal assemblage is scare and only consists in a few fragments of bivalves and calcispheres. The unit also contains three oyster biostromes of 2.1 m (between 219.7 m and 221.8 m), 4.5 m (between 230.36 m and 233.06 m) and 5.3 m (between 235.7 m and 241 m) thickness (figure 3.22).

At 241 m, a 10.6 m thick unit of coarse and medium-grained calcareous sandstone contains fragments of inoceramids and others bivalves as well as the echinoid *Pygurus* (*Pygurus*) *andinus* (figure 3.22).

A 15 m thick unit of limestone (wackestone biomicrite) is present between 251.6 m and 266. 6 m section and contains ammonoids and bivalves.

From 266.6 m to 275.7 m, medium to coarse-grained calcareous sandstone is intercalated by a 2.5 m thick unit of limestone (calci-mudstone biomicrite) (figure 3.22).

The overlying 49.6 m section, between 275.7 m and 325.3 m, consist of sandy limestone (wackestone biomicrite) with scare ammonoids and bivalves (figure 3.22).

An 18.7 m thick siltstone unit containing ammonoids and bivalves (figure 3.18) forms the top of the Lower Member, between 325.3 m to 344.6 m section.

Upper Member

The 192 m thick Upper Member is present between 344 m and 536 m and consists of siltstone, calcareous sandstone, sandy limestone and limestone (figure 3.23).

At 344.6 m, a 2.4 m thick limestone (wackestone biomicrite) and calcareous siltstone (figure 3.23) is unfossiliferous and forms layers between 0.1 m and 1.3 m thick. The 57 m thick interval between 347 m and 404 m consists of medium to coarse-grained calcareous sandstone with abundant ammonoids.

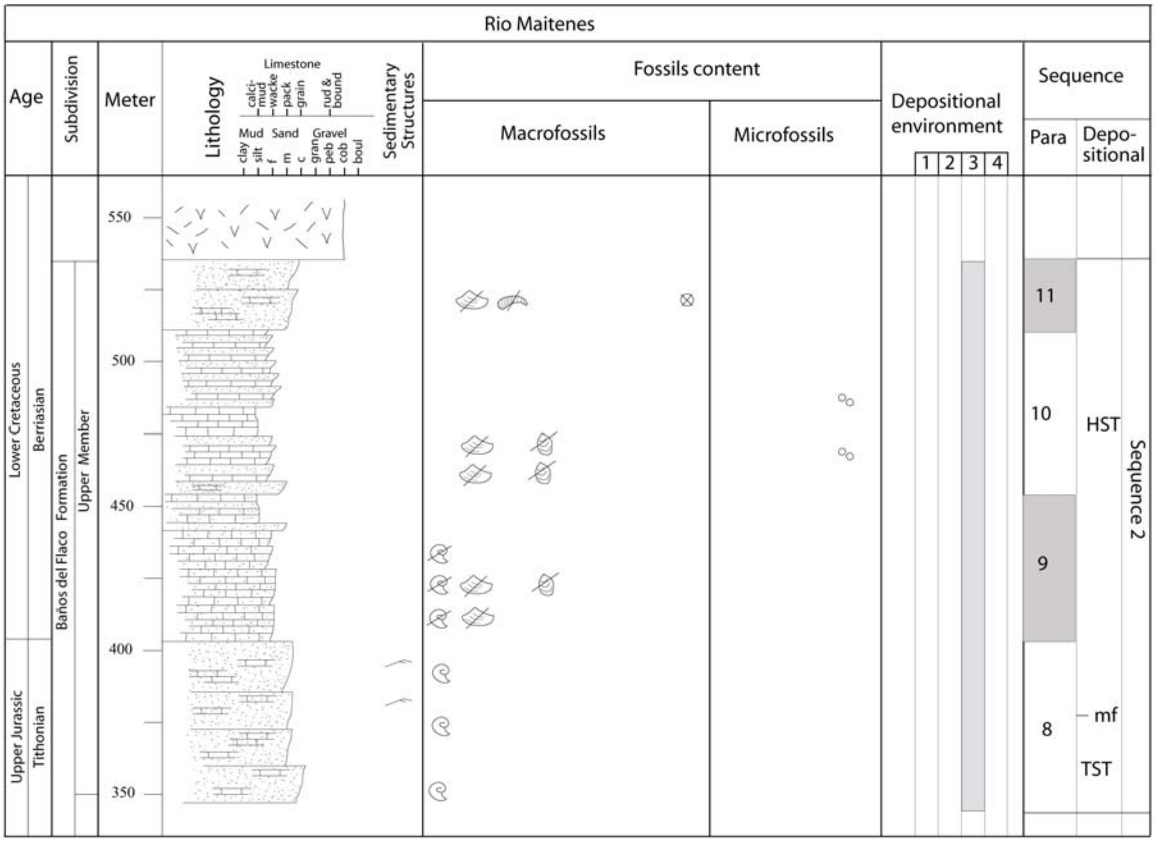


Figure 3.23. Detail of Upper member of Baños del Flaco Formation at at Rio Maitenes section.

Upsection, between 404 m and 511 m, a 107 thick unit consist of sandy limestone and intercalated limestone and sandstone (figure 3.23). A 32.3 m thick unit of sandy limestone (wackestone biomicrite) forms the base of this unit at 404 m and contains scare ammonoids, inoceramids and other bivalves. The 22.8 m thick interval between 436.3 m and 459.1 m of section is composed of alternating sandy limestone and calcareous sandstone forming layers of between 0.3 m and 11.7 m thickness and contains scare bivalves and calcispheres (figure 3.23). At 459.1 m, a 24.2 m thick unit of unfossiliferous limestone (calci-mudstone, biomicrite) is present. From 483.3 m to 511 m section, a 27.7 thick unfossiliferous unit consists of alternating sandy limestone and calcareous sandstone forming layers between 0.5 m and 1.1 m thickness (figure 3.23).

The top of the Upper Member (511 m and 536 m) is characterised by a 25 m thick unit of calcareous sandstone with oysters, other bivalves and echinoderms (figure 3.23).

Volcanoclastic rocks of the Aptian-Albian Coya-Machalí Formation, overlie the Upper Member at 536 m of section; the contact is abrupt and disconformous.

The figure 3.24, show the Rio Maitenes section, and the members, sedimentary structure, fossil content and contact relationship with the lower and upper units.

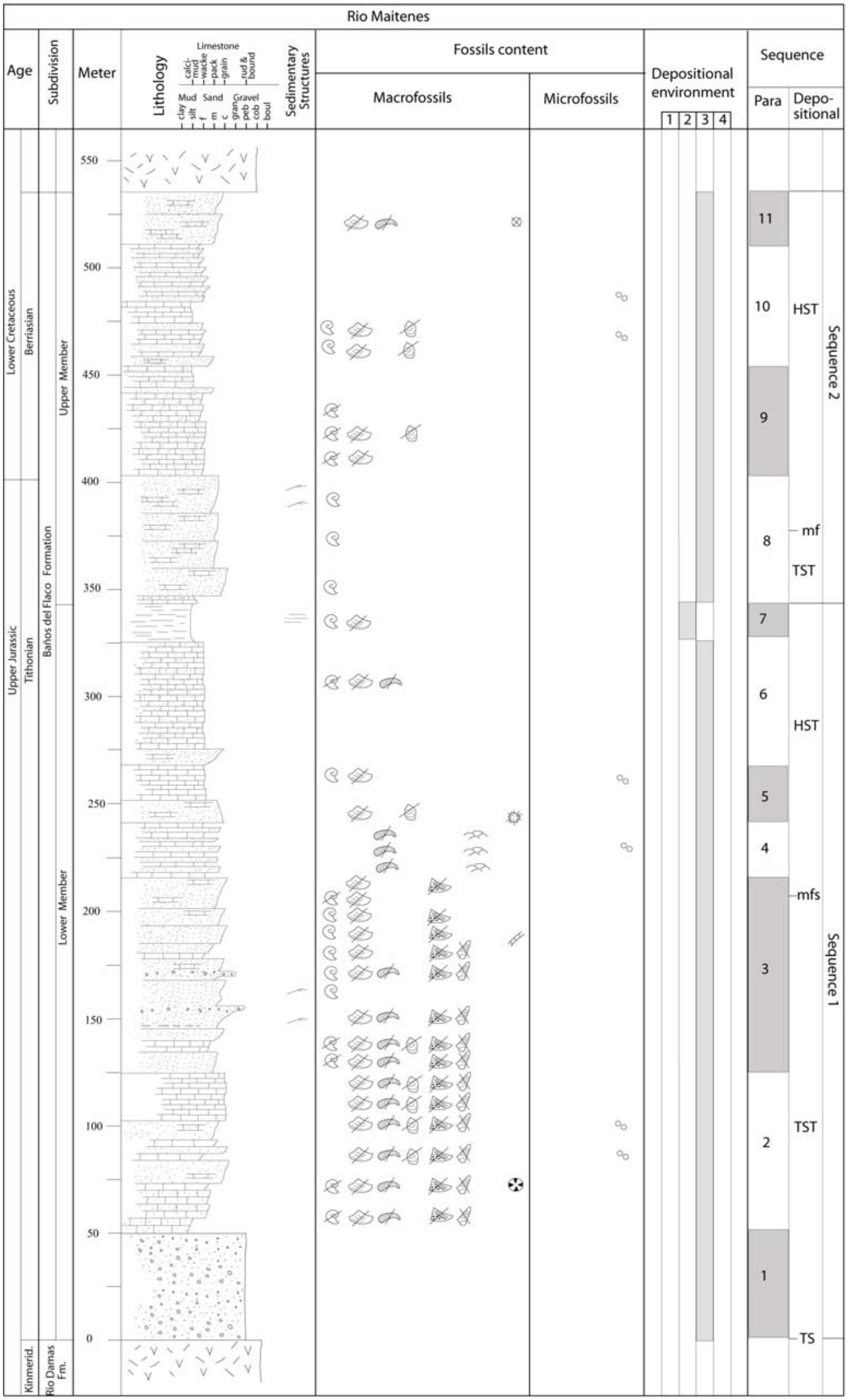


Figure 3.24. Column of the Baños del Flaco Formation at Rio Maitenes, with the lithological members.

3.4 Summary Sections

Catedral Formation

Catedral section

Members	Meters	Lithology	Description	Fossils
	117-760	andesite	- andesite porphyry, phenocrystals of plagioclase, matrix chloritized, sericitic alteration - 637-653 sedimentary layers, fine conglomerate, calcareous sandstone, silty limestone, sandy limestone, calcareous sandstone	ammonoids, inoceramids, trigoniids, other bivalves, echinoderms
	0-117	silty-limestone / andesite	- carbonate and shell fragments sedimentary structures: horizontal lamination - andesite porphyry	

Cajón del Morado section

Members	Meters	Lithology	Description	Fossils
	81-591	andesite	plagioclase, matrix chloritized, sericitc alteration 170-220 calcareous siltstone	
	0-81	calcareous siltstone/ andesite / calcareous sandstone	- siltstone clasts: silt, carbonate, volcanics matrix: fine-grained, silt, carbonate and organic matter; - andesite: plagioclase, matrix chloritized. - calcareous sandstone clasts: subangular to subrounded, well sorted; quartz, litics, carbonate matrix: fine-grained, carbonate, mud, pyrite disseminated - sedimentary structures: horizontal lamination	

Lo Valdés Formation

Lo Valdés Section

Members	Meters	Lithology	Description	Fossils
Limestone Member	446-539	sandy wackestone / calcareous siltstone	-wackestone: biomicrite - siltstone clasts: silt, carbonate, subangular to subrounded; matrix: fine-grained, silt, carbonate and organic matter; - sedimentary structures: horizontal lamination	ammonoids, calcispheres, rare inoceramids, trigoniids, other bivalves, sponge spicules, echinoderms, benthic foraminifera
	390-446	sandy wackestone	biomicrite	ammonoids, oysters, inoceramids, other bivalves, gastropods, bryozoans, echinoderms
	287-390	sandy wackestone	intra/biomicrite disseminated pyrite	ammonoids, oysters, inoceramids, other bivalves, echinoderms
Siltstone member	242-287	silty limestone / calcareous siltstone	- silty limestone: wackestone, calci-mudstone, biomicrite -siltstone clasts: silt, carbonate, subangular to subrounded; matrix: fine-grained, silt, carbonate and organic matter, disseminated pyrite - sedimentary structures: horizontal lamination	ammonoids, oysters, inoceramids, other bivalves, gastropods, calcispheres, rare benthic foraminifera, echinoderms, algae
	193-242	calcareous siltstone / silty limestone	-siltstone clasts: silt, carbonate, subangular to subrounded; matrix: fine-grained,silt, carbonate and organic matter, disseminated pyrite - silty limestone: calci-mudstone, biomicrite - sedimentary structures: horizontal lamination	ammonoids, oysters, inoceramids, other bivalves, calcispheres, annelids, rare benthic foraminifera
	94-193	siltstone / calcareous siltstone	clasts: silt, carbonate, volcanics, subangular to subrounded; matrix: fine-grained, silt, carbonate and organic matter, disseminated pyrite sedimentary structures: horizontal lamination	ammonoids, gastropods, oysters, inoceramids, other bivalves, calcispheres, rare radiolarians, benthic foraminifers, calpionellids?
	73-94	andesite	andesite, matrix chloritized	
Sandstone member	43-73	coarse calcareous sandstone	coarse calcareous sandstone clasts: volcanics, plagioclase, shell fragments, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud	ammonoids, inoceramids, oysters, trigoniids, other bivalves, gastropods
	0-43	calcareous sandstone	gradual change from coarse and medium to fine clasts: volcanics, plagioclase, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud	ammonoids, other bivalves, gastropods, corals

Cajón del Morado section

Members	Meters	Lithology	Description	Fossils
Limestone member	513-582	calcareous siltstone / silty limestone	calci-mudstone, wackestone, biomicrite - siltstone: clasts: carbonate, shell fragments matrix: fine-grained, silt, carbonate and organic matter sedimentary structures: horizontal lamination	ammonoids, oysters, inoceramids, other bivalves, echinoderms, sponge spicules, calcispheres, rare radiolarians, bryozoans
	441-513	limestone	wackestone, bio-intrasparite, biosparite, biomicrite, bio-intramicrite	ammonoids, oysters, inoceramids, echinoderms, echinoids, bryozoans, corals, algae, sponge spicules
	376-441	silty limestone / calcareous siltstone	limestone: calci-mudstone, wackestone, biomicrite, bio-intramicrite, bio-intrasparite - siltstone: clasts: carbonate, shell fragments matrix: fine-grained, silt, carbonate and organic matter, disseminated pyrite sedimentary structures: horizontal lamination	ammonoids, oysters, other bivalves, rare annelids, bryozoans, echinoderms and pentacrinoids
Siltstone member	273-376	calcareous siltstone /silty limestone	wackestone-calci-mudstone, biomicrite carbonate and shell fragments sedimentary structures: lamination disseminated pyrite, organic matter	ammonoids, oysters, inoceramids, trigoniids, gastropods, echinoderms, algae, calcispheres, rare radiolarians, benthic foraminifers, calpionellids? and annelids
	174-273	siltstone / calcareous siltstone	silty limestone: wackestone-packstone clasts: silt, carbonate, volcanics matrix: fine-grained, silt, carbonate and organic matter; disseminated pyrite sedimentary structures: horizontal lamination	ammonoids, inoceramids, trigoniids, other bivalves, gastropods, oysters, algae, sponges, calcispheres, foraminifers, calpionellids?
	160-174	calcareous siltstone / silty limestone	siltstone, silty limestone: biomicrite, wackestone-packstone clasts: silt, carbonate, volcanics, fine-grained, matrix: silt, carbonate and organic matter	ammonoids, oysters, other bivalves, gastropods, echinoderms
Sandstone member	144-160	calcareous sandstone	clasts: subangular to subrounded, well sorted; volcanics, plagioclase, shell fragments; matrix: fine-grained, carbonate	ammonoids, oysters, inoceramids, other bivalves, algae
	120-144	silty limestone / sandy limestone	- silty limestone: calci-mudstone, biomicrite - sandy limestone: packstone, oomicrite, wackstone, biomicrite	ammonoids, inoceramids, trigoniids, other bivalves, bryozoans
	35-120	calcareous sandstone / sandy packstone	- calcareous sandstone clasts: volcanics, plagioclase, shell fragments; subangular to subrounded, well sorted; matrix: fine-grained, carbonate - sandy packstone-biomicrite - sedimentary structures: horizontal lamination	ammonoids, oysters, inoceramids, trigoniids, other bivalves, gastropods, algae.
	0-35	sandy wackestone / calcareous sandstone	- wackestone-biomicrite, shell fragments - calcareous sandstone clasts: volcanics, shell fragments, plagioclase, fine-grained, subangular to subrounded, well sorted; matrix: carbonate, fine-grained - sedimentary structures: cross-bedded, ooids	ammonoids, bivalves, inoceramids, gastropods, corals, algae.

Cruz de Piedra section

Members	Meters	Lithology	Description	Fossils
Siltstone Member	50-150	calcareous siltstone / silty wackestone	-siltstone clasts: silt, carbonate, subangular to subrounded; matrix: silt, fine-grained,carbonate and organic matter; -wackestone, biomicrite sedimentary structures: horizontal lamination	ammonoids and calcispheres abundant, fragments bivalves, scare oysters, inoceramids, gastropods, echinoderms
Sanstone member	0-50	fine sandstone	clasts: quartz, lithics, plagioclase, carbonate, subangular to subrounded, well sorted; matrix: fine-grained,carbonate, mud	

Baños del Flaco Formation

Baños del Flaco

Members	Metres	Lithology	Description	Fossils
Upper member	338-369	calcareous sandstone / sandy limestone	-sandstone clasts: volcanics, plagioclase, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud -limestone wackestone, biomicrite	oysters, inoceramids, other bivalves, few echinoids, echinoderms, algae
	266-338	calcareous sandstone	- microconglomerate, 6m intercalated -sandstone clasts: volcanics, plagioclase, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud, disseminated pyrite	
	255-266	calcareous siltstone	clasts: silt, carbonate, subangular to subrounded; matrix: fine-grained, silt, carbonate and organic matter; - sedimentary structures: horizontal lamination	fragments inoceramids, other bivalves, algae, calcispheres
	191-255	calcareous sandstone	clasts: volcanics, plagioclase, fine-grained; subangular to subrounded, well sorted; matrix: carbonate, silt or mud, disseminated pyrite	fragments oysters, inoceramids, other bivalves, algae
	179-191	siltstone	clasts: silt, carbonate, subangular to subrounded; matrix: fine-grained, silt, carbonate and organic matter, disseminated pyrite - sedimentary structures: horizontal lamination	calcispheres, fragments ammonoids
Lower member	140-179	calcareous sandstone	clasts: quartz, volcanics, plagioclase, carbonate, shell fragments, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, mud - sedimentary structures: cross-lamination, horizontal lamination	fragments ammonoids, few oysters, inoceramids, other bivalves, echinoderms
	129-140	sandy wackestone	disseminated pyrite	bivalves
	118-129	grainstone- calci-mudstone	-grainstone: carbonate, shell fragments and litics, occasional ooids - calci-mudstone: biosparite	few oysters, other bivalves
	60-118 m	limestone	calci-mudstone, wackestone, biomicrite occasional ooids	oysters, inoceramids, bivalves, few trigoniids, gastropods, echinoderms, scare algae, calcispheres
	0-50	conglomerate	clasts: quartz, volcanics, plagioclase, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, mud	

Rio Maitenes

Members	Metres	Lithology	Description	Fossils
Upper member	511-536	calcareous sandstone	clasts: volcanics, plagioclase, shell fragments, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud	oysters, other bivalves, echinoids
	404-511	sandy limestone / limestone / sandstone	- limestone wackestone, calci-mudstone, biomicrite - sandstone clasts: volcanics, plagioclase, shell fragments, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud	ammonoids, inoceramids, other bivalves, rare calcispheres
	347-404	calcareous sandstone	medium to coarse clasts: volcanics, plagioclase, shell fragments, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud	ammonoids
	325.3-347	siltstone	clasts: silt, carbonate, subangular to subrounded; matrix: fine-grained, silt, carbonate and organic matter; sedimentary structures: horizontal lamination	ammonoids, bivalves
Lower member	275-325.3	sandy limestone	wackestone, biomicrite	ammonoids, oysters, other bivalves
	215-275	calcareous sandstone / limestone	- sandstone clasts: volcanics, plagioclase, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud - limestone wackestone, biomicrite	ammonoids, oysters, inoceramids, other bivalves, calcispheres echinoids
	124-215	sandstone / calcareous sandstone	clasts: volcanics, plagioclase, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud	ammonoids, oysters, inoceramids, trigoniids, other bivalves, gastropods, rare algae
	103-124	grainstone	carbonate, litics, shell fragments, occasional ooids	oysters, inoceramids, trigoniids, other bivalves, gastropods
	50-103	calcareous sandstone / sandy limestone	- sandstone clasts: volcanics, plagioclase, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, silt or mud - limestone wackestone, biomicrite	ammonoids, oysters, trigoniids, other bivalves, gastropods, corals
	0-50	conglomerate	clasts: quartz, volcanics, plagioclase, subangular to subrounded, well sorted; matrix: fine-grained, carbonate, mud	

4. Systematic Palaeontology

The ammonoids described in this chapter correspond to 1405 specimens; of 243 are from Baños del Flaco Formation and 1162 from Lo Valdés Formation. All specimens described and figured herein are registered and housed at the Paleontological Collection of the Departamento de Ciencias de la Tierra of the University of Concepción, Chile. Fossil preservation is good to very good, most being preserved three-dimensionally and some specimens are deformed. The fossil content is mainly moulds and preserves the ornamentations. Suture lines are observable only in few of them. The material includes new collections collected in few field campaigns, that are from Lo Valdés section (Cerro Catedral), Cajón del Morado section and Cruz de Piedra section (Nacientes del Rio Maipo), all of this bellow to Lo Valdés Formation (Figure 1.1). Also are including specimens housed at the University of Concepción, collected in the 1960s by the late Lajos Biro from Rio Maitenes section, bellow to Baños del Flaco Formation (Figure 1.1).

Dimensions. All dimensions are given in mm. Uncertain values due to deformation of specimens and ratios resulting from uncertain measurements are in brackets. Abbreviations: D: Diameter, W: Whorl Breadth, H: Whorl Height, U: Umbilicus.

Collections. The code of registration is the prefix CPUC (Colección Paleontológica de la Universidad de Concepción), followed by the code of the section from which fossils were collected (RM: Rio Maitenes) and the number of registration (e.g. CPUC/RM/65-45). All specimens described and figured here are registered and housed at the Paleontological Collection of the Departamento de Ciencias de la Tierra of the Universidad de Concepción, Chile. They were analysed at the Institut für Geowissenschaften of the Universität Heidelberg, Germany, with the respective authorization.

Other collections mentioned are UWBM, University of Washington Burke Museum; S.G.N., Servicio Geológico Nacional República Argentina; ГГМ.экз, “Новости из Геологического музея им. В. И. Вернадского” – Vernandsky State Geological Museum, Moscow; GZG, Geowissenschaftlices Zentrum Göttingen; STIPB, Steinmann Institut-Paläontologie Bonn; SNGM, Servicio Nacional de Geología y Mineria de Chile; B.M., British Museum of London.

Systematic. Systematic nomenclature follows the “Treatise of Invertebrate Paleontology” (Wright et al. 1996, Arkell et al. 1957) to subspecies level, Fossil catalogues I: Animalia, Lower

Cretaceous Ammonite I (Klein 2005), for the genera *Euvirgalithacoceras* and *Choicensisphinctes* (Parent 2011a); and *Catutosphinctes* (Leanza & Zeiss 1992).

Synonymies. Only references of the original description, some synonyms and all references used for the definition of species are included. Where possible, more complete lists of synonymy are indicated.

4.1. Ammonites from Baños del Flaco Formation

Order AMMONOIDEA Zittel, 1884
Suborder AMMONITINA Hyatt, 1889
Superfamily HAPLOCERATACEOIDEA Zittel. 1884
Family HAPLOCERATIDAE Zittel, 1884
Genus *Pseudolissoceras* Spath, 1925

Type species: *Neumayria zitteli* Burckhardt (1903, p. 55, pl. 10, figs. 1, 2), by subsequent designation of Roman (1938, p. 176).

Pseudolissoceras cf. *zitteli* (Burckhardt, 1903)
Figure 4.1a

1903	*Neumayria Zitteli* Burckhardt, p. 55, pl. 10, figs. 1-8.
1907	*Neumayria Zitteli* Burckhardt. Haupt, p. 200, pl. 7, figs. 3a-b, 4a-c.
1925	*Pseudolissoceras zitteli* (Burckhardt). Spath, p. 113 (Gen. nov).
1926	*Haploceras* (*Pseudolissoceras*) *Zitteli* (Burckhardt). Krantz, p. 436, pl. 17, figs. 4-5.
1928	*Haploceras* (*Pseudolissoceras*) *Zitteli* (Burckhardt). Krantz, p. 18, pl. 1, fig. 6 (= Krantz 1926).
1931	*Pseudolissoceras zitteli* (Burckhardt). Weaver, p. 401, pl. 43, fig. 291.
1942	*Pseudolissoceras* cf. *P. zitteli* (Burckhardt). Imlay, p. 1443, pl. 4, figs. 1, 3, 4, 7, 8, 11, 12.
? 1946	*Neumayria zitteli* Burckhardt. Sokolov, p. 9.
1950	*Pseudolissoceras zitteli* (Burckhardt). Spath, p. 101, pl. 6, figs. 8 a-c.
1967	*Pseudolissoceras zitteli* (Burckhardt). Cantu-Chapa, p. 4, pl. 1, fig. 5; pl. 7, fig. 9.

1973 *Pseudolissoceras zitteli* (Burckhardt). Verma & Westermann, p. 168, pl. 26, figs. 3-5, text-fig. 12-13.

1978 *Pseudolissoceras zitteli* (Burckhardt). Oloriz, p. 34, pl. 2, fig. 12, text-fig. 43.

1980 *Pseudolissoceras zitteli* (Burckhardt). H. Leanza, p. 17, pl. 1, figs. 1-2.

1989 *Pseudolissoceras zitteli* (Burckhardt). Myczynski, p. 85, pl. 1, fig. 2; pl. 5, fig. 8; pl. 9, fig. 10b; pl. 10, fig. 4b.

1990 *Pseudolissoceras zitteli* (Burckhardt). Myczynski, pl. 1, fig. 1b.

1996 *Pseudolissoceras* ex. gr. *zitteli* (Oppel *recte* Burckhardt). Sey & Kalacheva, p. 299, pl. 1, fig. 1-2.

1997 *Pseudolissoceras* ex. gr. *zitteli* (Burckhardt). Sey & Kalacheva, p. 93, pl. 1, fig. 13-17.

1999 *Pseudolissoceras zitteli* (Burckhardt). Parent & Capello, p. 349.

2001 *Pseudolissoceras zitteli* (Burckhardt). Parent, p. 23, figs. 2, 3a-b, 4a-b, 5a-e, 6, 7a-g; table 1.

2009 *Pseudolissoceras zitteli* (Burckhardt). Aguirre-Urreta & Vennari, p. 35, fig. 5a-h.

2011a *Pseudolissoceras zitteli* (Burckhardt). Parent et al., p. 89, figs. 34A-C.

2011b *Pseudolissoceras zitteli* (Burckhardt). Parent et al., p. 79, fig. 39B.

Lectotype. Designated by Parent (2001a) from the originals illustrated by Burckhardt (1903, pl. 6-7) from Mendoza (Argentina), Middle Tithonian.

Material: One internal mould, CPUC/RM/47-11, an incomplete and poorly preserved phragmocone.

Description: Coiling involute and depressed. Whorl section discoidal, umbilical border rounded, flanks parallel to the slightly convex and rounded venter. Ornamentation not preserved.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/47-11	(31.6)		(12.8)		(11.0)	

Discussion: The specimen described here is *conferred* (cf.), based on its poor preservation. Parent (2001) gives a full description and discussion of this species.

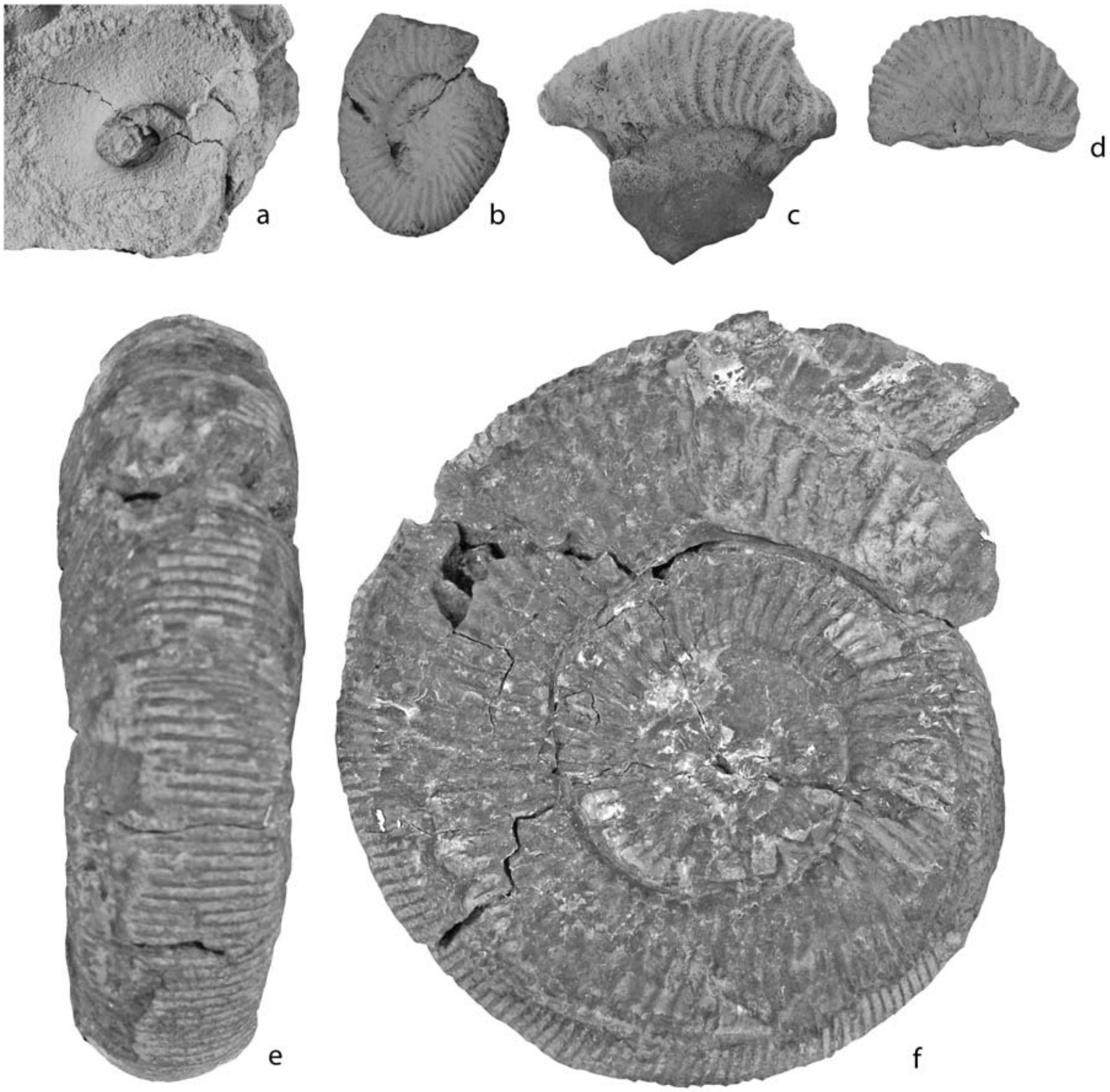


Figure 4.1. a: *Pseudolissoceras* cf. *zitteli* (Burckhardt, 1903). CPUC/RM/47-11 x1. **b-f:** *Euvirgalithacocers malarguense* (Spath 1931). **b:** CPUC/RM/47-3 x1; c: CPUC/RM/47-13 x1; **d:** CPUC/RM/47-4 x1; **e-f:** STIPB-24 = *Virgatosphinctes* (*S.*) *pseudolictor* in Indans (1954) x 1.

Occurrence: Our poorly preserved specimen was collected at Rio Maitenes in the Lower member of the Baños del Flaco Formation, in the unit of sandstone/calcareous sandstone at 166 metres from the base of the section (figure 5.4). *P. zitteli* is known from the Middle Tithonian of Argentina (Burckhardt 1903, Leanza 1980, Parent 2001, Parent et al. 2011a), the Middle Tithonian of Mexico (Cantu-Chapa 1967), the Lower Tithonian of Cuba (Myczynski 1990; in Parent 2001) and the Middle Tithonian of East Russia (Sey & Kalacheva 1997).

Superfamily PERISPHINCTOIDEA Steinmann, 1890
Family ATAXIOCERATIDAE Buckman, 1921
Subfamily LITHACOCERATINAE Zeiss, 1968
Genus *Euvirgalithacoceras* Zeiss et al., 1996

Type species. *Virgatosphinctes supremus* Sutner in Scheid 1915, by original designation.

Euvirgalithacoceras malarguense (Spath 1931)

Figure 4.1 b-f, 4.2 a-b, 4.3 a-c

1900a *Perisphinctes lictor* Fontannes. Burckhardt, p. 43, pl. 24, fig. 4.
1900a *Perisphinctes Tiziani* Oppel. Burckhardt, p. 43, pl. 24, fig. 3.
1900a *Perisphinctes pouzinensis* Toucas. Burckhardt, p. 45, pl. 24, fig. 8.
1903 *Perisphinctes* aff. *pseudolictor* Choffat. Burckhardt, p. 36, pl. 4, figs. 1 (lectotype), 2-4.
? 1906 *Virgatites* sp. Burckhardt, p. 119, pl. 30, fig. 4.
? 1906 *Perisphinctes* sp. Burckhardt, p. 113, pl. 30, fig. 8.
non 1906 *Virgatites mexicanus*. Burckhardt, p. 115, pl. 31, figs. 5-9.
1906 *Perisphinctes* cf. *danubiensis* Schlosser. Burckhardt, p. 112, pl. 32, fig. 1.
? 1906 *Virgatites* sp. Burckhardt, p. 118, pl. 32, fig. 2.
? 1919 *Perisphinctes* (*Aulacosphinctes*) aff. *praetransitorius* Fontannes. Burckhardt, p. 11, pl. 3, figs. 13-15.
1931 *Subplanites malarguensis* nom. nov. (recte sp. nov.). Spath, p. 468, 501.
? 1943 *Virgatosphinctes guadalupensis* Imlay, p. 533, pl. 90, figs. 1-6.
1954 *Virgatosphinctes* (*Subplanites*?) aff. *pseudolictor* Choffat. Indans, p. 119, pl. 19, figs. 3, 4.
1954 *Virgatosphinctes* cf. *raja* Uhlig. Indans, p. 110, pl. 14, figs. 1–3.
1954 *Virgatosphinctes communis* Spath. Indans, p. 108, pl. 15, fig. 6.
? 1964 *Perisphinctes* (*Dichotomosphinctes*) *bangei* Burckhardt: Muñoz, p. 9, pl. 2, fig. 3.
? 1964 *Substeueroceras durangoensis* Muñoz, p. 21, pl. 8, figs. 1-2.
? 1980 *Lithacoceras* (*Virgalithacoceras*) *acricostatum* Ohmert & Zeiss, p. 19, pl. 3, fig. 1, pl. 5, figs. 1–2.

1981a *Subplanites malarguense* Spath. H. Leanza, p. 571.
1981b *Subplanites malarguensis* Spath. H. Leanza, p. 81.
? 1988 *Discosphinctoides* (?) aff. *D. neohispanicus* (Burckhardt). Poulton et al., p. 106, pl. 5.3: figs. 1–2, 4–9.
? 1993 *Lithacoceras*? *mexicanus* (Burckhardt). Callomon, p. 267.
1997 *Subplanites* sp. Kraemer & Riccardi, p. 339, fig. 4(3).
1999 *Lithacoceras* (*Virgalithacoceras*) cf. *acricostatum* Ohmert & Zeiss. Parent & Capello, p. 349.
1999 *Torquatisphinctes* cf. *laxus* Olóriz. Parent & Capello, p. 349.
Non 2003a *Euvirgalithacocers malarguense* (Spath). Parent, p. 147, figs. 1, 4, 5A, 6A-D, 7A-E (= *Choisisphinctes platyconus*).

Type. The lectotype designated by Parent (2003a) is a specimen housed in the collection of the Museo de La Plata. It was illustrated by Burckhardt (1900a, pl. 24, fig. 4; drawing refigured 1903, pl. 4, fig. 1, referred by Spath, 1931, p. 468, 501) and was collected at Casa Pincheira, Argentina.

Material: 9 specimens, internal moulds regular to well preserved. CPUC/RM/47-3 is a complete and well preserved specimen which is slightly deformed. CPUC/RM/17-19, CPUC/RM/47-2, CPUC/RM/47-4, CPUC/RM/47-5, CPUC/RM/47-6, CPUC/RM/47-8, CPUC/RM/47-13 and CPUC/RM/Rod-43 are fragmentary phragmocones with regular to good preservation. Specimens STIPB-12, STIPB-15 and STIPB-24 are from the Indans (1954) collection housed at the Steinmann Institut für Paläontologie of the Universität Bonn, Germany, and are also included here.

Description: Coiling is evolute and compressed. In young stages (D < 40 mm) the whorl section is oval to subrectangular. Umbilical border rounded, flanks slightly convex and venter rounded. Ornament consists in fine prorsiradiate ribs. Primaries are slightly flexuous and bifurcate on the middle part of the flank; rare virgatotome ribs are intercalated. Constrictions are present in some specimens. In adult specimens (D > 40 mm) the whorl section is wider than high. The umbilical border is rounded, flanks are slightly convex and converge to the rounded-arched venter. Between 4 to 6 ribs are grouped in branches. On the umbilical border these branches are associated with elongated tubercles. 3-4 constrictions are present on the last whorl. Specimen STIPB-15 preserves the body chamber (figure 4.2a).

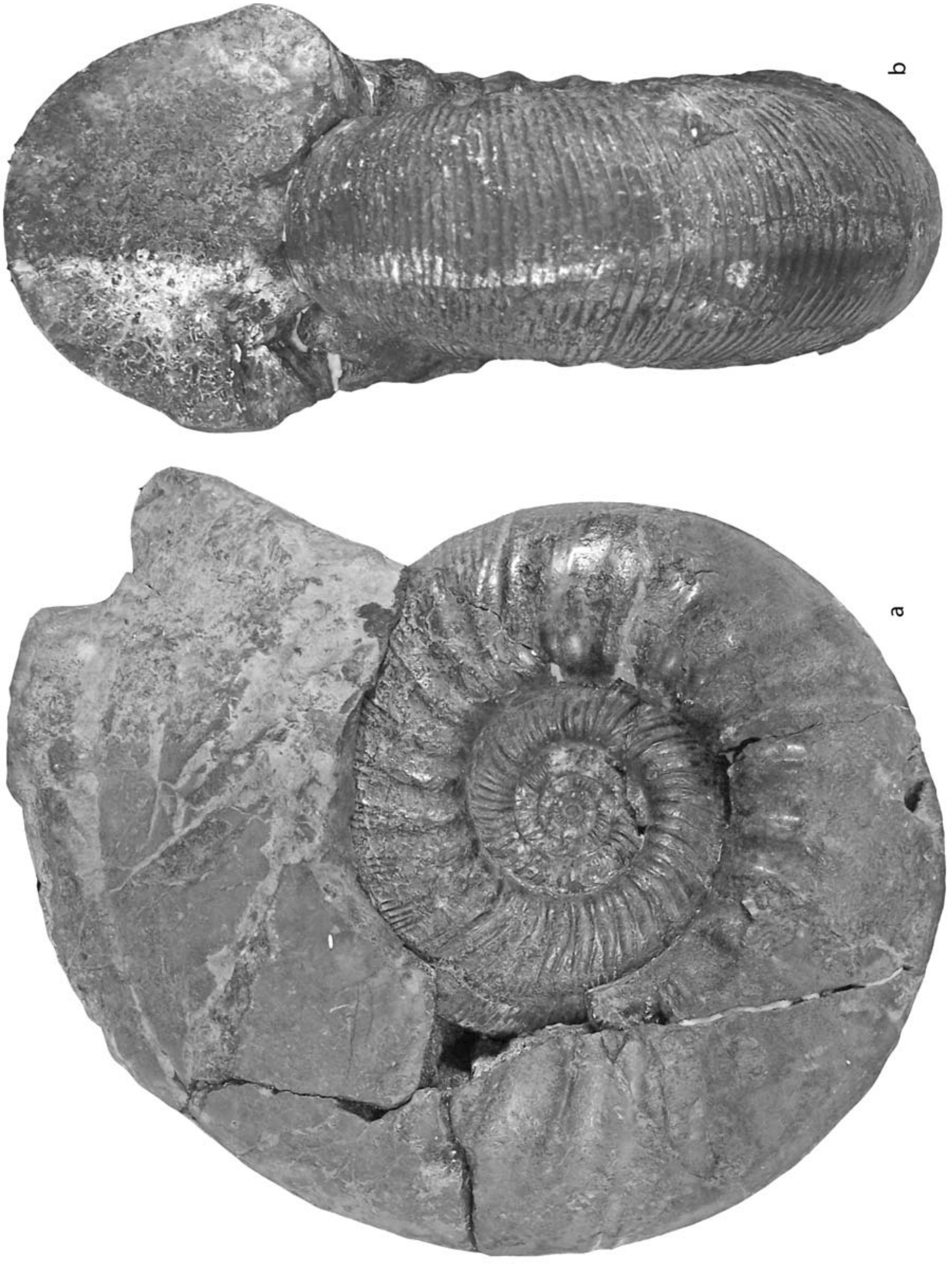


Figure 4.2. a-b: *Euvirgalithacoceras malarguense* (Spath 1931), STIPB-15 = *Virgatosphinctes* cf. *raja,* in Indans (1954) x 0.75.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/17-19			(18.0)			
CPUC/RM/47-2			(11.2)			
CPUC/RM/47-3	(27.9)	(9.3)	(10.5)	0.88	(11.7)	0.42
CPUC/RM/47-4			(16.1)			
CPUC/RM/47-5		(9.0)	(10.2)	0.88		
CPUC/RM/47-6			(11.8)			
CPUC/RM/47-8			(19.8)			
CPUC/RM/47-13		(17.9)	(20.6)	0.87		
CPUC/RM/Rod-43		(21.1)	(25.1)	0.84		

Remarks: Parent (2003a) presents a full description and discussion of this species. *Perisphinctes* (*Aulacosphinctes*) aff. *praetransitorius* described by Burckhardt (1919) and *Virgatosphinctes guadalupensis* described by Imlay (1943) closely resemble *E. malarguense* in morphology and ornamentation and may be conspecific. *Virgatosphinctes* (*Subplanites*?) aff. *pseudolictor* described by Indans (1954) clearly coincides with *E. malarguense*. *Virgatosphinctes* cf. *raja* described by Indans (1954) is an adult specimen of *E. malarguense*.

Occurrence: At Rio Maitenes, this taxon is present in the Lower member of the Baños del Flaco Formation, in the unit of sandstone/calcareous sandstone (figure 5.4). Elsewhere, the species is registered for the Lower Tithonian in Mexico (Burckhardt 1906, Imlay 1943 and Muñoz 1964), western Canada (Poulton et al. 1988), south Germany (Ohmert & Zeiss 1980), India (Spath 1931), Patagonia (Kraemer & Riccardi 1997) and Central Argentina (Burckhardt 1900, Indans 1954 and Parent 2003a). Parent (2003a) gives a full discussion about the age and distribution of *E. malarguense*.

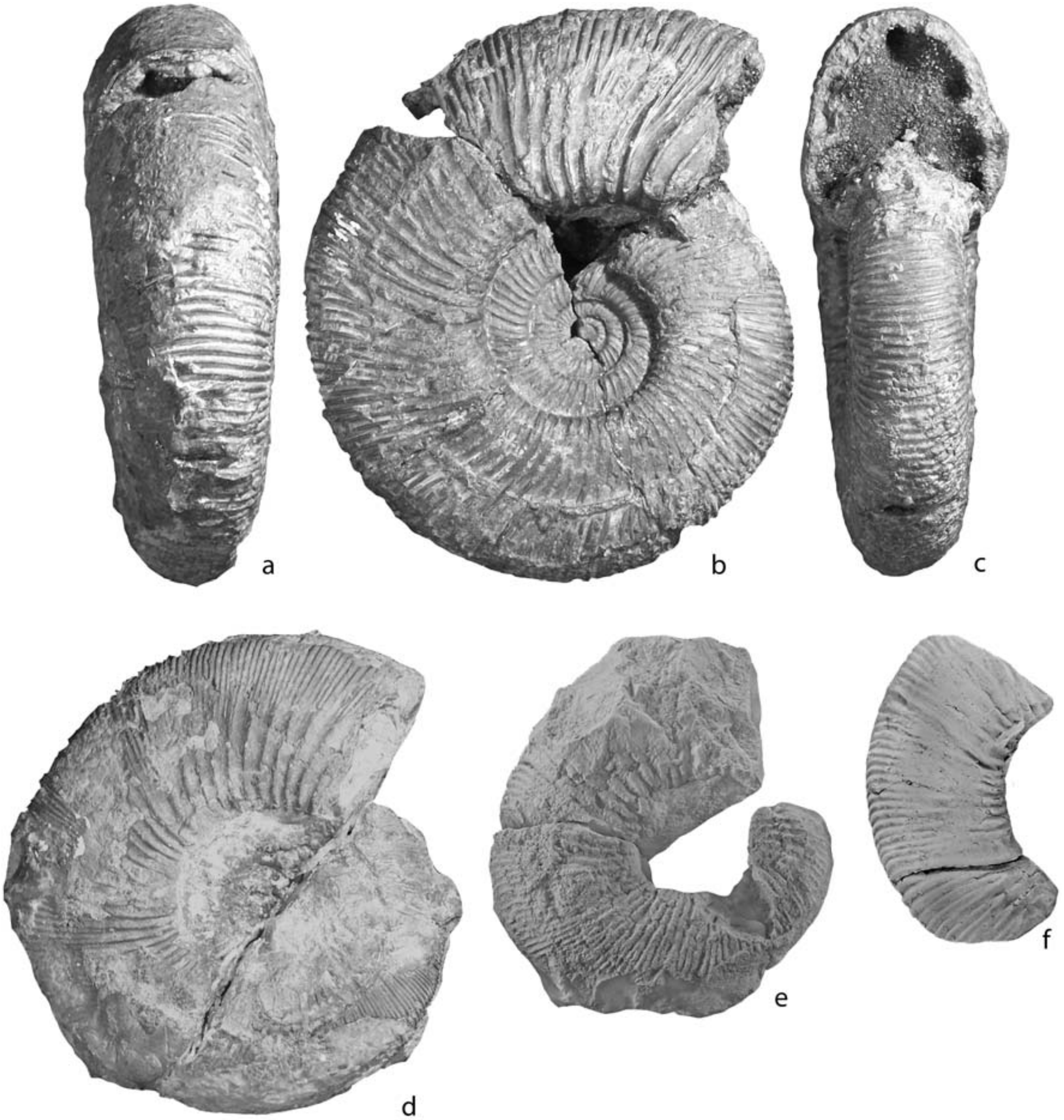


Figure 4.3. a-c: *Euvirgalithacoceras malarguense* (Spath 1931), STIPB-12 = *Virgatosphinctes communis* in Indans (1954) x1. **d-f:** *Choicensisphinctes windhauseni* (Weaver, 1931). **d:** STIPB-1=*Virgatosphinctes* (*L.*) *tenuilineatus* in Indans (1954) x1; **e:** CPUC/RM/18-1 x1; **f**:CPUC/RM/47-1 x1.

Genus *Choicensisphinctes* Leanza, 1980

Type species. *Perisphinctes choicensis* Burckhardt, 1903, p. 50, pl. 6, figs. 10-12; pl. 8, fig. 6, by original designation.

Remarks: Parent et al. (2011a, p. 62-66) give a full discussion and emendation of this genus. They give the following diagnosis: “Macroconchs moderately stout, serpenticonic to platyconic or compressed platyconic to suboxyconic, moderately involute, with a deep umbilicus formed by a relatively high, vertical umbilical wall. Inner (most) whorls covered by a simple sculpture of prosocline primaries bifurcated on the upper half or third of the flanks. Ribbing of outer whorls of phragmocone is rather fine and dense, slightly prosocline to flexuous, arising from the umbilical seam (but from the umbilical shoulder in the adult body chamber). Primary ribs bifurcate or polygyrate at about mid-flank. During ontogeny isolated virgatotomes are developed and intercalated with trifurcates or bifurcates with intercalars; some profusely divided polygyrates and/or polyschizotomics occur, especially behind constrictions. The adult body chamber may be strongly variocostate to completely smooth; commonly primary ribs are strong and inflated, raising on the umbilical shoulder and profusely divided in sheaves of three up to thirteen or more secondaries, all of them crossing the venter or vanishing completely towards the peristome. In the microconchs the phragmocone is identical with that of the macroconchs at comparable diameters; the adult body chamber is platyconic to inflate serpenticonic, more rarely suboxyconic, with a peristome possessing a pair of rather short and wide, subtriangular lappets” (Parent et al 2011a, p. 63).

The authors regard the following species to belong to *Choicensisphinctes*: *Perisphinctes densistriatus* Steuer (1897), *Virgatites australis* Burckhardt (1903), *Perisphinctes involutus* (in Burckhardt 1900a), *Virgatites buckhardti* Douvillé (1910a), *Holcodiscus wilfridi* Douvillé (1910a), *Virgatosphinctes andesensis* Douvillé (1910a), *Virgatosphinctes mexicanus* Burckhardt (1906), *Virgatites mendozanus* Burckhardt (1911), *Pseudoinvolunticeras decipiens* Spath (1925), *Pseudoinvolunticeras douville* Spath (1925), *Virgatosphinctes windhauseni* Weaver (1931), *Virgatosphinctes lotenoensis* Weaver (1931) and *Virgatosphinctes evolutus* Leanza (1980a).
Virgatosphinctes andesensis Douvillé (1910a), *Virgatosphinctes mexicanus* Burckhardt (1906), *Virgatites mendozanus* Burckhardt (1911) and *Virgatosphinctes evolutus* Leanza (1980) coincide with *Choicensisphinctes* regarding their inner whorls but significant differences exist in the ornamentation of outer whorls, where ribs are grouped in prominent branches. These are always divided into three or more secondaries without intercalated isolated ribs in the dorsolateral part of the flank. Ribs are spaced and strong and coiling is evolute and compressed. These characteristics exclude an assignation to *Choicensisphinctes* and the three taxa are here included in *Virgathosphinctes* as was previously suggested by other authors.

Choicensisphinctes windhauseni (Weaver, 1931)

Figure 4.3 d-f.

1900a *Perisphinctes involutus* Quenstedt. Burckhardt, p. 40, pl. 25, figs. 3-5; pl. 29, fig. 9.

1903 *Virgatites australis* Burckhardt, pl. 6, figs. 5-7.

1910a *Virgatites australis* Burckhardt. Douvillé, p. 10, pl. 1, figs. 5a-b.

1931 *Virgatosphinctes windhauseni* Weaver, p. 425, pl. 48. figs. 324, 325.

1954 *Virgatosphinctes* (*Lithacoceras*) *tenuilineatus* Indans, p. 103, pl. 13, figs. 1, 2.

1980a *Pseudinvolunticeras windhauseni* (Weaver). Leanza, p. 26, pl. 3, figs. 2, 4a-b, text-fig. 7b.

non 2006 *Choicensisphinctes* cf. *windhauseni* (Weaver). Parent et al., p. 259, figs. 5a-b (= *Choisisphinctes platyconus*).

2011a *Choicensisphinctes windhauseni* (Weaver). Parent et al., p. 74, fig. 13 a-b

Type: Lectotype is the specimen UWBM No. 346, illustrated by Weaver (1931, p. 425, pl. 48, fig. 325). It is from the Tithonian of Central Argentina, which was designated by Parent et al. (2011a p. 74).

Material: 6 fragmentary internal moulds of phragmocones. CPUC/RM/18-1 is an incomplete well preserved phragmocone. CPUC/RM/47-1 is a fragmentary phragmocone with regular preservation. CPUC/RM/14-2, CPUC/RM/18-2, CPUC/RM/20-14, CPUC/RM/Rd-17 are poorly preserved fragments. We also include specimen STIPB-1 of Indans (1954) housed in the collection at Universität Bonn, Germany.

Description: Coiling involute and whorl section discoidal, elliptically rounded, higher than wide. The umbilical border is almost vertical, flanks are flat to slightly convex and the venter is arched. Ornament consists of fine, equally spaced ribs, which initiate on the umbilical border with rursiradiate direction and gradually turn towards the aperture dorsolaterally. In the dorsolateral area primary ribs bifurcate and sometimes trifurcate, and cross the venter without interruption. Shallow constrictions are present; they are convex and prorsiradiate and interrupt the ribs.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/14-2		(16.7)	(17.2)	(0.97)		
CPUC/RM/18-1	(58.4)	21.4	(28.5)	(0.75)		
CPUC/RM/18-2			(14.1)			
CPUC/RM/20-14			(18.1)			
CPUC/RM/47-1		22.5	(23.4)	(0.96)		
CPUC/RM/Rd-17		(17.4)	(18.1)	(0.96)		

Remarks: "*Virgatosphinctes*" (*Lithacoceras*) *tenuilineatus* (Indans 1954) should be included in *Choicensisphinctes* and may even be conspecific with *C. windhauseni* (Leanza 1980). *Perisphinctes involutus* described by Burckhardt (1900a) only differs from *C. windhauseni* by the occasional presence of simple ribs intercalated between the regular bi- and trifurcated ribs. The two are also considered conspecific.

C. windhauseni is a close relative of *Virgatites australis* described by Burckhardt (1903) and Indans (1954). Coiling, ornamentation and whorl section are identical, but ribs are more distanced in *V. australis*.

C. windhauseni is closely related to *Virgatosphinctes denseplicatus* (Waagen 1875), but the whorl section in the latter species is wider than high. *Virgatosphinctes denseplicatus* changes morphological aspects during ontogeny and is generally a variable species (Waagen 1875, Uhlig 1910, Spath 1931, Indans 1954 and Leanza 1980a).

Occurrence: At Rio Maitenes, this taxon is registered in the Lower Member of the Baños del Flaco Formation, in the unit of sandstone/calcareous sandstone (figure 5.4). In Argentina, *Virgatosphinctes* (*Lithacoceras*) *tenuilineatus*, here regarded as synonymous to *C. windhauseni*, was described from the Lower Tithonian of Mendoza (Indans 1954). *C. windhauseni* is recorded for the Middle Tithonian of Central Argentina (Weaver 1931), the Uppermost Lower Tithonian of Neuquén (Leanza 1980a) and the Lowermost Tithonian of the Neuquén-Mendoza basin (Parent et al. 2006).

Family PERISPHINCTIDAE Steinmann, 1890

Subfamily VIRGATOSPHINCTINAE Spath, 1925

Genus *Virgatosphinctes* Uhlig, 1910

Type species. *Persiphinctes* (*Virgatosphinctes*) *broilii* Uhlig (1910: 336, pl. 91, figs. 1a-d), as designated by Douvillé (1910b, p.737).

Genus description: Coiling moderate evolute, whorls are rounded to slightly compressed. The ribs are biplicate, gradually becoming triplicate, virgatotome, then fasciculate, they gradually enlarge and become more distant; at all stages ribbing is smoother than in *Pseudovirgatites* (Uhlig 1910 and Arkell et al. 1957).

Complementary description: Ribs in the inner whorls are fine and dense. Ribs in the outer whorls are stronger and spaced, grouped in branches that divide into three or more secondaries around the middle part of the flank.

Remarks: The type material of *Virgathosphinctes* and *Choicensisphinctes* only presents few isolated virgatotome ribs which are intercalated with simple and irregulary arranged bi or trifurcate ribs, (Enay & Cariou 1997 and Yin & Enay 2004). *Virgathosphinctes* and *Choicensisphinctes* are similar in their ornamentation of the inner whorls (Parent et al 2011a). However, ribbing in *Choicensisphinctes* is finer in the inner and outer whorls than in *Virgathosphinctes*, and the latter is moderately evolute, ribs of the outer whorls are distanced, stronger, and grouped in branches that are divided in three or more secondaries above or below the middle part of the flank.

Virgatosphinctes scythicus (Vischniakoff, 1882)

Figure 4.4, 4.5, 4.6, 4.7

1861 *Ammonites biplex truncates* Trautschold, p. 84, pl. 8, figs. 3-4.

1882 *Ammonites scythicus* Vischniakoff, pl. 3, figs. 1-2.

1890 *Perisphinctes scythicus* Vischniakoff. Michalski, p. 121, 425, pl. 5, figs. 6-7; pl. 7, figs. 1-7; pl. 8, fig. 1; pl. 13, fig. 10.

1899 *Perisphinctes scythicus* Vischniakoff. Siemiradzki, p. 232.

1900a *Perisphinctes* aff. *lothari* Oppel. Burckhardt, p. 41, pl. 25, figs. 6-8.

1903 *Virgatites scythicus* (Vischniakoff). Burckhardt, p. 45, pl. 7, figs. 1-8.

1906 *Virgatites mexicanus* Burckhardt, p. 115, pl. 31, figs. 5-9.

1910a *Virgatites andesensis* Douvillé, p. 7, pl. 1, figs. 3a-b, 4a-f.

1910a *Virgatites mexicanus* Douvillé, p. 8, pl. 1, figs. 1-2.

1911 *Virgatites mendozanus* Burckhardt, p. 482.

1914 *Perisphinctes mendozanus* (Burckhardt). Steiger, p. 502.

1923 *Provirgatites scythicus* (Vischniakoff). Lewinski, p. 101, pl. 9, figs. 3-4.

1927 *Dorsoplanites mendozanus* (Burckhardt). Spath, p. 527.

1931 *Virgatosphinctes andesensis* (Douvillé). Weaver, p. 422, pl. 47, figs. 313-314, pl. 48; figs. 318-321.

? 1943 *Subplanites* aff. *S. reisi* (Scheid). Imlay, p. 533, pl. 91, fig. 1.

1954 *Virgatosphinctes andesensis* (Douvillé). Indans, p. 111, pl. 13, fig. 9; pl. 16, figs. 1-5.

1954 *Virgatosphinctes*n.sp. aff. *andesensis* (Douvillé). Indans, p.112, pl. 17, figs. 1-3.

1954 *Virgatosphinctes* cf. *mexicanus* (Burckhardt). Indans, p. 113, pl. 18, fig. 1.

1958 *Virgatosphinctes andesensis* (Douvillé). Corvalán & Pérez, p. 43, pl. 8, fig. 18a-b. (=Douvillé, p. 7, pl. 1, fig. 4).

1959 *Virgatosphinctes andesensis* (Douvillé). Corvalán, p. 23, pl. 4, fig. 18; pl. 5, fig. 19.

1959 *Virgatosphinctes leñaensis* Corvalán, p. 22, pl. 14-15.

1964 *Subplanites mendozanus* (Burckhardt). Enay, p. 365.

1964 *Virgatosphinctes andesensis* (Douvillé). Biro, p. 58.

1970 *Virgatosphinctes andesensis* (Douvillé). Tavera, p. 181, pl. 2, fig. 3.

1973 *Zaraiskites scythicus* (Vischniakoff). Dembowska, p. 65, 85, 102, pl. 5, figs 2, 4-5.

1974 *Zaraiskites scythicus* (Vischniakoff). Kutek & Zeiss, p. 531, pl. 27, figs. 2-5; pl. 28, figs. 1-4; pl. 29, figs. 1-3; pl. 30, figs. 1-2; pl. 31, figs. 1-4; pl 32, figs. 3-5.

1979 *Virgatosphinctes* sp. nov. aff. *andesensis* (Douvillé). Thomson, p. 18, pl. 4, figs. e-g.

1979 *Virgatosphinctes* aff. *mexicanus* (Burckhardt). Thomson, p. 20, pl. 4, fig. h.

1980 *Virgatosphinctes mexicanus* (Burckhardt). Leanza, p. 28, pl. 2, figs. 1a-b; text-figs. 7c.

1980 *Virgatosphinctes andesensis* (Douvillé). Leanza, p. 29, pl. 2, figs. 5a-b; text-figs. 7d, 9.

1981a *Virgatosphinctes mexicanus* (Burckhardt). Leanza, pl. 1, figs. 5-6 (= Leanza 1980)

1989 *Virgatosphinctes* cf. *mexicanus* (Burckhardt). Howlett, p. 16, pl. 1, fig. 4; pl. 2, fig. 3.

1989 *Virgatosphinctes* cf. *andesensis* (Douvillé). Howlett, p. 17, text-fig. 2C.

1992 *Virgatosphinctes* cf. *mexicanus* (Burckhardt). Sey et al. pl. 90, fig. 16.

1997 *Virgatosphinctes* cf. *andesensis* (Douvillé). Riley et al. p. 438, fig. 3j.

1999 *Zaraiskites scythicus* (Vischniakoff). Mitta et al. p 36, pl. 2, fig. 6; pl. 3 (8), fig. 1 (1) (lectotype), fig 2 (=Vischniakoff, 1882).

2006 "*Torquatisphinctes*" cf. *mendozanus* (Burckhardt). Parent et al., p. 259, figs. 4c-d.

2011a *Choicensisphinctes* cf. *mendozanus* (Burckhardt). Parent et al., p. 77, fig. 24.

Type: Lectotype was designated by Mitta et al. (1999). It is the specimen ГГМ.экз N° VI-64/35, illustrated by Vischniakoff (1882, p. 41, pl. 25, figs. 6-8), from the Volgian of Russia.

Material: 9 internal moulds of fragmentary phragmocones. CPUC/RM/10-5, CPUC/RM/33-12 and CPUC/RM/Rd-45 are well preserved fragments. CPUC/RM/10-4, CPUC/RM/14-1, CPUC/RM/20-12, CPUC/RM/20-13 and CPUC/RM/33-20 are small and poorly preserved fragments. CPUC/RM/10-8 is an imprint of a fragmentary phragmocone.

Description: Coiling evolute and discoidal. Whorl section subovally rounded, higher than wide. The umbilical border is rounded, flanks are convex and the venter rounded. Maximum width is reached dorsolaterally. Ornament consists of prominent primary ribs that initiate near the umbilical shoulder, the latter is crossed in rursiradiate direction. From the umbilical border to the middle part of the flank ribs are more prominent and are prorsiradiate. At the middle part of the flank ribs exhibit a slight inflection backwards and are divided into secondary ribs at different heights (virgate) of the middle part of the flanks. These secundaries are grouped as virgatotomic branches of two to four ribs. Intercalated single ribs are also present but disappear dorsolaterally. All ribs cross the venter without interruption. Fragmentary phragmocone CPUC/RM/Rd-4 also presents a constriction.

Complementary description: Specimens described by Indans (1954) as *V. andesensis* and *V. mexicanus* are included here. STIPB-17 is an adult (D: 195; its last whorl presents a subovally rounded whorl section which is higher than wide. The umbilical border is rounded, flanks are convex and the venter rounded. Maximum width is reached dorsolaterally. Ornament consists of primary ribs that are bi- to trifurcated and intercalate with one to two single ribs on the ventrolateral area and the venter. Ribs are more distanced than in juvenile stages.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/10-4			31.7			
CPUC/RM/10-5		24.9	27.3	0.91		
CPUC/RM/10-8			(26.8)			
CPUC/RM/14-1		(26.5)	(27.3)	0.97		
CPUC/RM/20-12		34.1	36.0	0.95		
CPUC/RM/20-13			24.6			
CPUC/RM/33-12		28.7	31.9	0.90		
CPUC/RM/33-20		31.2				
CPUC/RM/Rd-45		31.1	(30.8)	(1.00)		

Remarks: *Virgatosphinctes mexicanus* and *V. andesensis* are closely related and resemble *V. scythicus* in whorl section and ornamentation. *V. mexicanus* is distinguished by constrictions on the last whorl (Burckhardt 1906, Douvillé 1910a, Indans 1954 and Leanza 1910). Occasional constrictions are also reported for *V. andesensis* (e.g., Douvillé, 1910a, Weaver, 1931, Indans, 1954, Leanza, 1980). In *V. mexicanus* constrictions are bordered by a stronger rib and in *V. andesensis* by a fine prominent rib (Douvillé 1910a, Indans 1954 and Leanza 1980). These differences are minor and can also be attributed to a preservational bias. In addition, Thomson (1979) indicated that ornamentation of *V. andesensis* changes during various stages of growth. Here we consider *V. mexicanus* and *V. andesensis* as conspecific.

Virgathosphinctes evolutus was considered to be slightly more inflated than *V. andesensis* but all other morphological characteristis are identical (Parent et al. 2011a). Based on the high variability of both taxa they are here considered synonymous.

Weaver (1931) indicated that *V. andesensis* is closely allied to *V. scythicus* from the Tithonian of Russia, which was regarded closely related with *V. mexicanus* by Burckhardt (1906).

V. mexicanus and *V. andesensis* are highly similar to *V. mendozanus* (e.g., Burckhardt 1903, Douvillé 1910a, Weaver 1931, Indians 1954, Thomson 1979, Leanza 1980 and Howlett 1989), but the nomenclatural history of *V. mendozanus* is complex: According to Leanza (1980, p. 13), Burckhardt (1900) figured the taxon as *Perisphinctes* aff. *Lothari*, but later (Burckhardt, 1903).refered the species to *Virgatites scythicus* Vischniakoff. This classification was questioned by Douvillé (1910a) who establishing *Virgatites andesensis* and considered *Virgatites scythicus* in Burckhardt (1903) to by a synonym. Burckhardt (1911 and 1912) included *V. andesensis* in his synonymy of *Virgatites scythiscus*. Burckhardt (1911) proposed a new name, *Virgatites mendozanus,* for the same specimens.

Douville (1910a) suggested that *Virgatites scythicus* differed from *V. andesensis* by more distanced ribs, a slightly higher whorl section and finer ribs. However, the Russian type is an adult specimen (D=113 mm) and morphological differences with *Virgatites andesensis* may well be the result of ontogenetic variation and comparison between juvenile and adult stages (e.g. figure 6). Ribs on the last whorl of the type specimen of *Ammonites scythicus* Vischniakoff (1882) are more spaced than in internal ones. These changes are diagnostic to the genus *Virgathosphinctes* (Uhlig 1910). Juvenile specimens figured by Vischniakoff (1882) show evolute coiling, discoidal shell, suboval–rounded whorl section and prominent primary ribs that are tri-tetrafurcated.

Ammonites scythicus Vischniakoff (1882; see also complementary descriptions by Lewinski 1923, Dembowska 1973, Kutek & Zeiss 1974) may thus be inseparable from *V. mexicanus*, *V. andesensis* and *V. mendozanus* (e.g., Burckhardt 1903, Douvillé 1910a, Weaver 1931, Indians 1954, Thomson 1979, Leanza 1980 and Howlett 1989). These species are here considered synonymous with *Virgatosphinctes scythicus* (Vischniakoff, 1882), which appears to be a morphologically variable taxon (figure 4.4).

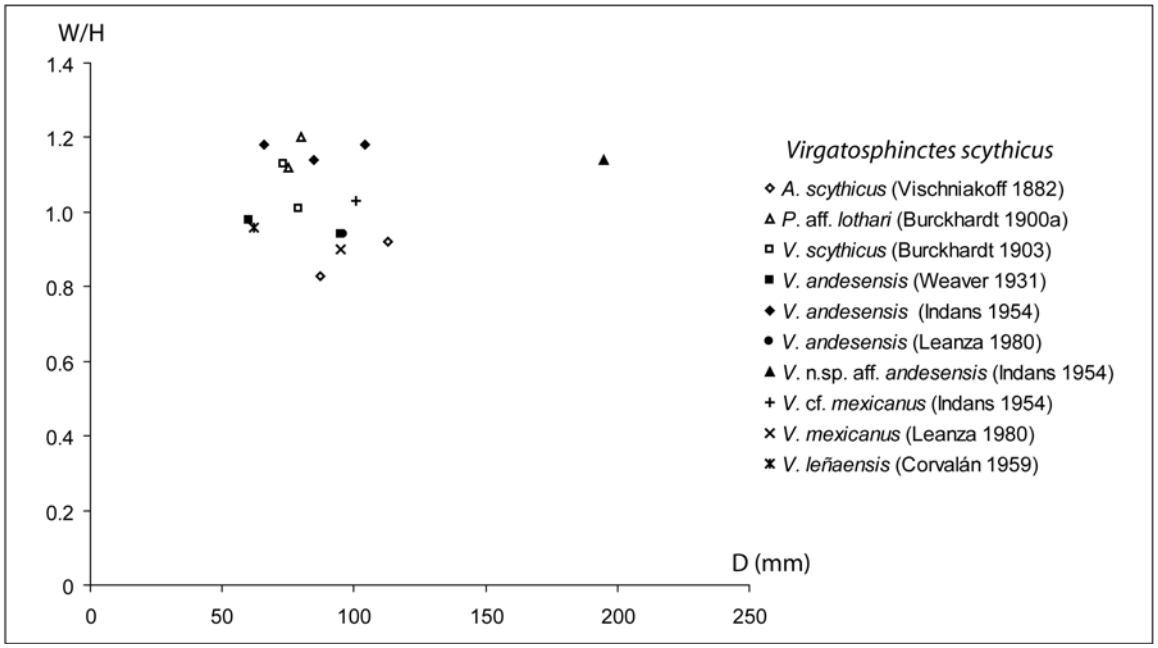


Figure 4.4. Relationship between W/H and D in *Virgatosphinctes scythicus* (Vischniakoff 1882). The data indicate that this species is morphologically variable.

Figure 4.5. a-e: *Virgathosphinctes scythicus* (Vischniakoff, 1882), **a-b:** *Ammonites scythicus* Vischniakoff, 1882, Lectotype ГГМ.экз N° VI-64/35 x1. **c-e:** *Virgatosphinctes andesensis* (Douvillé 1910), described by Indans (1954), STIPB-16a x1.

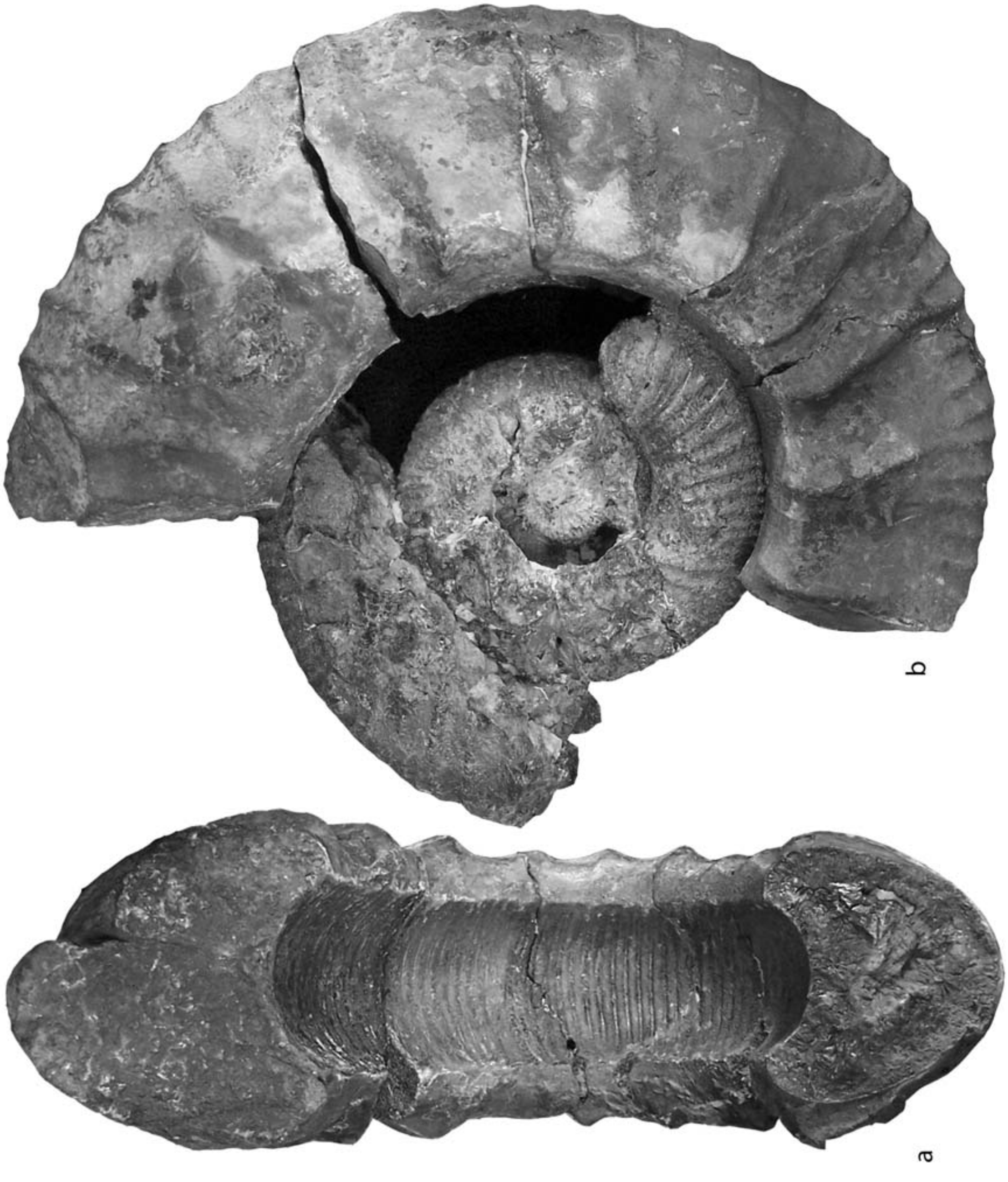


Figure 4.6. a-b: *Virgathosphinctes scythicus* (Vischniakoff, 1882), **a-b*:*** *Virgatosphinctes* n. sp. aff. *Andesensis,* in Indans (1954) x0.75

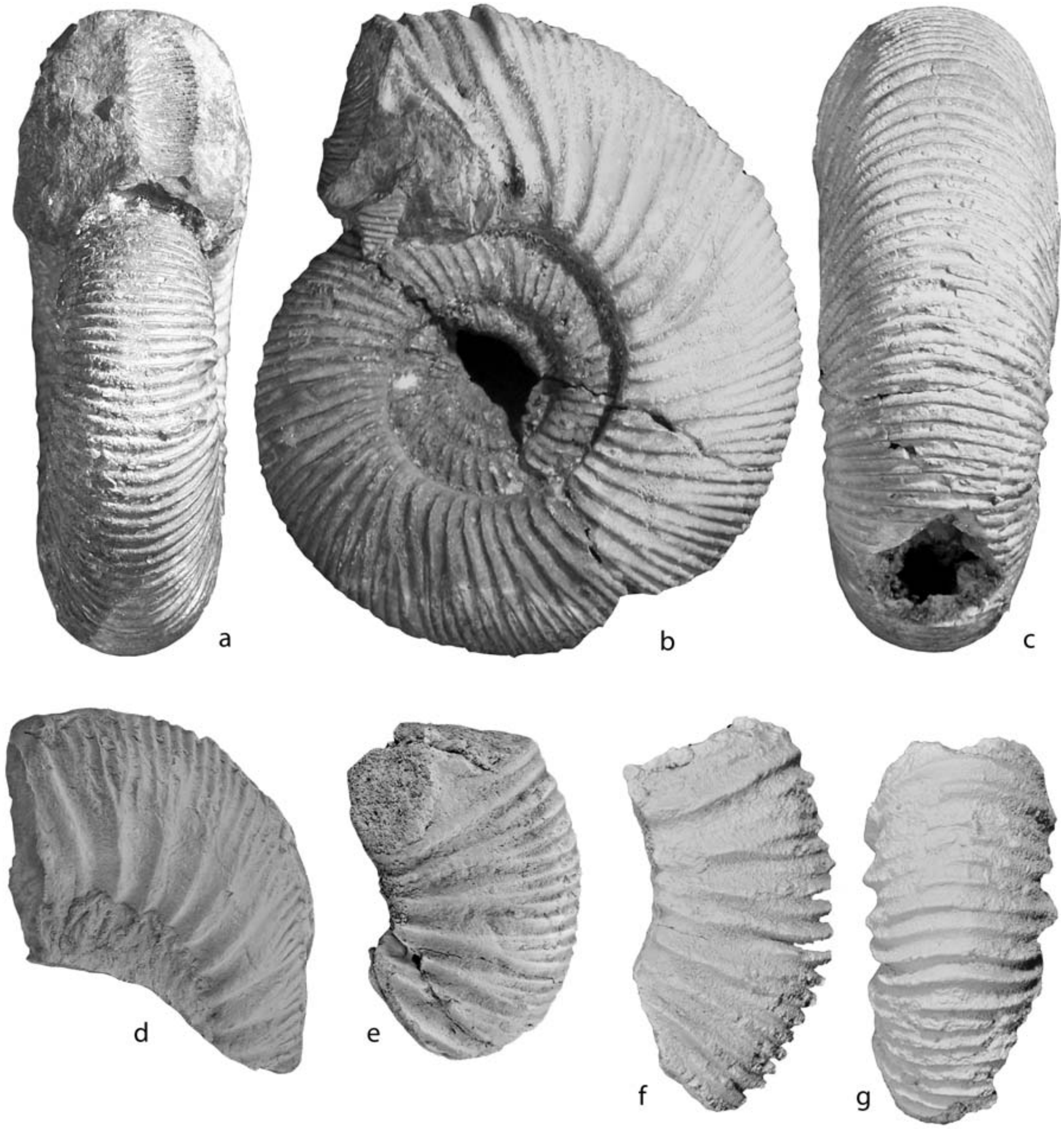


Figure 4.7. a-g:*Virgathosphinctes scythicus* (Vischniakoff, 1882), **a-c:** *Virgatosphinctes* cf. *mexicanus,* in Indans (1954), x1; **d-g:** *Virgathosphinctes scythicus* from the Baños del Flaco Formation; **d:**CPUC/RM/10-05, x1; **e:** CPUC/RM/33-12, x1; **f-g:** CPUC/RM/Rd-45, x1.

Occurrence: At Rio Maitenes, this taxon is present in the Lower member of the Baños del Flaco Formation, in the unit of sandstone/calcareous sandstone (figure 5.4). *V. mexicanus* was described for the Tithonian in Mexico (Burckhardt 1906), the Lower Tithonian of Far East Russia (Sey et al. 1992), the Lower Tithonian of Mendoza in Argentina (Indians 1954) and the Uppermost Lower Tithonian of the Vaca Muerta Formation at Cerro Lotena in Argentina (Leanza 1980). *V. andesensis* was reported from the Lower Tithonian of Mendoza and Neuquen in Argentina (Weaver 1931, Indians 1954, Leanza 1980) and from the Lower Tithonian of Central Chile

(Corvalán & Pérez 1958, Corvalán 1959, Biro 1980a, Hallam et al. 1986). *Virgatosphinctes mendozanus* is considered a Lower Tithonian biozone index in the Neuquen basin in Argentina (Leanza 1980). In Antarctica, *V. andesensis* and *V. mexicanus* were recorded from Alexander Island and were assigned to the Lowermost Tithonian (Thomson 1979, Howlett 1989).

In Poland *Virgatosphinctes scythicus* was assigned to the Lower to Middle Volgian by Kutek & Zeiss (1994), or to the Middle Volgian by Rogov (2004). In Russia the taxon is assigned to the Lowermost Middle Volgian (Rogov 2010).

Subfamily TORQUATISPHINCTINAE Tavera, 1985

Genus *Catutosphinctes* Leanza & Zeiss, 1992

Type species. *Catutosphinctes rafaeli* Leanza & Zeiss 1992, by original designation. Parent et al. (2011a), give a complementary description and discussion of this genus.

Catutosphinctes cf. *americanensis* (Leanza, 1980)

Figure 4.8

1980 *Pachysphinctes americanensis* Leanza, p. 41, pl. 7, fig. 1a-d; text-fig. 7k. (Holotype).

Type: Holotype designated by Leanza (1980, pl. 7, fig. 1a-d), is the specimen S.G.N 8952/1, from the Middle Tithonian Vaca Muerta Formation, Argentina.

Material: A single internal mould, CPUC/RM/55-1, an incomplete and poorly preserved phragmocone.

Description: Coiling evolute and umbilicus wide. Whorl section is deformed but apparently discoidal. The umbilical border is rounded, flanks are convex and the venter is rounded. Maximum width is reached on the dorsal flank. Ornamentation on the last whorl consists in distanced and wide ribs with elongated tubercles on the umbilical border. Two ribs initiate at each tubercle. Internal whorls are ornamented by slightly prorsiradiate single ribs that are bifurcated on the middle part of the flank.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/55-1	(145.2)	42.6	(38.0)	(1.12)	65.4	(0.45)
S.G.N 8952/1 (Holotype)	196.0	69.0	58	1.18	101.0	0.51

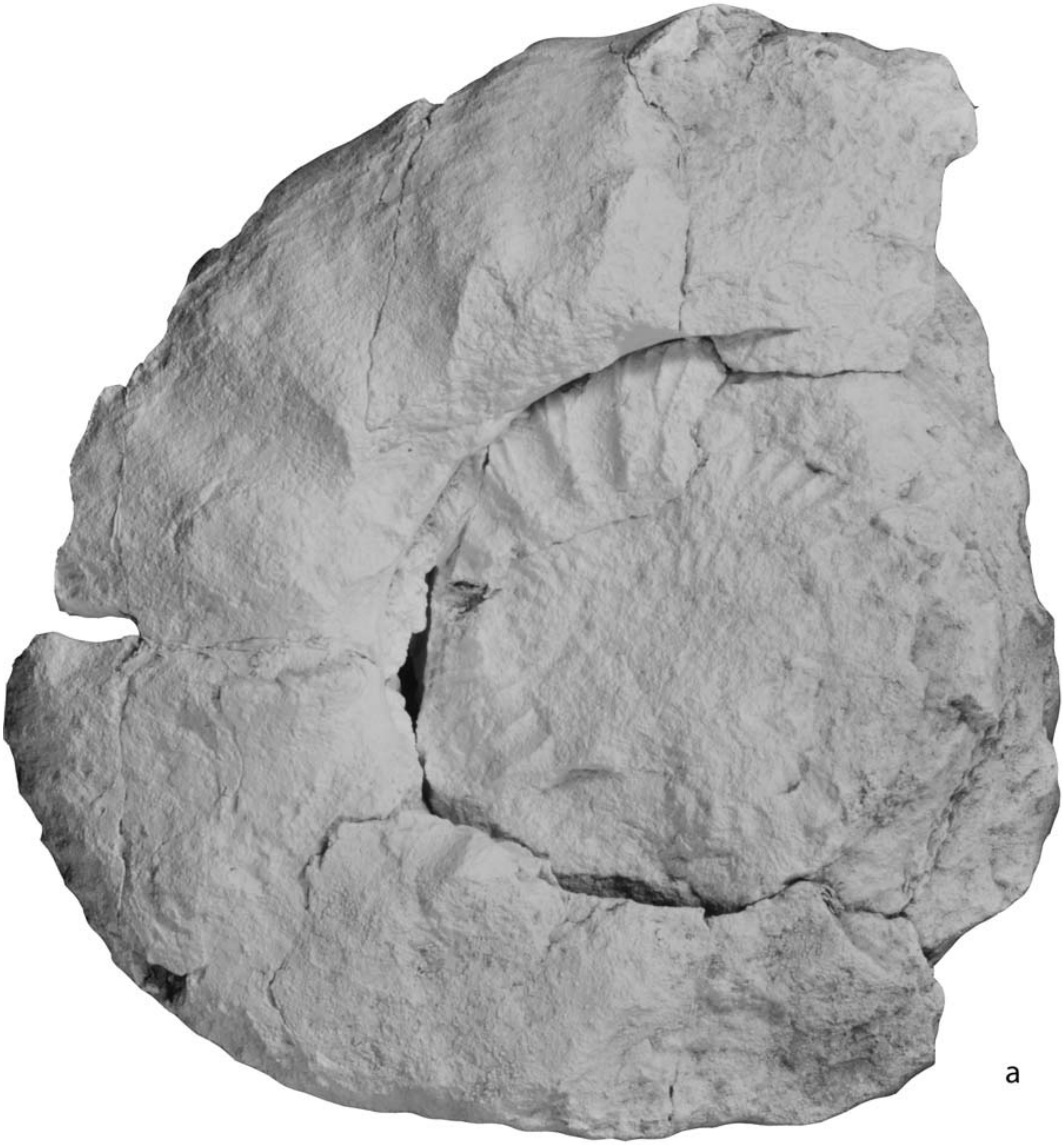


Figure 4.8. a: *Catutosphinctes* cf. *americanensis* Leanza (1980), CPUC/RM/55-01 x1.

Remarks: The specimen here is *conferred* (cf.), because is poorly preserved. Leanza & Zeiss (1992) give a full description and discussion of this species.

Occurrence: At Rio Maitenes, this taxon is present in the Lower member of the Baños del Flaco Formation, in the upper part of the sandstone/calcareous sandstone unit (figure 5.4). In Argentina *Pachysphinctes americanensis* is recorded from the Uppermost Middle Tithonian of the Vaca Muerta Formation (Leanza 1980).

Family HIMALAYITIDAE Spath, 1925

Genus *Windhauseniceras* Leanza, 1945

Type species. *Perisphinctes internispinosus* Krantz (1926, p. 453, pl. 14, figs. 1-2), STIPB 25a, as designated by Leanza (1945, p. 22).

Windhauseniceras internispinosum (Krantz, 1928)

Fig. 4.9, 4.10

1897	*Reineckeia* cf. *stephanoides* Oppel sp. Steuer, p. 157, pl. 28, fig. 11-12.
1921	*Reineckeia* cf. *stephanoides* Oppel sp. Steuer, p. 58, pl. 14, figs. 11-12 (= Steuer 1897).
1926	*Perisphinctes internispinosus* Krantz, p. 453, pl. 14, figs. 1-2.
1926	*Aulacosphinctes hebecostatus* Krantz, p. 455.
1928	*Perisphinctes internispinosus* Krantz, p. 39, pl. 2, figs. 3-4 (= Krantz 1926).
1928	*Aulacosphinctes hebecostatus* Krantz, p. 42, pl. 3, fig. 8 (= Krantz 1926).
1931	*Perisphinctes internispinosus* Krantz. Weaver, p. 419, pl. 47. fig. 312.
1945	*Windhauseniceras* cf. *internispinosum* (Krantz). Leanza, p. 23, pl. 21, fig. 6.
1957	*Windhauseniceras internispinosum* (Krantz). Arkell et al., p. L356, fig. 468: 7a-d (= Krantz 1928a).
1958	*Windhauseniceras internispinosum* (Krantz). Corvalán & Pérez, p. 44, pl. 10, fig. 23a, 23b, 23c (= Krantz 1928a).
1959	*Windhauseniceras internispinosum* (Krantz). Corvalán, p. 16, pl. 4, figs. 16-17.
1960	*Windhauseniceras* aff. *internispinosum* (Krantz). Bürgl, p. 197, pl. 1, fig. 5.

1980 *Windhauseniceras internispinosum* (Krantz). Leanza, p. 43, pl. 8, fig. 4a, 4b; pl. 9, fig. 1a-b; text-fig. 10d

1980 *Hemispiticeras* aff. *steinmanni* (Steuer). Leanza, p. 43, pl. 9, fig. 2.

1981a *Windhauseniceras internispinosum* (Krantz). Leanza, pl. 2, figs. 7-8 (= Leanza 1980, pl. 9, fig. 1a-b)

1990 *Windhauseniceras* sp. cf. *internispinosum* (Krantz). Aguirre-Urreta & Charrier, p. 265, pl. 1, fig. 9.

1994 *Windhauseniceras internispinosum* (Krantz). Pérez & Reyes, p. 59.

1998 *Windhauseniceras internispinosum* (Krantz). Furrazola-Bermúdez et al. p.17.

2003b *Windhauseniceras internispinosum* (Krantz). Parent, p. 354, figs. 1a-d (=Krantz 1928a, pl. 14, fig. 1-2) fig. 1e-f (=Krantz 1928a, pl. 15, fig. 5-6).

2007 *Windhauseniceras internispinosum* (Krantz). Parent et al. p. 20, figs. 9-10.

Type: Lectotype is STIPB 25a, the original from Krantz (1926, p. 453, pl. 14, figs. 1-2), from the Tithonian of Mendoza (Argentina), by subsequent designation of Parent (2003b, p. 354, fig. 1).

Material: 71 internal moulds, which are complete and fragmentary phragmocones. CPUC/RM/60-45, CPUC/RM/60-49, CPUC/RM/60-52, CPUC/RM/60-55, CPUC/RM/60-75b, CPUC/RM/Rd-21, CPUC/RM/Rd-22, CPUC/RM/Rd-24 are complete phragmocones and regular to well preserved. CPUC/RM/59-18, CPUC/RM/59-55, CPUC/RM/59-63, CPUC/RM/60-22, CPUC/RM/60-28, CPUC/RM/60-50, CPUC/RM/60-70, CPUC/RM/60-74, CPUC/RM/60-75a, CPUC/RM/Rd-18, CPUC/RM/Rd-23 are well preserved fragmentary phragmocones.

Description: Coiling evolute and umbilicus wide. In young specimens ($D < 50$ mm) the whorl section is wider than high. The umbilical border is rounded, flanks are convex and converge towards the narrowly rounded venter. Maximum width is reached on the dorsolateral part of the flank. Ornamentation consists of strong primary ribs, which are slightly prorsiradiate. Ribs bi- to trifurcate on the middle part of the flank. Elongate tubercles were not observed, but their absence may result from preservation of the material as internal moulds. 1-2 constrictions are present on the last whorl and are parallel to primary ribs. Whorl section changes gradually towards higher than wide in adult stages ($D > 50$ mm) (figure 4.9). The umbilical border is rounded; flanks are convex and converge towards the rounded venter. Maximum width is reached on the dorsolateral part of the flank. Ornament consists of primary ribs which are slightly prorsiradiate and bifurcate on the middle part of the flank. On the last whorl, 1-2 constrictions are parallel to the primary ribs.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/59-04	(30.0)	(14.2)	(14.9)	(0.95)	(6.6)	(0.22)
CPUC/RM/59-14	28.7	12.7	11.9	1.06	9.0	0.31
CPUC/RM/59-18	29.0	12.7	11.9	1.07	10.0	0.34
CPUC/RM/59-36	41.7	18.8	15.6	1.20	16.0	0.38
CPUC/RM/59-39	29.0	14.2	(11.2)	1.27	9.2	0.32
CPUC/RM/59-40	25.7	(11.4)	(11.7)	0.97	6.4	0.25
CPUC/RM/59-50	(29.1)	(12.7)	(10.4)	(1.22)	13.1	(0.45)
CPUC/RM/59-59	34.2	(14.0)	(13.9)	(1.00)	(11.8)	(0.35)
CPUC/RM/59-63	23.3	10.3	9.9	1.04	8.6	0.37
CPUC/RM/60-20	33.0	(12.9)	(12.8)	(1.00)	(10.8)	(0.33)
CPUC/RM/60-22	36.3	(16.5)	(14.3)	(1.15)	15.1	0.42
CPUC/RM/60-26	37.9	(15.0)	(15.5)	(0.97)	(15.2)	0.40
CPUC/RM/60-31	36.8	16.1	14.4	1.12	(10.7)	(0.29)
CPUC/RM/60-32	(33.7)	15.0	14.0	1.07	12.2	(0.36)
CPUC/RM/60-36	32.3	(14.3)	(13.0)	(1.10)	(11.4)	0.35
CPUC/RM/60-37	36.7	15.5	13.6	1.14	14.9	0.41
CPUC/RM/60-45	47.5	18.7	15.8	′1.18	20.3	0.43
CPUC/RM/60-49	23.7	11.5	9.5	1.21	8.7	0.37
CPUC/RM/60-50	27.8	13.7	12.5	1.10	9.8	0.35
CPUC/RM/60-52	36.0	(14.5)	(13.7)	(1.06)	11.8	0.33
CPUC/RM/60-55	18.9	9.7	8.7	1.11	5.2	0.28
CPUC/RM/60-58	20.8	10.6	9.0	1.18	7.1	0.34
CPUC/RM/60-60	31.5	(12.2)	(12.3)	(0.99)	(10.8)	0.34
CPUC/RM/60-61	18.8	(8.1)	(7.7)	(1.05)	5.1	0.27
CPUC/RM/60-69	(32.4)	(16.6)	(14.4)	(1.15)	(9.1)	(0.28)
CPUC/RM/60-74	42.5	16.8	14.5	1.16	17.0	0.40
CPUC/RM/60-75b	17.1	(8.2)	7.7	(1.06)	5.2	0.30
CPUC/RM/60-80	30.6	(12.6)	(12.4)	(1.02)	10.6	0.35
CPUC/RM/Rd-9	61.7	(17.9)	(21.9)	(0.82)	(25.6)	(0.41)
CPUC/RM/Rd-18	(63.1)	23.8	20.1	1.18	24.4	(0.39)

CPUC/RM/Rd-21	39.9	17.8	16.0	1.11	14.1	0.35
CPUC/RM/Rd-22	22.5	10.8	9.3	1.16	8.0	0.36
CPUC/RM/Rd-23	31.9	13.7	13.0	1.05	9.6	0.30
CPUC/RM/Rd-24	40.8	17.4	15.7	1.11	14.3	0.35
CPUC/RM/Rd-37	26.8	13.1	(12.1)	(1.08)	(6.9)	(0.26)

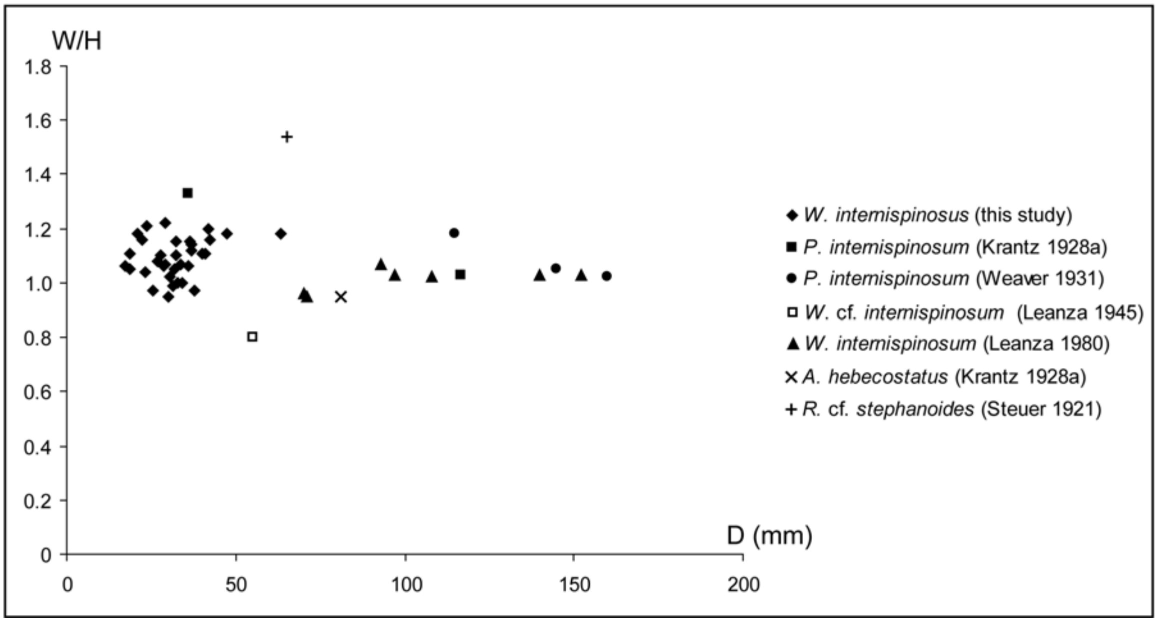


Figure 4.9. *Windhauseniceras internispinosus* (Krantz, 1926). Relationship between W/H and D. Note that the whorl section changes gradually between juvenile and adult stages.

Remarks: Parent (2003b, 2007) gives a full description and discussion of this species and also discusses the important intraspecific variation of this taxon.

Occurrence: At Rio Maitenes, this taxon is present in the Lower member of the Baños del Flaco Formation, in the upper part of the unit of sandstone/calcareous sandstone (figure 5.4). In Argentina, *W. internispinosum* is recorded from the upper part of the Middle Tithonian in the Mendoza and Neuquén provinces (Krantz 1928 a-b, Weaver 1931, Leanza 1945, Leanza 1980, Leanza & Zeiss 1990-1992, Steuer 1897-1921). In Colombia, the species was recorded from the Upper Tithonian (Bürgl 1960). In central Chile it was registered for the Middle-Upper Tithonian boundary at Nacientes del Maipo (Aguirre-Urreta & Charrier 1990) and the Upper Tithonian of Rio Leñas (Corvalán 1959).

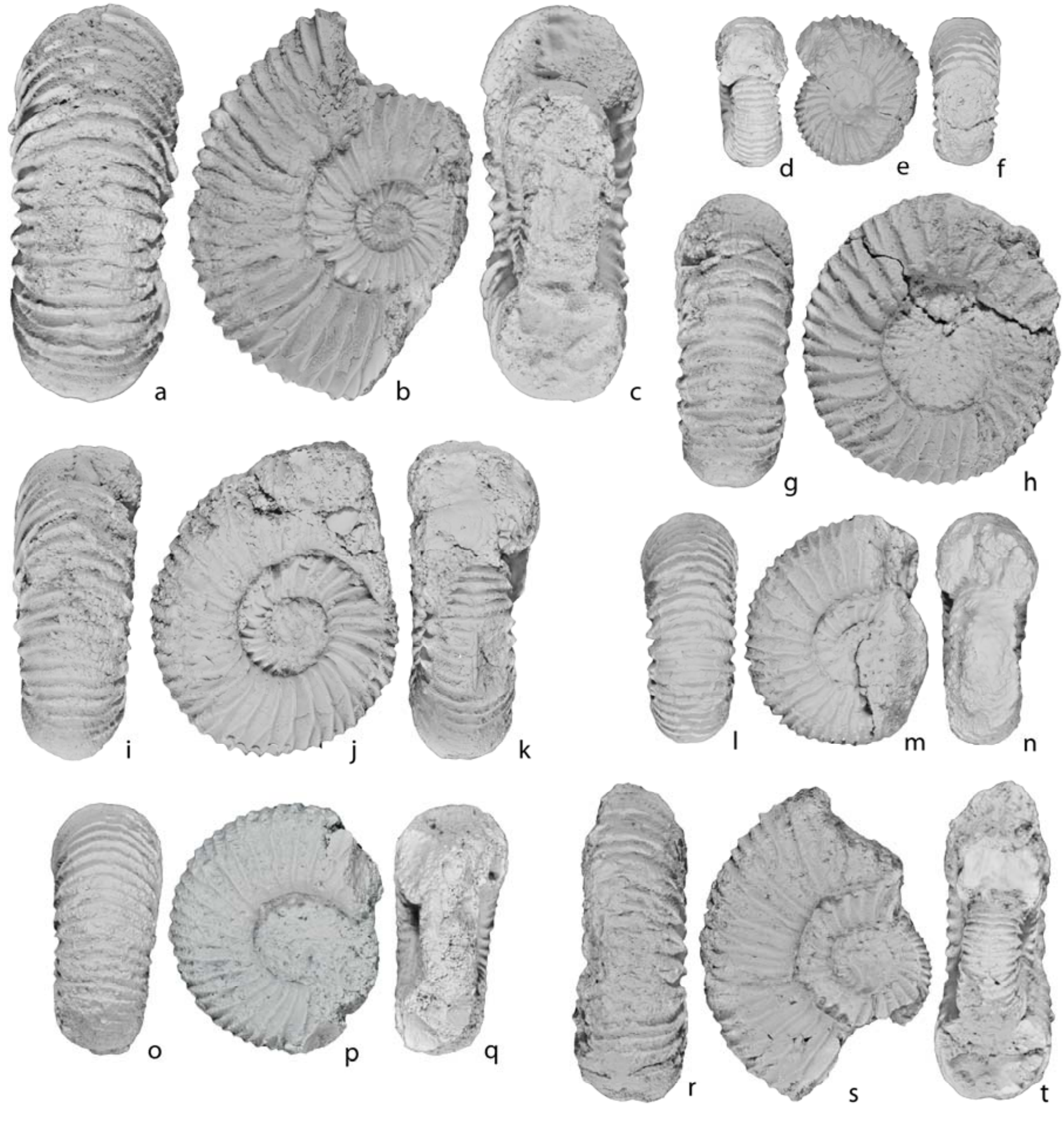


Figure 4.10. a-t: *Windhauseniceras internispinosum* (Krantz, 1926) from the Baños del Flaco Formation, **a-c:** CPUC/RM/Rd-18, x1; **d-f:**CPUC/RM60-49, x1; **g-h:** CPUC/RM/60-45, x1; **i-k:** CPUC/RM/Rd-24, x1; **l-n:** CPUC/RM/60-13, x1; **o-q:** CPUC/RM/Rd-21, x1; **r-t:** CPUC/RM/60-70, x1.

Genus *Aulacosphinctes* Uhlig, 1910

Genus description: Coilling evolute and compressed, ribs are strong, distant, widely biplicate, some simple. Tubercles are absent, ventral groove deep and persistent; rather long lappets (Uhlig 1910 and Oppel 1865, in Arkell et al. 1957).

Remarks: The style of ribbing of this genus is close related with Himalayitinae (Arkell et al. 1957), but the morphological characteristics are also present in Berriasellinae, being the density and spacing of the ribs the main differences.

Aulacosphinctes proximus (Steuer, 1897)

Figure 4.11

1897 *Reineckeia proxima* Steuer, p. 160, pl. 8, figs. 7-9.
1897 *Perisphinctes colubrinus* Reinecke. Steuer, p. 188, pl. 15, fig. 11.
1900 *Perisphinctes contiguus* Catullo. Burckhardt, p. 45, pl. 24, fig. 1.
1900 *Reineckeia* aff. *cimbrica* Neumayr. Burckhardt, p. 40, pl. 24. fig. 2.
1900 *Perisphinctes colubrinus* Reinecke. Burckhardt, p. 44, pl. 24, figs. 5-6.
1900 *Perisphinctes colubrinus* Reinecke. Burckhardt, p. 46, pl. 26, fig. 4.
1907 *Perisphinctes proximus* (Steuer). Haupt, p. 192.
1921 *Reineckeia proxima* Steuer, p. 61, pl. 8, figs. 7-9 (= Steuer 1897)
1921 *Perisphinctes colubrinus* Reinecke. Steuer, p. 90, pl. 5, fig. 11 (= Steuer 1897).
1928 *Aulacosphinctes wanneri* Krantz, p. 42, pl. 2, figs. 6a, b.
1931 *Aulacosphinctes proximus* (Steuer). Weaver, p. 411, pl. 44, figs. 298-299.
1931 *Aulacosphinctes colubrinus* (Reinecke). Weaver, p. 413, pl. 44, figs. 301-303.
? 1954 *Virgatosphinctes inaequicostatus* Indans, p. 120, pl. 15, figs. 2-3.
? 1954 *Virgatosphinctes prorsocostatus* Indans, p. 120, pl. 15, figs. 4-5.
1954 *Perisphinctes* (*Dichotomosphinctes*?) sp. Indans, p. 124, pl. 20, fig. 3.
1959 *Aulacosphinctes* sp. aff. *A. colubrinus* (Reinecke). Corvalán, p. 12, pl. 5, fig. 22.
1959 *Aulacosphinctes proximus* (Steuer). Corvalán, p. 13, pl. 6, fig. 23.
1959 *Aulacosphinctes chilensis* Corvalán, p. 15, pl. 6, fig. 24.
1964 *Aulacosphinctes proximus* (Steuer). Biro, p. 46.
1980a *Aulacosphinctes proximus* (Steuer). Biro, p. 143-144.

1980	*Aulacosphinctes proximus* (Steuer). Leanza, p. 44, pl. 6, figs. 2, 4-5.
1981a	*Aulacosphinctes proximus* (Steuer). Leanza, pl. 2, figs. 9-10 (= Leanza 1980).
1999	*Troquatisphinctes* cf. *proximus* (Steuer). Parent & Capello, p. 349.
2003a	*Troquatisphinctes proximus* (Steuer). Parent, p. 159, figs. 1, 9i-l, 12a-b, 13a-c.
2004	*Aulacosphinctes* cf. *proximus* (Steuer). Yin & Enay, p. 673, pl. 3, fig. 4a, b).
? 2009	*Aulacosphinctes proximus* (Steuer). Aguirre-Urreta & Vennari, p. 39, figs. 5r-t.
2011b	*Catutosphinctes proximus* (Steuer). Parent et al., p. 81. fig. 25B. (= Steuer 1897).

Type: Lectotype is GZG 499-30, the original of Steuer (1897, p. 160, pl. 8, figs. 7-9) from the Tithonian of Mendoza (Argentina), by subsequent designation by Parent (2003, p. 159, fig. 9i-j).

Material: 51 internal moulds, which are complete and fragmentary phragmocones. CPUC/RM/47-14, CPUC/RM/59-2, CPUC/RM/59-4, CPUC/RM/59-24, CPUC/RM/59-71 and CPUC/RM/Rd-30 are complete phragmocones and regular to well preserved. CPUC/RM/59-3, CPUC/RM/59-6, CPUC/RM/59-21, CPUC/RM/59-20, CPUC/RM/59-26, CPUC/RM/59-32, CPUC/RM/Rd-7 and CPUC/RM/Rd-33 are fragmentary well preserved phragmocones.

Description: Coiling evolute, umbilicus wide and shell discoidal. Whorl section subquadrate, slightly higher than wide. The umbilical border is rounded, flanks are convex and slightly rounded towards the smooth and flat venter. Maximum width is reached on the middle part of the flank. Ornament consists of primary ribs that are slightly flexuous, rursiradiate to prorsiradiate, slightly convex on the dorsolateral and on the middle part of the flank. On the ventrolateral area ribs bend forward and are prorsiradiate. Ribs are bifurcated in the middle part of the flank and some are trifurcate. With increasing diameter, trifurcate ribs are gradually more common. Shallow constrictions are detected in larger specimens.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/47-14	(27.9)		(10.8)		(11.1)	(0.39)
CPUC/RM/59-2		(18.1)	18.5	(0.98)	(24.8)	
CPUC/RM/59-2	32.7	(11.2)	(13.0)	(0.86)	11.0	0.33
CPUC/RM/59-3		(20.2)	(19.3)	(1.04)		
CPUC/RM/59-5		(25.6)	(26.0)	(0.98)		
CPUC/RM/59-6		27.8	28.7	0.97		
CPUC/RM/59-15		(15.3)	(16.0)	(0.96)		

CPUC/RM/59-20	(62.9)	20.0	23.7	(0.84)	(28.0)	(0.44)
CPUC/RM/59-21		17.1	18.4	0.93		
CPUC/RM/59-24	(52.1)	15.6	16.5	0.95	(20.2)	(0.39)
CPUC/RM/59-26		9.9	10.8	0.92		
CPUC/RM/59-31		15.3	17.5	0.87		
CPUC/RM/59-32		(14.8)	15.2	(0.97)		
CPUC/RM/59-71	(23.6)	(8.4)	(9.9)	(0.85)	7.6	(0.32)
CPUC/RM/60-27		(19.1)	(19.8)	(0.96)		
CPUC/RM/60-42		9.9	12.3	0.80		
CPUC/RM/Rd-7		13.2	(12.5)	(1.01)		
CPUC/RM/Rd-33		(14.4)	18.2	(0.79)		
CPUC/RM/Rd-40		15.8	20.1	0.79		

Remarks: Parent (2003a) gives a full description and discussion of this species, assignating the taxon to *Torquatisphinctes*. However, this genus is characterized by denser ribs, a more inflated whorl section and occasional virgatitid-like triplicates at constrictions thoughout the ontogeny. These morphological characteristics are absent in *Aulacosphinctes proximus*. Parent et al. (2011b) assigned the taxon to *Catutosphinctes*, but this genus differs by an outer flank with bifurcated ribs alternating with trifurcated or intercalatory ribs. Constrictions are followed by distant primaries and secondaries which either present bifurcation, polygyration, or irregular splitting (Leanza & Zeiss 1991).

In a complementary diagnosis of *Catutosphinctes*, Parent et al. (2011b) indicate that lamellar tubercles may be present at the point of rib furcation. These are also present in the paralectotype of *A. proximus* figured by Steuer (1897-1921), a small phragmocone with himalyitid characteristics, and on the inner whorls of *Aulacosphinctes proximus* (Verma & Westermann 1973). Based on this element, Parent et al. (2011b) suggest that the taxon *proximus* forms part of *Catutosphinctes.* However, all other morphological elements coincide with those for a himalayitid ammonite. We therefore do not consider the presence of tubercles to be an argument strong enough to differentiate *Aulacosphinctes* from *Catutosphinctes* and follow Oppel (1863), Uhlig (1910) and Spath (1924) in assigning the taxon *proximus* to *Aulacosphinctes*.

Aulacosphinctes chilensis Corvalán (1959) differs only by constrictions on the last whorl of a large specimen, with 95 mm diameter. The area with constrictions may correspond to the living chamber of the individual, and not the phragmocone; it is here assigned to *A. proximus*.

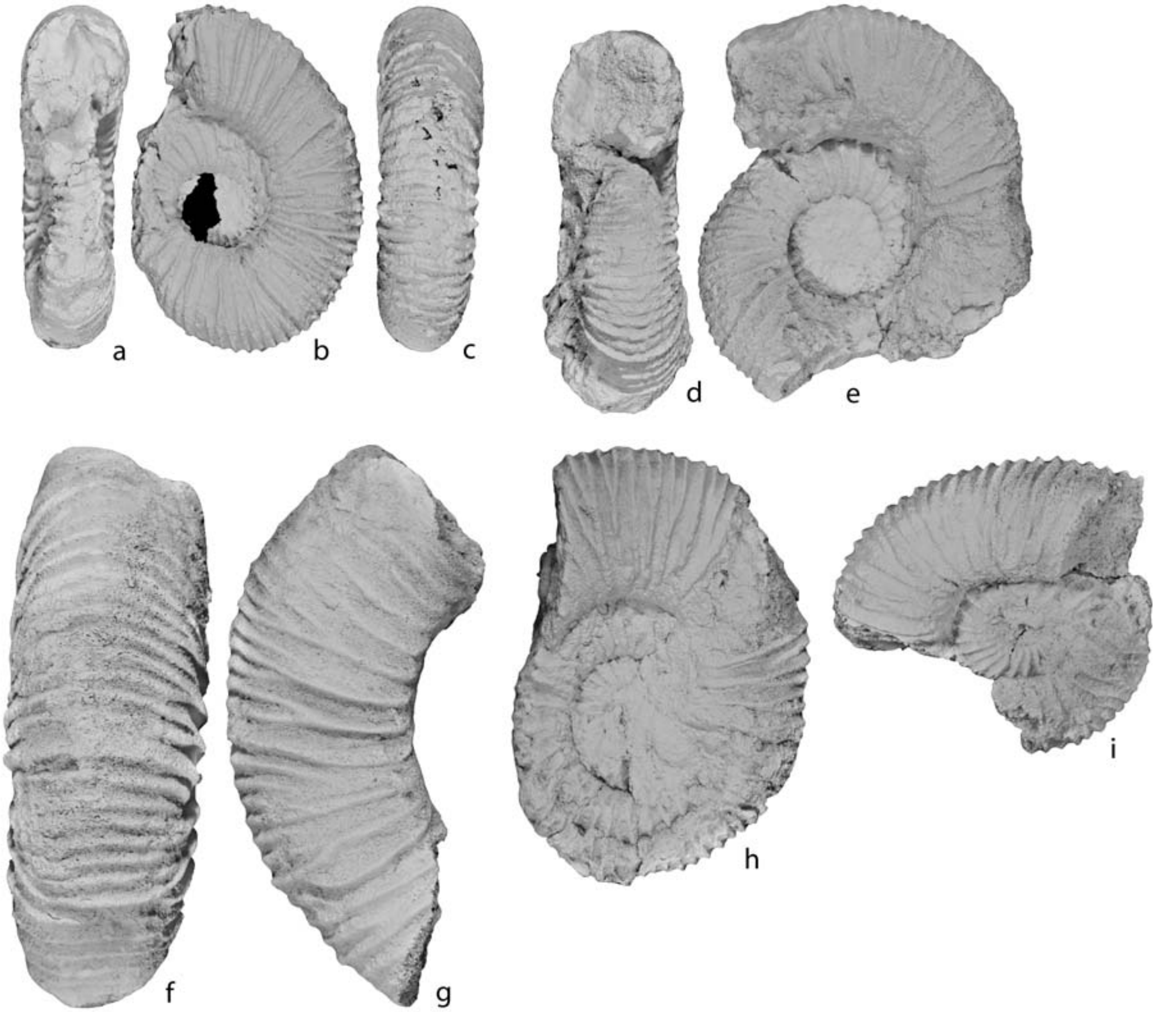


Figure 4.11. a-i: *Aulacosphinctes proximus* (Steuer, 1897) from the Baños del Flaco Formation. **a-c:** CPUC/RM/59-24, x1; **d-e:** CPUC/RM/59-02, x1; **f-g:** CPUC/RM/59-06, x1; **h:** CPUC/RM/59-20; **i:** CPUC/RM/59-21, x1.

Occurrence: At Rio Maitenes, this taxon is present in the Lower member of the Baños del Flaco Formation, in the upper part of the unit of sandstone/calcareous sandstone (figure 5.4). Elsewhere in Chiles *A. proximus* is registered from the Middle Tithonian of the Rio Leñas Formation (Corvalán 1959) which today is considered Baños del Flaco Formation (Charrier 1982), and from the middle to uppermost Tithonian of the Lo Valdés Formation (Biro 1964 and 1980a; Hallam et al. 1986). In Argentina, *A. proximus* was recorded from the middle Tithonian of Neuquén and Mendoza (Steuer 1897-1921, Burckhardt 1900, Haupt 1907, Krantz 1928, Weaver 1931, Leanza 1980, Parent 2003a and Aguirre-Urreta & Vennari 2009). *A. proximus* is also recorded for the upper part of the Lower Tithonian in Tibet in the eastern Himalaya (Yin & Enay 2004).

Genus *Micracanthoceras* Spath, 1925

Type species. *Ammonites microcanthus* Oppel (1865, p. 555), by original designation in Zittel (1868, pl. fig. 3a-b). The specimen was subsequently designated by Spath (1925, p. 144).

Micracanthoceras microcanthum (Oppel, 1865)

Figure 4.12, 4.13

1865 *Ammonites microcanthus* Oppel, p. 555.
1868 *Ammonites microcanthus* Oppel. Zittel, p. 93, pl. 17, figs. 3--, non pl. 17, fig. 1a, 2 (= *Himalayites* sp.), ?pl. 17, fig. 1b, non pl. 17, fig. 4.
1897 *Reineckeia microcantha* (Oppel). Steuer, p. 156, pl. 21, fig. 3-5.
1919 *Hoplites* aff. *microcanthus* (Oppel). Burckhardt, p. 54.
1921 *Hoplites* aff. *microcanthus* (Oppel). Burckhardt, pl. 18, figs. 5-9.
1921 *Reineckeia microcantha* (Oppel). Steuer, p. 56, pl. 7, figs. 3-5 (= Steuer 1897).
1945 *Micracanthoceras tapiai* Leanza A., p. 43, pl. 6, figs. 5-6.
1945 *Himalayites concurrens* A. Leanza, p. 46, pl. 3, figs. 5-6 (lectotype).
1945 *Micracanthoceras lamberti* Leanza A., p. 44, pl. 3, figs. 9-10.
1981b *Micracanthoceras lamberti* Leanza A. Leanza H., p. 570, pl. 3, figs. 5-6 (= Leanza A., 1945).
1981a *Himalayites concurrens* Leanza A. Leanza H., pl. 3, figs. 9-10.
1981b *Micracanthoceras tapiai* Leanza A. Leanza H., p. 570, pl. 3, figs. 14-15 (= Leanza A., 1945).
1985 *Micracanthoceras* (*Micracanthoceras*) *microcanthum* (Oppel). Tavera, p. 169-175, pl. 21, figs. 1-4, pl. 22, figs. 1-6.
2005 *Micracanthoceras concurrens* (A. Leanza). Klein, p. 18.
2005 *Micracanthoceras lamberti* Leanza A. Klein, p. 19.

2005 *Micracanthoceras microcanthum* (Oppel). Klein, p. 19. (with additional synonymy).

2009 *Micracanthoceras* cf. *microcanthum* (Oppel). Shome & Bardhan, p. 6, pl. 4, figs a-g.

? 2011b *Micracanthoceras* sp.A. Parent et al., p. 75, fig. 29E.

Type: Lectotype is the original of Oppel (1865), designed by Zittel (1868). This specimen is also the generotype.

Material: 35 internal moulds, which are complete and fragmentary phragmocones. CPUC/RM/99-43, CPUC/RM/99-72, CPUC/RM/99-75 are complete phragmocones and regular to well preserved. CPUC/RM/99-08, CPUC/RM/99-70, CPUC/RM/99-71, CPUC/RM/99-83, CPUC/RM/Rd-31, CPUC/RM/Rd-32, CPUC/RM/Rd-35 are well preserved fragmentary phragmocones. CPUC/RM/99-03, CPUC/RM/99-23, CPUC/RM/99-36, CPUC/RM/99-37, CPUC/RM/99-38, CPUC/RM/99-51, CPUC/RM/99-73, CPUC/RM/99-82, CPUC/RM/99-84, CPUC/RM/Rd-04, CPUC/RM/Rd-19 CPUC/RM/Rd-44 are regular to poorly preserved fragmentary phragmocones.

Description: Coiling evolute and umbilicus wide. Whorl section is rounded and wider than high. Maximum width on the middle part of the flank. Umbilical border is rounded, flanks are convex and the venter is widely-rounded with a smooth furrow. Ornament is composed by fine rectiradiate ribs. Simple and bifurcated ribs alternate irregularly. Many bi- and trifurcated ribs show fine tubercles on the point of bifurcation. All ribs end in fine tubercles on the venter where a smooth furrow is present. Some specimens show constrictions parallel to the ribs. Juvenile stages (D<50 mm) are rather variable in ornamentation, but adults are more homogenous (figure 4.12).

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/99-08	38.9	13	16	1.23	16.8	0.43
CPUC/RM/99-36	40.1	13.2	14.1	1.07	18.9	0.47
CPUC/RM/99-43	46.1	14.4	13.6	0.94	24.5	0.53
CPUC/RM/99-70	29.4	9.9	12	1.21	13.3	0.45
CPUC/RM/99-71	38.7	14.6	12.1	0.83	19.4	0.50
CPUC/RM/99-72	34.4	14.6	13.2	0.90	12.2	0.35

CPUC/RM/99-73	34.4	12.9	13.7	1.06	16.5	0.48
CPUC/RM/99-75	33.2	10.1	12	1.19	15.7	0.47
CPUC/RM/99-83	56.8	17.6	18	1.02	24.1	0.42
CPUC/RM/99-08	38.9	13	16	1.23	16.8	0.43
CPUC/RM/99-36	40.1	13.2	14.1	1.07	18.9	0.47
CPUC/RM/99-43	46.1	14.4	13.6	0.94	24.5	0.53
CPUC/RM/99-70	29.4	9.9	12	1.21	13.3	0.45
CPUC/RM/99-71	38.7	14.6	12.1	0.83	19.4	0.50
CPUC/RM/99-72	34.4	14.6	13.2	0.90	12.2	0.35
CPUC/RM/99-73	34.4	12.9	13.7	1.06	16.5	0.48
CPUC/RM/99-75	33.2	10.1	12	1.19	15.7	0.47
CPUC/RM/99-83	56.8	17.6	18	1.02	24.1	0.42

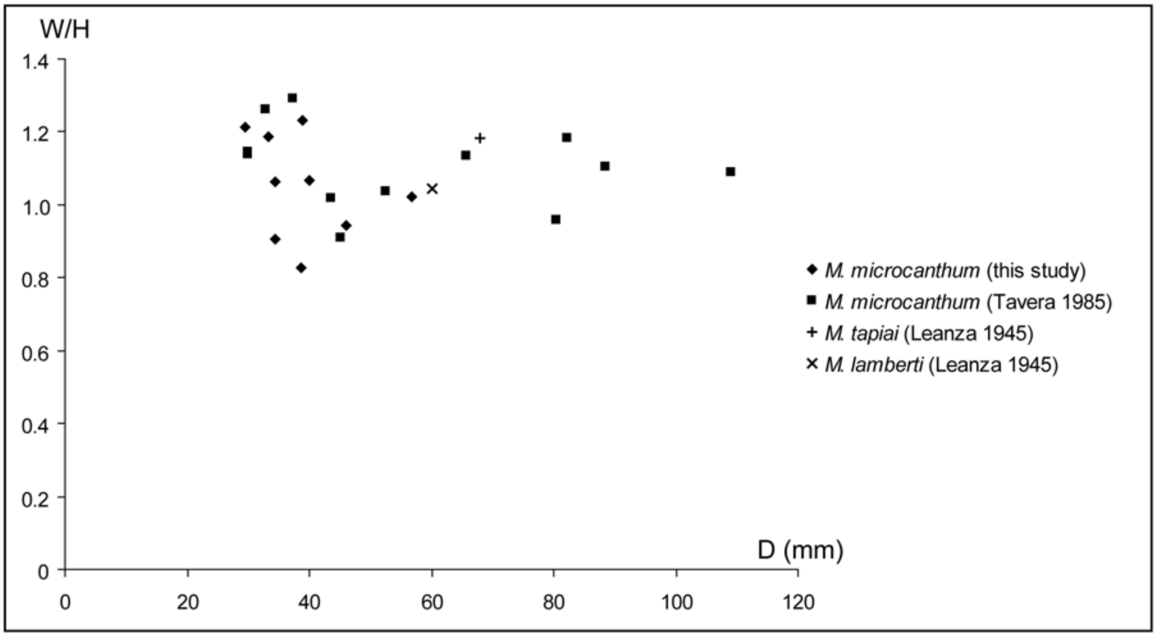


Figure 4.12. Relationship between W/H and D in *Micracanthoceras microcanthum* (Oppel, 1865). During juvenile stages (D< 50 mm), the whorl section is much more variable than in adults (D>50 mm).

Remarks: *Micracanthoceras microcanthum* is well known for its wide range of morphological variation (Tavera 1985). *Micracanthoceras lamberti* described by A. Leanza (1945) was separated based on a point of rib bifurcation situated more externally than in *M. microcanthum*. Leanza (1945) distinguished *M. tapiai* based on a more irregular ornamentation and tubercles on the external part of the shell. These morphological differences are, however, within the variability of *M. microcanthum* and *M. lamberti* and *M. tapiai* are here considered synonymous. *M.*

spinulosum is closely related but distinguished by a more rounded whorl section, denser and ventrolaterally more prorsiradiate ribs.

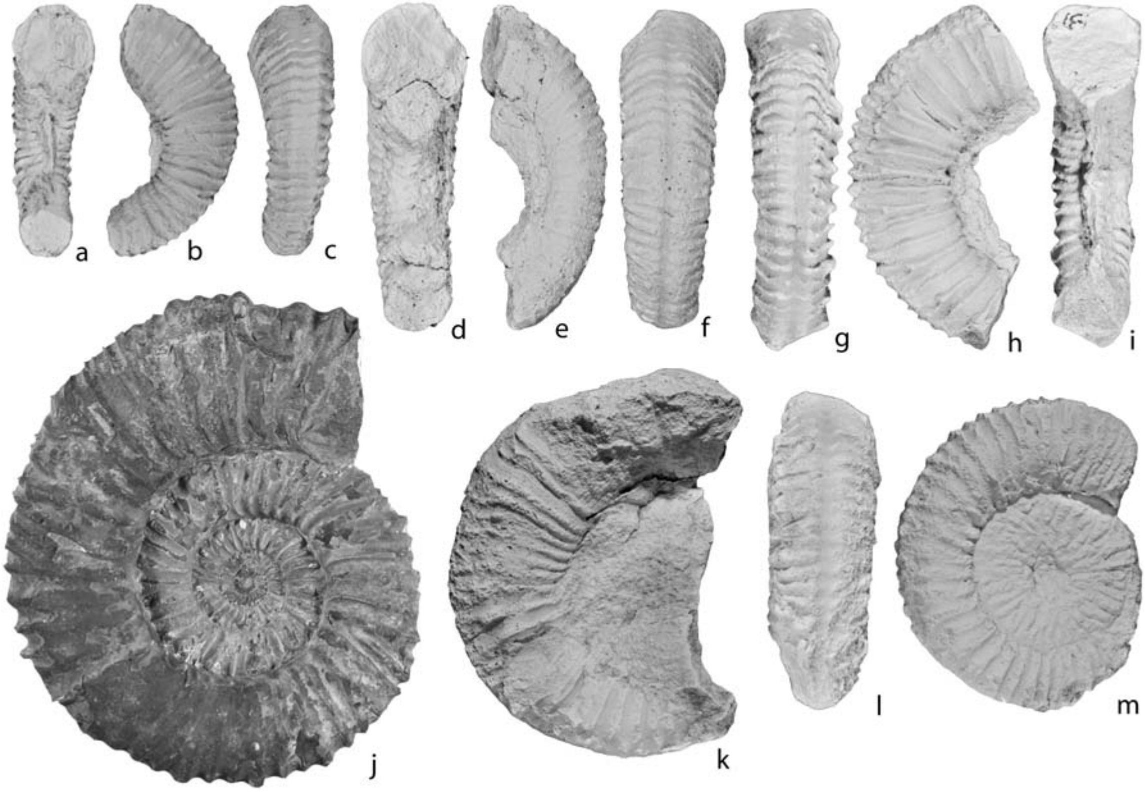


Figure 4.13. a-n: *Micracanthoceras microcanthum* (Oppel, 1865); **a-m** *M. microcantum* from the Baños del Flaco Formation, **a-c:** CPUC/RM/99-71, x1; **d-f:** CPUC/RM/Rd-32, x1; **g-i:** CPUC/RM/Rd-31, x1; **j:** CPUC/RM/99-83, x1; **k-l:** CPUC/RM/99-43, x1; **m:** *Reineckeia microcantha,* in Steuer (1897) GZG 499-21, x1.

Occurrence: At Rio Maitenes section, *M. microcanthum* is recorded from the Upper member of the Baños del Flaco Formation, from the unit of calcareous sandstone (figure 5.4). *M. microcanthum* was recorded from the Tithonian of México (Burckhardt 1919) and from the Tithonian of Mendoza in Argentina (Steuer 1897-1921). *M. lamberti,* which is here regarded conspecific with *M. microcanthum*, is registered from the Upper Tithonian of Mendoza in Argentina (Leanza 1945). In the Tethys region, *M. microcanthum* is recorded at Stromberg-Germany, and from the Italian Alps (Zittel 1868), south-east France (Mazenot 1939), south Spain (Tavera 1985), Bulgary (Sapunov 1979), Hungary (Fözy 1990), Sicily in Italy (Fözy 1995), from Pakistan (Fatmi & Zeiss 1999), and from Western India (Shome & Bardhan 2009). This taxon is considered an index fossil of the lowermost Upper Tithonian *M. microcanthum* Zone (Enay & Geyssant 1975, Tavera 1985 and Ogg 2004).

Micracanthoceras spinulosum (Gerth, 1925)

Figure 4.14, 4.15

1921 *Berriasella spinulosa* Gerth, p. 147 (*nomen nudum*).
1921 *Berriasella inaequicostata* n. sp. Gerth, p. 147 (*nomen nudum*).
1925 *Berriasella spinulosa* Gerth, p. 91, pl. 6, figs. 1 (lectotype) and 2-2a (paralectotype).
1925 *Berriasella inaequicostata* n. sp. Gerth, p. 90, pl. 6, figs. 4, 4a-4b (lectotype).
1928 *Berriasella spinulosa* Gerth. Gerth, p. 475, pl. 19, fig. 11 (= Gerth 1925).
1937 *Berriasella spinulosa* Gerth. Feruglio, p. 65. 8, figs. 7-13.
? 1937 *Berriasella* cf. *inaequicostata* Gerth. Feruglio, p. 69.
1945 *Berriasella inaequicostata* Gerth. A. Leanza, p. 34, pl. 4, fig. 2.
1960 *Berriasella* aff. *spinulosa* Gerth. Bürgl, p. 194, pl. 5, fig. 13.
1964 *Berriasella spinulosa* Gerth. Biro, p. 56.
1964 *Berriasella inaequicostata* Gerth. Biro, p. 101, pl. 2, fig. 1-2.
1967 *Berriasella spinulosa* Gerth. A. Leanza, p.145.
1972 *Micracanthoceras spinulosa* (Gerth). Enay, p. 375.
1983 *Berriasella* (*Malbosiceras*?) *inaequicostata* (Gerth). Geyer, p. 341, text-fig. 3i.
2005 *Micracanthoceras*? *spinulosum* (Gerth). Klein, p. 20.
2005 *Malbosiceras*? *inaequicostatum* (Gerth) Klein, p. 209.
2011b *Steueria alternans* (Gerth). Parent et al., p. 66, figs. 29A-D, 30-31.

Type: Lectotype is STIPB 949, designed here from the originals of Gerth (1925, p. 91, pl. 6, figs. 1), from the Tithonian of Mendoza (Argentina).

Material: 27 internal moulds, which are complete and fragmentary phragmocones. CPUC/RM/99-25, CPUC/RM/99-26, CPUC/RM/99-28, CPUC/RM/99-52, CPUC/RM/99-60, CPUC/RM/99-70, CPUC/RM/99-88, CPUC/RM/99-11, CPUC/RM/99-89 are regular to well preserved complete phragmocones. CPUC/RM/99-44, CPUC/RM/99-50, CPUC/RM/99-63, CPUC/RM/99-68, CPUC/RM/99-98 are well preserved fragmentary phragmocones. CPUC/RM/99-01, CPUC/RM/99-13, CPUC/RM/99-18, CPUC/RM/99-19, CPUC/RM/99-24, CPUC/RM/99-45, CPUC/RM/99-97 are regular to poorly preserved fragmentary phragmocones. CPUC/RM/99-02, CPUC/RM/99-27, CPUC/RM/99-35, CPUC/RM/99-51, CPUC/RM/99-52, CPUC/RM/99-56, CPUC/RM/99-99 are small fragments.

Description: Coiling evolute and umbilicus wide. Whorl section is rounded and gradually changes during ontogeny, from wider than high in young specimens (D < 30 mm) to slightly higher than wide in adults (D > 30 mm) (figure 4.14). Umbilical border is rounded, flanks are convex and the venter rounded with a smooth furrow. Maximum width is reached on the middle part of the flank. Ornamentation consists of rectiradiate ribs, bending to slightly prorsiradiate on the ventrolateral area. Most ribs bifurcate on the middle part of the flank, but others are unbranched and a few show trifurcation. At their point of bifurcation, small tubercles are commonly present; their absence in some cases may be the result of preservation as internal moulds. All ribs end in small ventral tubercles at both sides of the smooth furrow.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/99-01		10.4	7.6	1.37		
CPUC/RM/99-11	37.2	12.6	11.5	1.10	17.8	0.48
CPUC/RM/99-13		10.3	7.9	1.30		
CPUC/RM/99-18		(20.5)	(14.8)	(1.39)		
CPUC/RM/99-19		(10.6)	(7.4)	(1.43)		
CPUC/RM/99-24	30.2	(11.0)	(7.5)	(1.47)	(17.1)	(0.57)
CPUC/RM/99-25	(14.5)	(8.0)	(6.2)	(1.29)		
CPUC/RM/99-26	24.4	11.5	7.9	1.46	12.0	0.49
CPUC/RM/99-28	23.1	10.5	7.0	1.50	11.4	0.49
CPUC/RM/99-44	33.5	14.2	12.2	1.16	17.3	0.52
CPUC/RM/99-50		10.0	7.9	1.27	(14.7)	
CPUC/RM/99-52	34.4	13.8	12.0	1.15	15.4	0.45
CPUC/RM/99-60	(32.3)	(16.2)	(9.5)	(1.71)	(16.4)	(0.51)
CPUC/RM/99-68	25.5	9.6	6.7	1.43	14.4	0.56
CPUC/RM/99-70	26.8	10.0	8.0	1.25	13.3	0.50
CPUC/RM/99-88	33.4	12.1	10.8	1.12	16.4	0.49
CPUC/RM/99-89	36.3	15.3	15.1	1.01	17.2	0.47

Remarks: *Micracanthoceras* is characterised by evolute coiling, rounded whorls, small tubercles on bifurcation points of ribs and small ventral tubercles on each side of the smooth furrow (Arkell, 1957). *Berriasella* aff. *spinulosa* described by Bürgl (1960, p. 194) differs only by the absence of unbranched ribs. *Micracanthoceras vetustus* (Steuer 1897), *Corongoceras duraznense* (Krantz 1928) and *Riasanites rjasanensoides* Krantz (1928) are closely related, but ribs in these species are more spaced.

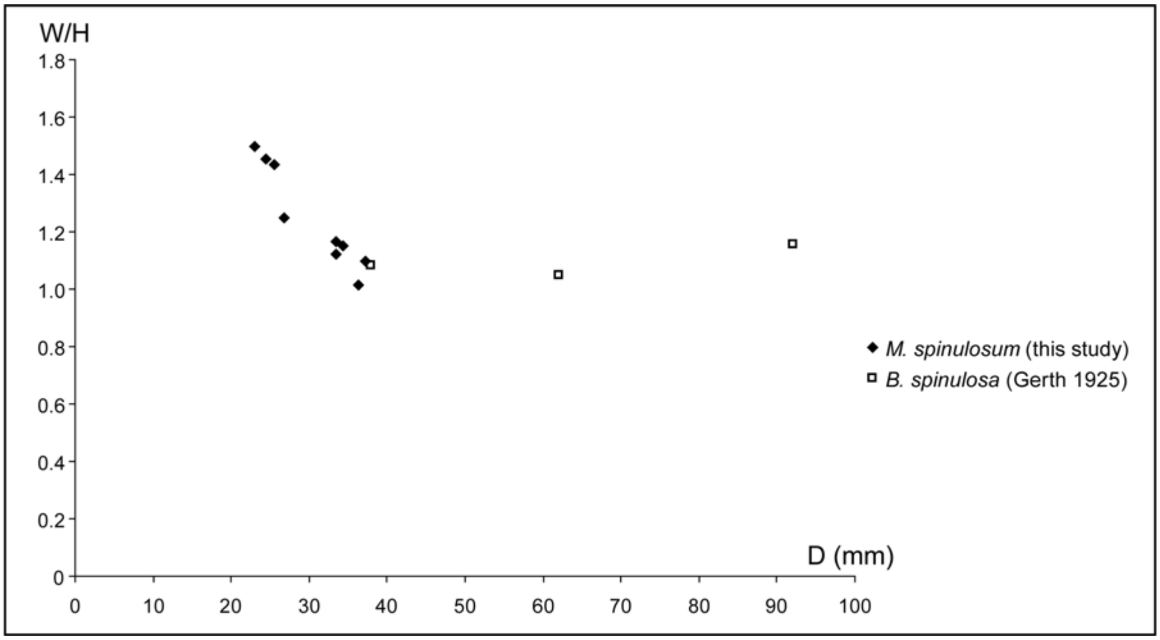


Figure 4.14. Relationship between W/H and D in *Micracanthoceras spinulosum* (Gerth, 1925). The whorl section changes during ontogeny. It is wider than high in juveniles (D < 30 mm) and gradually changes to wider than high in adults (D > 30 mm).

Occurrence: At Rio Maitenes, this taxon is present in the Upper member of the Baños del Flaco Formation, in the unit of calcareous sandstone (figure 5.4). In Central Argentina, *Micracanthoceras spinulosum* was recorded co-occuring with *Kilianella burckhardti* by Gerth (1925, p. 128); according to Leanza (1945), this horizon corresponds to the level of *Corongoceras alternans* of the Upper Tithonian. In Colombia the taxon was described for the Upper Berriasian (Bürgl, 1960). In Chile, Biro (1964, p. 56) recorded the species from the *Corongoceras alternans* zone, which corresponds to the middle part of the Upper Tithonian.

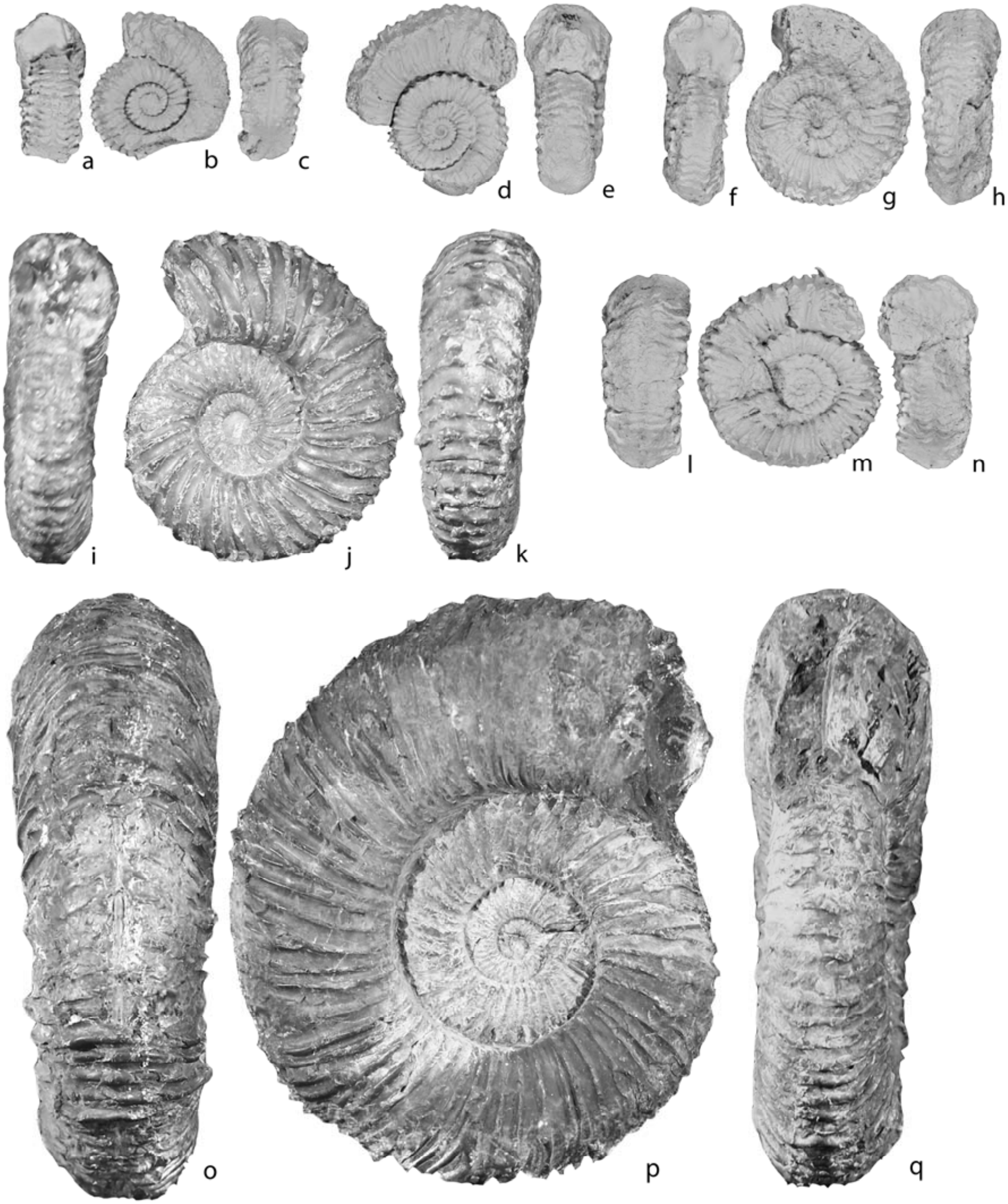


Figure 4.15. a-h, **l-n:** *Micracanthoceras spinulosum* (Gerth, 1925) from the Baños del Flaco Formation, **a-c:** CPUC/RM/99-26, x1; **d-e:** CPUC/RM/99-44, x1; **f-h:** CPUC/RM/99-52, x1; **l-n:** CPUC/RM/99-60, x1. **i-k**, **o-q:** *Berriasella spinulosa* Gerth (1925), **i-k:** STIPB-947, x1; **o-q:** STIPB-949 (Lectotype).

Genus *Corongoceras* Spath, 1925

Type species. *Corongoceras lotenoense*, pro *Hoplites köllikeri* (Oppel, 1863), *sensu* Haupt (1907, pl. 9, fig. 7a-b), STIPB 201, by subsequent designation of Spath (1925, p. 144). This genus was discussed by Parent (2001).

Genus description: In inner whorls ribs are bifurcated with a lateral and a ventral tubercle bordering a smooth concave venter. Outer whorls have strong and distant bituberculated ribs with lateral and ventral tubercles on the ribs and some secondary ribs and/or looped or zigzag between them; ventral tubercle may be spinous (Spath 1925 and Arkell et al. 1957).
Complementary description: The venter in juvenile inner whorls is rounded or flat and during growth changes gradually to slightly flat.

Corongoceras alternans (Gerth 1925)

Figure 4.16, 4.17, 4.18

1900b *Reineckeia Koellikeri* (Oppel). Burckhardt, p. 16, pl. 20, figs.14-15, pl. 21, fig. 1.

1900b *Reineckeia microcantha* (Oppel). Burckhardt, p. 16, pl. 20, fig. 16-17 (?= *Corongoceras alternans*).

1921 *Berriasella alternans* Gerth, p. 147 (*nomen nudum*).

1925 *Berriasella alternans* n.sp. Gerth, p. 89, pl. 6, figs. 3, 3a. (Lectotype).

1928 *Berriasella alternans* Gerth. Gerth p. 474, pl. 19, fig. 10, 10a (= Gerth 1925).

1931 *Berriasella alternans* Gerth. Windhausen, pl. 30, fig. 6 (= Gerth 1925).

non 1937 *Berriasella alternans* (n var.?) Gerth. Feruglio, p. 70, pl. 8, fig. 6 (= *Lytohoplites burckhardti*).

1945 *Berriasella pastorei* n. sp. A. Leanza, p. 33, pl. 3, figs. 12-13.

non 1945 *Berriasella groeberi* n. sp. A. Leanza, p. 37, pl. 4 (= *Corongoceras mendozanum*).

non 1945 *Berriasella* (?) *delhaesi* n. sp. A. Leanza, p. 39, pl. 6, fig. 1-2 (= *Corongoceras mendozanum*).

non 1945 *Himalayites concurrens* n. sp. A. Leanza, p. 46, pl. 3, figs. 5-6 (= *Micracanthoceras microcanthum*).

1945 *Corongoceras alternans* (Gerth). Leanza A., p. 47, pl. 1, fig. 2-3.

1945 *Corongoceras rigali* n. sp. A. Leanza, p. 48, pl. 6, figs. 3-4.

1958 *Corongoceras alternans* (Gerth). Corvalán & Pérez, p. 46, pl. 13, fig. 32a-b (= Gerth 1925).

1964 *Corongoceras alternans* (Gerth). Biro, p. 103, pl. 24, figs. 1a-b, 2a-b, 3a-b, pl. 25, figs. 1a-b, 2a-b.

1966 *Berriasella* cf. *alternans* Gerth. Fuenzalida, p. 135, figs. 24-26.

1973 *Blanfordiceras* aff. *pastorei* (A. Leanza). Geyer, p. 83, text-fig. 29.

1981 *Berriasella pastorei* A. Leanza. H. Leanza, pl. 3, figs. 13-14.

non 1981 *Himalayites concurrens* A. Leanza. H Leanza, pl. 3, figs. 9-10 (= *Micracanthoceras microcanthum*).

2001 *Corongoceras* cf. *alternans* (Gerth). Parent, p. 32, figs. 5F, 8K, 8L.

2001 *Corongoceras alternans* (Gerth). Parent, fig. 9D-E (= Gerth 1925).

non 2005 *Micracanthoceras concurrens* (A. Leanza). Klein, p. 18 (= *Micracanthoceras microcanthum*).

2005 *Corongoceras alternans* (Gerth). Klein, p. 22.

non 2005 *Berriasella* (*Berriasella*)? *delhaesi* A. Leanza. Klein, p. 169 (= *Corongoceras mendozanum*).

non 2005 *Berriasella* (*Berriasella*) *groeberi* A. Leanza. Kelin, p. 170 (= *Corongoceras mendozanum*).

2005 *Blanfordiceras* (*Blanfordiceras*) *pastorei* (A. Leanza). Klein, p. 202.

non 2011b *Steueria alternans* (Gerth). Parent et al., p. 66, figs. 29A-D, 30-31 (= *Micracanthoceras spinulosum*).

Type: Holotype was defined by monotypy. It is specimen STIPB 939, an original of Gerth (1925, p. 89, pl. 6, figs. 3, 3a) from the Tithonian of Mendoza, Argentina.

Material: 6 internal moulds, which are complete and fragmentary phragmocones. CPUC/RM/99-07, CPUC/RM/99-69, CPUC/RM/99-95, CPUC/RM/99-96, CPUC/RM/99-97 are well preserved fragmentary phragmocones. CPUC/RM/99-46 is a regular to poorly preserved fragmentary phragmocone. CPUC/RM/99-14 is a small fragment.

Description: Coiling evolute and umbilicus wide. Whorl section is rounded and wider than high in young stages (D < 30 mm.), and progressively higher than wide in adult stages (D > 30 mm.)

when the whorl section becomes oval and flanks are rounded. The venter is rounded with a smooth furrow (figure 4.16). Ornamentation consists of prominent and widely spaced primary ribs which are slightly prorsiradiate and convex. They initiate on the umbilical border and either remains single, or they bifurcate on the middle or outer part of the flank. These secondary ribs are as strong as primaries. Points of rib bifurcation are characterised by tubercles. On the venter, ribs end in tubercles on both sides of the smooth furrow.

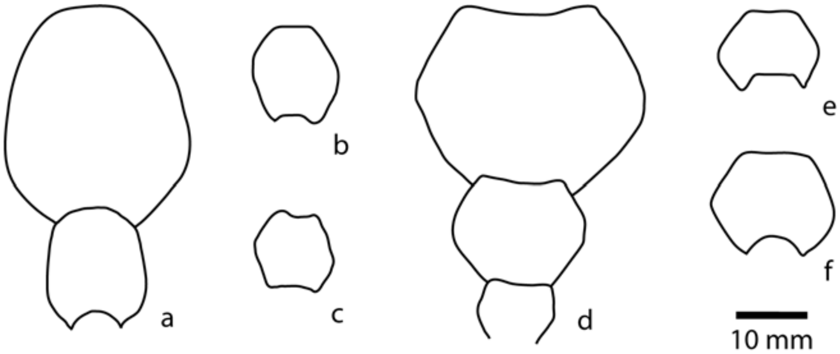


Figure 4.16. Whorl sections in *Corongoceras*. **a:** *Corongoceras alternans*, holotype of Gerth (1925), STIPB-939. **b-c:** *Corongoceras alternans*, CPUC/RM/99-95 and CPUC/RM/99-96. **d:** *Corongoceras evolutum*, holotype of Corvalán (1959), SNGM 7001 (= IIG 133). **e:** *Corongoceras evolutum*, CPUC/RM/99-80. **f:** Holotype of *Corongoceras lotenoense* Spath (1925), (= *Hoplites köllikeri*, original from Haupt 1907), STIPB-201.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/99-07	28.9	10.4	9.1	(1.14)	14.5	0.47
CPUC/RM/99-46		14.7	13.1	1.12		
CPUC/RM/99-69	28.9	11.2	9.9	1.13	12.1	0.42
CPUC/RM/99-95	43.2	(13.1)	(14.2)	(0.92)	20.9	0.48
CPUC/RM/99-96		12.6	10.5	1.2	16.0	

Remarks: *Corongoceras* is characterized by spaced ribs on the outer whorl and less distant ribs on inner whorls; these primary ribs bifurcate, with tubercles in the division point and spinous tubercles on the ventral ends of the secundaries. Parent et al. (2011b) include *Corongoceras alternans* in the new genus *Steueria*. *Steueria* differs by a well rounded venter and finer and denser ribbing. According to the original description of Spath (1925) and Arkell et al. (1957), and the complementary description of the genus *Corongoceras* give here, a rounded venter is present in inner whorls of *Corongoceras* and during ontogeny grades into the flat venter known from adults. These characteristics are observed in the specimens described here, which are therefore assigned to *Corongoceras*.

Corongoceras alternans is characterized by evolute coiling and a whorl section that progressively changes from wider than high in young stages to higher than wide in adult stages (figure 4.17) Ribs are strong and distanced; both simple and bifurcate ribs occur. Specimens described as *Steueria alternans* by Parent et al. (2011b) are characterized by denser ribs throughout ontogeny; the whorl section is wider and tubercles are finer than those in the lectotype of *Corongoceras alternas*. These specimens of Parent et al. (2001b) described as *Steueria alternans* are here assigned to *Micracanthoceras spinulosum*.

C. rigali designated by Leanza (1945) presents fine and dense ribs on inner whorls but the differences with *C. alternans* are minor and are here considered part of a common intraspecific variation. *C. evolutum* is a closely related species but differs by closer-standing ribs, a wider umbilicus, a wider than high whorl section and a venter which is wider and presents a well-marked furrow (figure 4.17). *C. lotenoense* differs by a subhexagonal whorl section, a flat venter, a slightly higher evolution and denser ribbing in young stages.

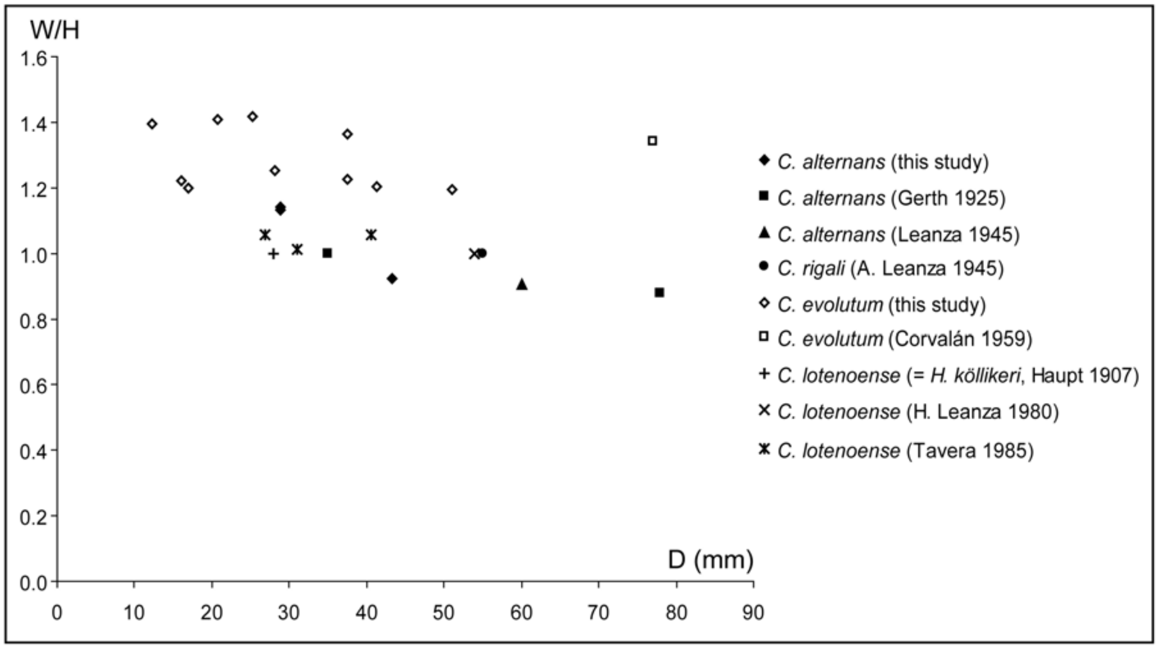


Figure 4.17. Relationship between W/H and D in *Corongoceras alternans* (Gerth 1925), *Corongoceras evolutum* Corvalán (1959) and *Corongoceras lotenoense* Spath (1925). These three species of *Corongoceras* are close related, but *C. evolutum* is clearly distinguished from the other two.

Ocurrence: At Rio Maitenes, this taxon is registered in the Upper member of the Baños del Flaco Formation, in the unit of calcareous sandstone (figure 5.4). *C. alternans* was recorded for the lower part of the Upper Tithonian in Mendoza, Argentina (Gerth 1925, Leanza 1945, Parent 2001). In Chile, the taxon is registered from the Upper Tithonian of Alto Palena (Fuenzalida 1966) and from the middle part of the Upper Tithonian at Lo Valdés (Biro 1964).

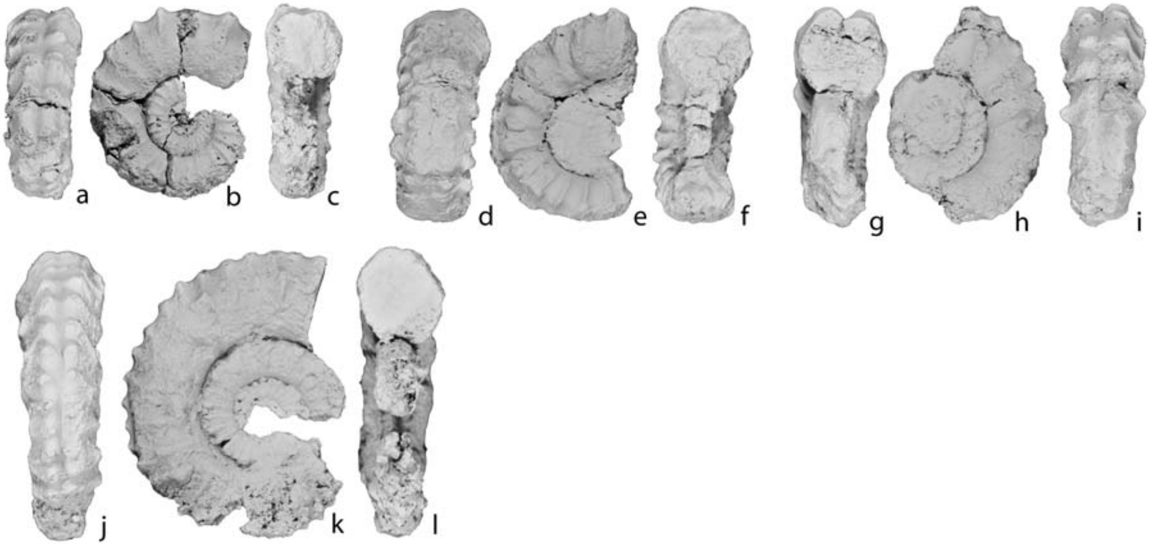


Figure 4.18. a-l: *Corongoceras alternans* (Gerth 1925) from the Baños del Flaco Formation, **a-c:** CPUC/RM/99-69, x1; **d-f:** CPUC/RM/99-07, x1; **g-i:** CPUC/RM/99-96, x1; **j-l:** CPUC/RM/99-95, x1.

Corongoceras evolutum Corvalán, 1958

Figure 4.16, 4.17, 4.19a-q

1958 *Corongoceras evolutum* Corvalán. In Corvalán & Pérez, p. 43, pl. 10, fig. 21a-b. (*nomen nudum*)

1959 *Corongoceras evolutum* n. sp. Corvalán, p. 18, pl. 7, figs. 25-26.

1964 *Corongoceras evolutum* Corvalán. Biro, p. 104, pl. 26, fig. 1a-d.

1994 *Corongoceras evolutum* Corvalán. Pérez & Reyes, p. 50.

2005 *Corongoceras evolutum* Corvalán. Klein, p. 23.

Type: Holotype is SNGM 7001 (= IIG 133), the original from Corvalán (1959, p. 18, pl. 7, figs. 25-26), by monotypy. The specimen is from the Upper Tithonian of Rio Leñas (Chile).

Material: 26 internal moulds, which are complete and fragmentary phragmocones. CPUC/RM/99-80, CPUC/RM/99-90, CPUC/RM/99-91, CPUC/RM/99-92, CPUC/RM/99-94 and CPUC/RM/99-100 are complete phragmocones and regular to well preserved. CPUC/RM/99-64, CPUC/RM/99-93, CPUC/RM/99-97 are well preserved fragmentary phragmocones. CPUC/RM/99-09, CPUC/RM/99-15, CPUC/RM/99-32, CPUC/RM/99-40, CPUC/RM/99-41, CPUC/RM/99-44, CPUC/RM/99-47, CPUC/RM/99-48, CPUC/RM/99-04, CPUC/RM/99-55, CPUC/RM/99-62, CPUC/RM/99-73, CPUC/RM/99-75, CPUC/RM/Rd-16 are regularly to poorly preserved fragmentary phragmocones. CPUC/RM/99-16, CPUC/RM/99-33, CPUC/RM/99-65 are small fragments.

Description: Coiling very evolute and umbilicus wide (U/D: 0.42-0.58). Whorl section is sub-hexagonal, wider than high. The umbilical border is straight and steep, flanks are strongly convex, and the venter is wide with a well-marked wide and smooth furrow (figure 4.16). The maximum width is on the middle part of the flank. Ornamentation consists of strong primary ribs which are rectiradiate to slightly prorsiradiate. They initiate on the umbilical border. On the middle part of the flank, most primaries bifurcate into secondary ribs, as strong as the primary ribs. Acute tubercles are preserved in some specimens on the point of bifurcation. On the ventral shoulder, all ribs terminate in acute tubercles on both sides of the smooth ventral furrow.

Dimensions	D	W	H	W/H	U	U/D
CPUC/RM/99-15	(16.0)	6.6	5.4	1.22	7.0	(0.44)
CPUC/RM/99-47	37.5	(13.0)	(10.6)	1.23	(19.5)	(0.52)
CPUC/RM/99-62	37.5	(15.0)	(11.0)	1.36	16.8	(0.45)
CPUC/RM/99-80	41.3	16.1	13.4	1.20	20.1	0.49
CPUC/RM/99-90	25.2	8.8	6.2	1.42	14.7	0.58

Remarks: *Corongoceras evolutum* Corvalán (1958) was briefly described in Corvalán & Pérez (1958 p. 43, pl. 10, figs. 21a-b), but without a determination of a holotype and fossil locality. Corvalán (1959, p.18, pl. 7, figs. 25-26) identify the holotype (SNGM 7001 = IIG 133) which is described for the Upper Tithonian of Río Leñas, Chile. *C. evolutum* is characterized by a wide umbilicus, strong ribs, and a wide venter with a well-marked wide and smooth furrow (Corvalán 1959).

C. mendozanus and *C. involutum* are closely related, but *C. evolutum* clearly differs by the wide umbilicus and the wide venter with a well-marked furrow. *C. lotenoense* is a closely related species, but is more involute, ribs are more distanced, and the whorl section is higher (figure 4.16). *C. alternans* s also closely related but the whorl section is higher than wide, the coiling more involute and ribs are more separated (figure 4.16). The whorl section of *C. evolutum* is wider than high and clearly differs from *C. alternans* and *C. lotenoense* (figure 4.16 and 4.17).

Occurrence: At Rio Maitenes, this taxon is registered in the Upper member of the Baños del Flaco Formation, in the unit of calcareous sandstone (figure 5.4). *C. evolutum* is endemic to central Chile and was only reported by Corvalán (1959) for the Upper Tithonian at Rio Leñas and by Biro (1964) for the middle part of the Upper Tithonian at Lo Valdés (Lo Valdés Formation).

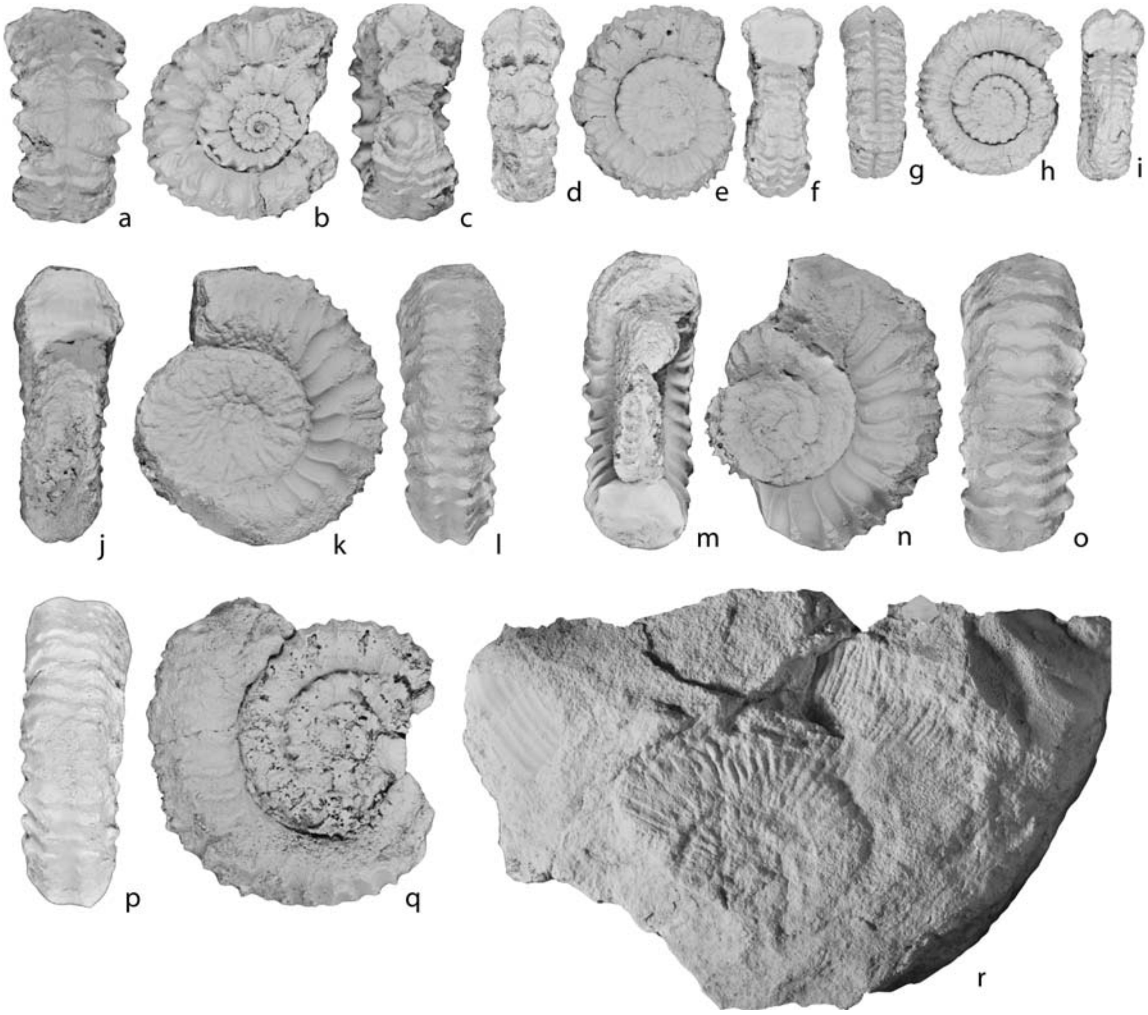


Figure 4.19. a-q: *Corongoceras evolutum* Corvalán (1959) from the Baños del Flaco Formation, **a-c:** CPUC/RM/99-100, x2; **d-f:** CPUC/RM/99-94, x1; **g-i:** CPUC/RM/99-90, x1; **j-l:** CPUC/RM/99-80, x1; **m-o:** CPUC/RM/99-64, x1; **p-q:** CPUC/RM/99-97, x1; r: *Substeueroceras koeneni* (Steuer 1897) from the Baños del Flaco Formation, CPUC/RM/115-04, x1.

Family NECOMITIDAE Salfeld, 1921

Subfamily BERRIASELLINAE Spath, 1922

Genus *Substeuroceras* Spath, 1923

Type Species: *Odontoceras koeneni* Steuer, 1897, p. 171, pl. 17, fig. 1-3 (OD)

Substeueroceras koeneni (Steuer 1897)

Figure 4.19r

1897 *Odontoceras Koeneni* Steuer, p. 171, pl. 31, figs. 1-3 (lectotype), figs. 4-5.
1906 *Perisphinctes* cfr. *Koeneni* (Steuer). Burckhardt, p. 137, pl. 39, fig. 1.
1923 *Substeueroceras koeneni* (Steuer). Spath, p. 305.
1925 *Steueroceras koeneni* (Steuer). Gerth, p. 83, pl. 6, fig. 6.
non 1945 *Substeueroceras koeneni* (Steuer). Leanza A. p. 28, pl. 5, figs. 7-8 (= *Paraulacosphinctes striolatus* in Parent 2003).
1945 *Substeueroceras koeneni* (Steuer). Leanza A. p. 28, pl. 7, fig. 4.
1959 *Substeueroceras koeneni* (Steuer). Corvalán, p. 20, pl. 7, fig. 27.
1964 *Substeueroceras koeneni* (Steuer). Biro, p. 55.
1990 *Substeueroceras koeneni* (Steuer). Aguirre-Urreta & Charrier, p. 266, pl. 1, fig. 3.

Type specie: Lectotype is GZG 499-57, the original of Steuer (1897, p. 171, pl. 31, figs. 1-3) from the Tithonian of Mendoza (Argentina), by subsequent designation of Spath (1923, p. 305).

Material: a single imprint of half a phragmocone (CPUC/RM/115-4), which is regular to well preserved.

Description: Involute coiling. Ornament consists of fine and dense ribs. On the umbilical border the ribs are slightly rursiradiate. On the flank they bend forward to a prorsiradiate direction and they are concave on the ventrolateral area. Ribs are divided on the dorsolateral area and again on the middle part of the flank, where bifurcation is irregular. Some ribs are undivided.

Remarks: The single specimen here described is an imprint of a fragmentary phragmocone, but preserves the typical ornamentation elements of *S. koeneni*.

Occurrence: At Rio Maitenes, this taxon is registered in the Upper member of the Baños del Flaco Formation, in the unit of sandy limestone (figure 5.4). In Argentina and Chile *S. koeneni* has been considered an index for the Upper Tithonian (Steuer 1897, Gerth 1925, Corvalán 1959) and even the uppermost part of the Upper Tithonian (Biro 1964, Leanza 1981b, Parent & Capello 1999, Parent 2001). In their review on ammonites of the Baños del Flaco Formation Hallam et al. (1986) indicate that the occurrence of *Substeueroceras koeneni* may correspond to the basal Berriasian, if Zeiss's (1983) correlation is accepted.

6.2. Ammonites of the Lo Valdés Formation

Order AMMONOIDEA Zittel, 1884
Suborder LYTOCERATINA Hyatt, 1889
Superfamily LYTOCERATOIDEA Neumayr, 1875
Family LYTOCERATIDAE Neumayr, 1875
Subfamily LYTOCERATINAE Neumayr, 1875
Genus *Pterolytoceras* Spath 1927

Type species: *Ammonites exoticus* Oppel (1863, p. 278, pl. 76, figs. 5a, 5b, 5c) by original designation of Spath (1927, p. 64).

Pterolytoceras exoticum (Oppel, 1863)
Figure 4.23a-c

1863 *Ammonites exoticus* Oppel, p. 278, pl. 76, figs. 5a, 5b, 5c.
1897 *Lytoceras* cf. *sutile* (Oppel). Steuer, p. 76, pl. 7, figs. 1-2.
1903 *Lytoceras exoticum* (Oppel). Uhlig, p. 14, pl. 1, figs. 3-4, text-fig. 1.
1921 *Lytoceras* cf. *sutile* (Oppel). Steuer, p. 105, pl. 7, figs. 1-2 (= Steuer 1897).
1926 *Lytoceras sutile* (Oppel). Krantz, p. 429.
1927 *Pterolytoceras exoticum* (Oppel). Spath, p. 65.
1928 *Lytoceras sutile* (Oppel). Krantz, p. 9.
1960 *Pterolytoceras exoticum* (Oppel). Collignon, pl. 140, figs ?532, 533.
1968 *Pterolytoceras exoticum* (Oppel). Fatmi, p. 82, pl. 2, figs. 1, 2, 6.
1972 *Pterolytoceras exoticum* (Oppel). Fatmi, p. 329, pl. 2, fig. 2 (= Fatmi 1968).
1976 *Pterolytoceras exoticum* (Oppel). Chao, p. 513, pl. 2, figs. 17-18.
1979 *Pterolytoceras exoticum* (Oppel). Thomson, p. 9, pl. 2, fig. 2l, 2m.
1980 *Pterolytoceras magnum* n. sp. Biro, p. 223, pl. 1, figs. 1a-1g.
1989 *Pterolytoceras* cf. *exoticum* (Oppel). Howlett, p. 10, pl. 2, fig. 6.
1999 *Pterolytoceras* aff. *P. exoticum* (Oppel). Fatmi & Zeiss, p. 39.
2005 *Pterolytoceras exoticum* (Oppel). Klein et al., p. 127 (with additional synonymy).

Type: The lectotype corresponds to *Ammonites exoticus* Oppel (1863, p. 278, pl. 76, figs. 5a, 5b, 5c), by original designation of Spath (1927, p. 64).

Material: One specimen, CPUC/CP/60-32, a complete and well preserved phragmocone.

Description: The coiling is evolute and the umbilicus wide, with whorls barely in contact. The whorl section is rounded to subrounded, gently wider than high. The umbilical border, flanks and venter are rounded. The sculpture consists of fine lirae, that are slightly prorsiradiate and slightly sinuous. Growth lines are parallel to the lirae.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CP/60-32	47.5	17.5	16.3	1.07	22.2	0.47

Remarks: Uhlig (1903) gives a full description of this species. The specimen described as "*Lytoceras* cf. *sutile*" by Steuer (1897-1921) is a fragmentary phragmocone that corresponds to *Pterolytoceras exoticum*. *Pterolytoceras magnum* Biro (1980) was differentiated from *P. exoticum* based on a wider section and constrictions: However, these differences result from the figure of *P. exoticum* presented in Arkell et al. (1957). Considering the full description given by Uhlig (1903), *Pterolytoceras magnum* is here considered a junior synonymy of *Pterolytoceras exoticum*.

Occurrence: *Pterolytoceras exoticum* is recorded for the first time in Chile. In the Lo Valdés Formation the taxon is present in the Siltstone member of the Cruz de Piedra section (figure 5.8). *Pterolytoceras exoticum* is registered for the Tithonian-Berriasian interval in the Himalayas (Oppel 1863, Uhlig 1903), in China (Chao 1976), Pakistan (Fatmi 1972, Fatmi & Zeiss 1999), Madagascar (Collignon 1960) and Antarctica (Thomson 1979, Howlett 1989).

Suborder AMMONITINA Hyatt, 1889
Superfamily PERISPHINCTOIDEA Steinmann, 1890
Family ASPIDOCERATIDAE Zittel, 1895
Subfamily ASPIDOCERATINAE Zittel, 1895
Genus *Aspidoceras* Zittel, 1868

Type species: *Ammonites rogoznicensis* Zeuschner (1846), by monotypy, in Zittel (1868), p. 117, pl. 24, figs. 4-5.

Synonym. *Acanthosphaerites* Rollier, 1922. (type species, *Ammonites acanthicus* Oppel, 1863)

Diagnosis of the genus: Coiling evolute and semi-evolute. Whorl section varies between rounded, oval or sub-quadrate and depressed, with two rows of lateral tubercles or spines, outer row placed near the middle of whorl sides and fading in many species. Some species also are fine or strongly ribbed (Arkell et al. 1957, Checa 1985).

Aspidoceras rogoznicense (Zeuschner, 1846)

Figure 4.20, 4.21, 4.22

1846 *Ammonites rogoznicensis* Zeuschner, pl. 4, fig. 4.
1868 *Ammonites* (*Aspidoceras*) *rogoznicensis* Zeuschner. Zittel, p. 116, pl. 24, fig. 4-5.
1870 *Aspidoceras zeuschneri* Zittel, p. 87, pl. 7, fig. 4.
1872 *Ammonites catalaunicus* Loriol et al., p. 44, pl. 4, fig. 1a.
1875 *Aspidoceras iphiceroides* n. sp.Waggen, p. 102, pl. 23, figs. 1-2.
1875 *Aspidoceras binodiferum* n. sp. Waggen, p. 105, pl. 24, fig. 1.
1897 *Aspidoceras euomphalum* Steuer, p. 69, pl. 5, figs. 1-4.
1897 *Aspidoceras andinum* Steuer, p. 69, pl. 5, figs. 5-7.
1897 *Aspidoceras cieneguitense* Steuer, p. 101, pl. 5, fig. 8-10.
1906 *Aspidoceras euomphaloides* Burckhardt, p. 37, pl. 6, figs. 5-8.
? 1906 *Aspidoceras quemadense* Burckhardt, p. 154, pl. 6, fig. 1-4.
1907 *Aspidoceras euomphalum* Steuer. Haupt, p. 191.
1907 *Aspidoceras gourguechoni* Previnquiere, p. 33, pl. 2, figs. 2a, 3a,b,f.
1912 *Aspidoceras* aff. *longispinum* Sowerby. Burckhardt, p. 73, pl. 16, fig. 7.
1921 *Aspidoceras euomphalum* Steuer, p. 98, pl. 5, figs. 1-4.
1921 *Aspidoceras andinum* Steuer, p. 99, pl. 5, figs. 5-7.
1921 *Aspidoceras cieneguitense* Steuer, p. 101, pl. 5, figs. 8-10.
1926 *Aspidoceras euomphalum* Steuer. Krantz, p. 432.
1928 *Aspidoceras haupti* n. sp. Krantz, p. 12, pl. 4, fig. 2.
1931 *Aspidoceras neuquensis* n. sp. Weaver, p. 435, figs. 341-342.
1931 *Aspidoceras euomphalum* Steuer. Weaver, p. 436.
non 1931 *Aspidoceras iphiceroides* Waggen. Spath, p. 635, pl. 23, fig. 8 (= *Aspidoceras longispinum*).

1931 *Aspidoceras subwynnei* n. sp. Spath, p. 640, pl. 74, fig. 2, pl. 117, fig. 5.
? 1943 *Aspidoceras iphiceroides* Waggen. Scott, p. 77, pl. 16, figs. 1, 3.
1958 *Aspidoceras zeuschneri* Zittel. Buck, p. 98, pl. 8, fig. 1.
1959 *Aspidoceras* aff. *binodum* Oppel. Collignon, pl. 129, fig. 482.
1959 *Aspidoceras* cf. *iphiceroides* Waggen. Collignon, pl. 130, fig. 485.
1959 *Aspidoceras subwynnei* Spath. Collignon, pl. 131, fig. 491.
1959 *Aspidoceras spinosum* Collignon, pl. 131, fig. 492.
1961 *Spiticeras* (*Kilianiceras*?) cf. *euomphalum* (Steuer). Sato, p. 550, pl. 13, fig. 2.
1973 *Aspidoceras* cf. *A. andinum* Steuer. Verma & Westermann, p. 191, pl. 36, fig. 1.
1973 *Aspidoceras haupti* Krantz. Verma & Westermann, p. 193, pl. 36, fig. 2, pl. 37, fig. 1.
1973 *Aspidoceras* cf. *A. haupti* Krantz. Verma & Westermann, p. 194, pl. 35, fig. 3.
1976 *Aspidoceras rogoznicensis* (Zeuschner). Fülop, p. 75, pl. 35, fig. 7.
1976 *Aspidoceras* sp. aff. *A. longispinum* (Sowerby). Oloriz, p. 293, pl. 24, fig. 1.
? 1980 *Aspidoceras* (*Aspidocerae*) *altum* n. sp. Biro, p. 227, pl. 2, fig. 1.
1980 *Aspidoceras euomphalum* Steuer. Leanza, p. 41, pl. 8, fig. 1, text-fig. 10e.
1981 *Aspidoceras euomphalum* Steuer. Leanza, pl. 2, fig. 11.
1983 *Aspidoceras andinum* Steuer. Matsumoto & Sakai, p. 78, pl. 7, fig. 1.
1984 *Aspidoceras iphiceroides* Waagen. Verma & Westermann, p. 66. pl. 15, fig. 3, pl. 16, fig. 1.
1985 *Aspidoceras rogoznicensis* (Zeuschner). Checa, p. 98, pl. 16, figs. 1-4.
1988 *Aspidoceras andinum* Steuer. Riccardi pl. 2, figs. 3-5
1990 *Aspidoceras* aff. *altum* Biro. Leanza & Zeiss, p. 176, pl. 36, fig. 3.
1998 *Aspidoceras rogoznicense* (Zeuschner). Howarth, p. 63, pl. 10, fig. 1.
? 2007 *Aspidoceras* cf./aff. *altum* Biro. Gründel et al. p. 144.
? 2007 *Aspidoceras* aff. *neuquensis* Weaver. Gründel et al. p. 144.

Type: As for the genus.

Material: Two specimens, CPUC/CM/14-16-1 and CPUC/CP/70-53. Both are well preserved complete phragmocones. Specimens GZG 499-13 (*A.* "*andinum*"), GZG 499-14 (*A.* "*cieneguitense*") and GZG 499-90 (*A.* "*euomphalum*") of the Steuer collection are also included here.

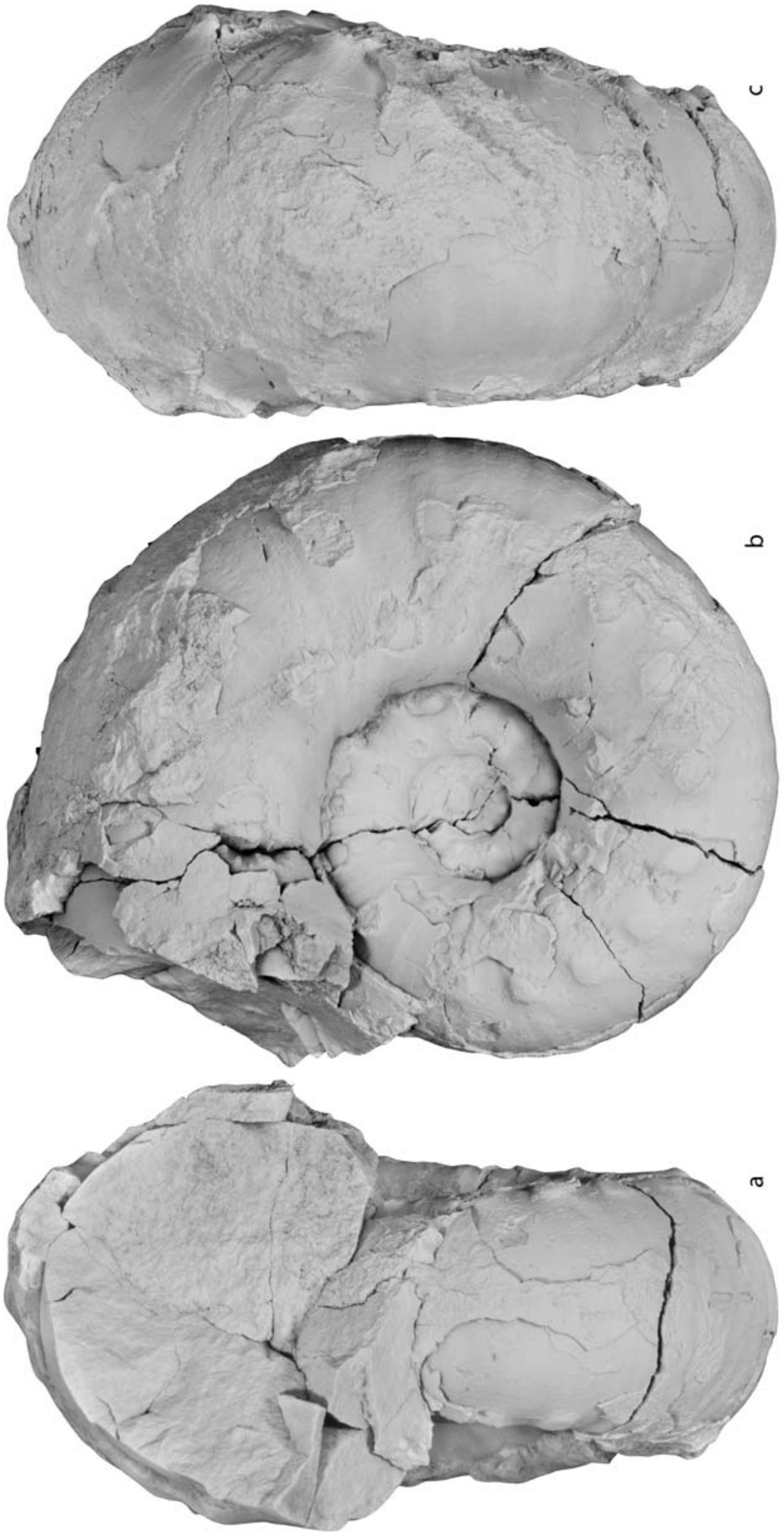


Figure 4.20. a-c: *Aspidoceras rogoznicense* (Zeuschner, 1846) from Lo valdés Formation, a-c: CPUC/CP/70-53 x0.9

Description: Coiling is evolute and compressed. In juvenile stages (D < 50 mm), the whorl section is considerably wider than high, but it changes gradually in adult stages (D > 50 mm) to lesser wide; even then the cross section remains wider than high (figure 4.21). The maximum width is reached in the dorsolateral area. The umbilical border is rounded, flanks are convex and the venter widely rounded. Strong single and spaced ribs are present on the flank. Lirae are also present but are only visible when the shell is preserved (e.g., in CPUC/CP/70-53). The ribs are sculptured by two rows of spined tubercles, one on the umbilical border and the second on the center of the flank.

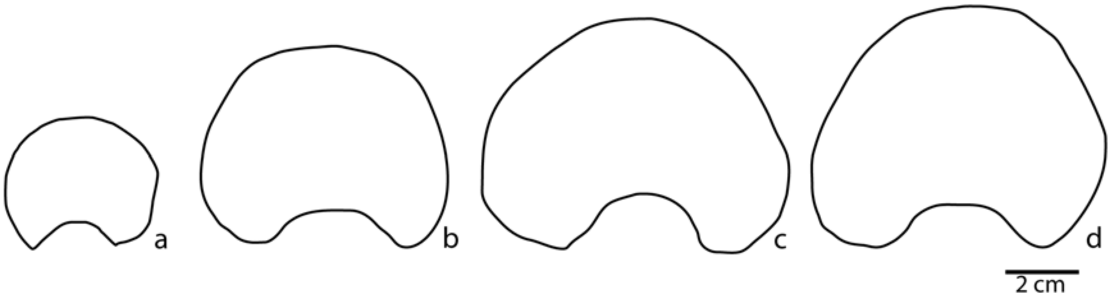


Figure 4.21. Whorl section of *Aspidoceras rogoznicense* (Zeuschner, 1846). **a-c:** *Aspidoceras* species described by Steuer (1897-1921). **a:** GZG 499-14 (*A.* "*cieneguitense*"); **b:** GZG 499-13 (*A.* "*andinum*"); **c:** GZG 499-90 (*A.* "*euomphalum*"); **d:** CPUC/CP/70-53 *Aspidoceras rogoznicense* from Lo Valdés Formation.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/14-16-1	132.1	60.8	50.9	1.19	40.1	0.30
CPUC/CP/70-53	134.5	70.8	59	1.20	46.8	0.35

Remarks: *Aspidoceras rogoznicense* is known to be a highly variable species and, according to Checca (1985) and Howarth (1998), includes all bituberculated *Aspidoceras* with depressed whorl sections. Here we agree with this interpretation.

In *Aspidoceras euomphalum* described by Steuer (1897), the figured whorl section appears to be wider than in the specimens described here. However, this may be an artifact resulting from a preservational bias of sediment preserved on the last whorl; only the row of tubercles on the middle part of the flank is well preserved. *Aspidoceras cieneguitense* Steuer (1897) is based on juvenile specimens (figures 4.21-4.22), in which the whorl section is wide and irregular tubercles are present on the umbilical shoulder, whereas the middle part of the flank is smooth.

Aspidoceras andinum Steuer (1897) was differentiated based on a faint row of tubercles on the middle part of the flank and irregular umbilical tubercles. Both taxa are here considered synonymous with *Aspidoceras rogoznicensis* and their morphological differences the result of a preservational bias as well as intraspecific variability.

Aspidoceras haupti Krantz (1928) was differentiated from *A. andinum* based on a higher whorl section and a narrow umbilicus, but considering the morphological variability of *A. rogoznicensis*, it is here regarded as conspecific. This is also the case for *A. neuquensis* Weaver (1931) and *Aspidoceras* aff. *binodum*, *Aspidoceras* cf. *iphiceroides* and *Aspidoceras spinosum* described by Collignon (1959).

Aspidoceras altum Biro (1980), is based on a large specimen (D = 210 mm). It is higher than wide whorl section (figure 4.22) but this is the result of tectonic deformation. The taxon is thus also regarded to be a synonym of *A. rogoznicensis*.

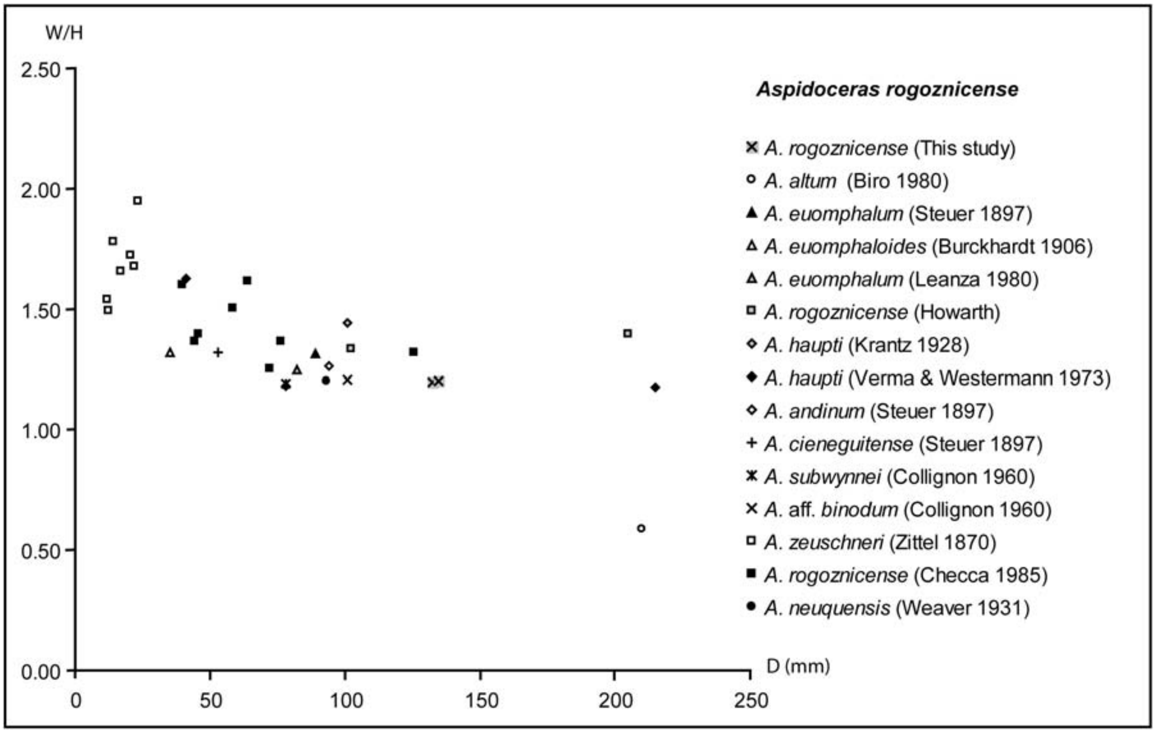


Figure 4.22. Relationship between W/H and D in *Aspidoceras rogoznicense* (Zeuschner, 1846) and the junior synonymies included in this study.

Occurrence: In the Lo Valdés Formation *A. rogoznicensis* is recorded for the first time in Chile. It is present in the Siltstone Member of the Cruz de Piedra section and in the Sandstone Member of the Cajón del Morado section (figure 5.7 and 5.8). In the Lo Valdés Formation at Lo Valdés the taxon was previously registered as *A. altum* by Biro (1980) in the upper part of the Spilite member, here redefined as the Catedral Formation, which corresponds to the lower part of the Upper Tithonian. In Argentina *A. rogoznicensis* (known there as *A. euomphalum*, *A. andinum*, *A. cieneguitense*, *A. haupti* and *A. neuquensis*) is recorded for the Middle-Upper Tithonian (Steuer 1897, 1921, Krantz 1928, Weaver 1931, Leanza 1980, Riccardi 1988, Gründel 2007), whereas in Mexico, the taxon is registered for the Upper Kimmeridgian (Burckhardt 1906) and the Lower-Upper Tithonian (Verma & Westermann 1973). In Europe *A. rogoznicensis* is registered for the Tithonian to basal Berriasian in southern Spain (Checca 1985), the Lower Tithonian in southern Poland (the Hybonotum to Fallauxi Zones; Kutek & Wierbowski 1986), and for the Lower Tithonian of the Carpates in Romania (Fülop 1976). *A. andinum* (=*A. rogoznicensis)* is recorded for the Tithonian in Nepal (Matsumoto & Sakai 1983). *A. rogoznicensis* is also recorded for the Lower Tithonian of India (Spath 1931) and Kenya (Verma & Westermann 1984), the Tithonian of Madagascar and the Berriasian of Yemen (Howarth 1998).

Genus *Aulacosphinctes* Uhlig, 1910

Type species. *Ammonites mörikeanus* Oppel (1863, p. 281, fig. 2a, b), designated by Uhlig (1910), and by subsequent designation by Spath (1924, p. 16).

Aulacosphinctes proximus (Steuer, 1897)

Figure 4.23d-k, 4.24, 4.25

1897 *Reineckeia mangaensis* n. sp. Steuer, p. 33, pl. 13, figs. 7-9.
1897 *Reineckeia proxima* n. sp. Steuer, p. 160, pl. 8, figs. 7-9.
1897 *Perisphinctes colubrinus* Reinecke. Steuer, p. 188, pl. 15, fig. 11.
1900a *Reineckeia* aff. *cimbrica* Neumayr. Burckhardt, p. 40, pl. 24. fig. 2.
1900a *Perisphinctes colubrinus* Reinecke. Burckhardt, p. 44, pl. 24, figs. 5-6.
1900a *Perisphinctes colubrinus* Reinecke. Burckhardt, p. 46, pl. 26, fig. 4.
1900 *Perisphinctes contiguus* Catullo. Burckhardt, p. 45, pl. 24, fig. 1.
1900 *Reineckeia* aff. *cimbrica* Neumayr. Burckhardt, p. 40, pl. 24. fig. 2.
1900 *Perisphinctes colubrinus* Reinecke. Burckhardt, p. 46, pl. 26, fig. 4.
1907 *Perisphinctes mangaensis* (Steuer). Haupt, p. 192.
1907 *Perisphinctes* aff. *bifurcatus* Quenstedt. Haupt, p. 195.
1912 *Berriasella* aff. *Oppeli* (Killian). Burckhardt, p. 138, pl. 35, figs. 1-3.

1921 *Perisphinctes proximus* (Steuer). Haupt, p. 192.
1921 *Reineckeia mangaensis* n. sp. Steuer, p. 60, pl. 13, figs. 7-9 (= Steuer 1897).
1921 *Reineckeia proxima* n. sp.Steuer, p. 61, pl. 8, figs. 7-9 (= Steuer 1897)
1921 *Perisphinctes colubrinus* Reinecke. Steuer, p. 90, pl. 5, fig. 11 (= Steuer 1897).
1928 *Aulacosphinctes mangaensis* (Steuer). Krantz, p. 40.
1928 *Aulacosphinctes wanneri* n. sp. Krantz, p. 42, pl. 2, figs. 6a, b.
1931 *Aulacosphinctes proximus* (Steuer). Weaver, p. 411, pl. 44, figs. 298-299.
1931 *Aulacosphinctes colubrinus* (Reinecke). Weaver, p. 413, pl. 44, figs. 301-303.
1945 *Aulacosphinctes azulensis* Leanza, p. 20, pl. 1, figs. 6-7.
1945 *Aulacosphinctes mangaensis* (Steuer). Leanza, p. 21, pl. 3, figs. 1-2.
1945 *Berriasella australis* A. Leanza, p. 36, pl. 2, figs. 6, 10, 10, 11, 14.
1951 *Aulacosphinctes* aff. *A. proximus* (Steuer). Rivera, p. 18, pl 3, fig. 4, pl. 6, fig. 2.
1959 *Aulacosphinctes* sp. aff. *A. colubrinus* (Reinecke). Corvalán, p. 12, pl. 5, fig. 22.
1959 *Aulacosphinctes proximus* (Steuer). Corvalán, p. 13, pl. 6, fig. 23.
1959 *Aulacosphinctes chilensis* Corvalán, p. 15, pl. 6, fig. 24.
1960 *Aulacosphinctes proximus angustus* Collignon, fig. 731.
1964 *Aulacosphinctes proximus* (Steuer). Biro, p. 46.
? 1979 *Aulacosphinctes smithwoodwardi* (Uhlig). Thompson, p. 22, pl. 6, figs a-b.
1980a *Aulacosphinctes proximus* (Steuer). Biro, p. 143-144.
1980 *Aulacosphinctes proximus* (Steuer). Leanza, p. 44, pl. 6, figs. 2, 4-5.
1981 *Aulacosphinctes proximus* (Steuer). Leanza, pl. 2, figs. 9-10 (= Leanza 1980).
1999 *Troquatisphinctes* cf. *proximus* (Steuer). Parent & Capello, p. 349.
2003a *Troquatisphinctes proximus* (Steuer). Parent, p. 159, figs. 1, 9i-l, 12a-b, 13a-c.
2004 *Aulacosphinctes* cf. *proximus* (Steuer). Yin & Enay, p. 673, pl. 3, figs. 4a, b.
2005 *Berriasella* (*Berrsiasella*) *australis* A. Leanza. Klein, p. 165.
non 2009 *Aulacosphinctes proximus* (Steuer). Aguirre-Urreta & Vennari, p. 39, figs. 5r-t. (= ? *Corongoceras mendozanum*)
2011b *Catutosphinctes proximus* (Steuer). Parent et al., p. 37. fig. 25B. (= Steuer 1897).

Type: Lectotype is GZG 499-30, the original of Steuer (1897, p. 160, pl. 8, figs. 7-9) from the Tithonian of Mendoza (Argentina), by subsequent designation by Parent (2003, p. 159, fig. 9i-j).

Material: 100 internal moulds, which correspond to complete and fragmentary phragmocones. CPUC/CM/17-37, CPUC/CM/17-108, CPUC/CP/20-16, CPUC/CP/40-03, CPUC/CP/40-04,

CPUC/CP/40-05, CPUC/CP/40-14, CPUC/CP/40-70-19, CPUC/CP/40-70-30, CPUC/CP/40-70-35, CPUC/CP/40-70-38, CPUC/CP/40-70-33, CPUC/CP/50-02, CPUC/CP/50-04, CPUC/CP/50-07, CPUC/CP/50-22, CPUC/CP/60-21, CPUC/CP/60-33, CPUC/CP/60-35, CPUC/CP/70-03, CPUC/CP/70-04, CPUC/CP/70-10, CPUC/CP/70-11, CPUC/CP/70-15, CPUC/CP/70-23, CPUC/CP/70-24, CPUC/CP/70-26, CPUC/CP/70-31, CPUC/CP/70-54, CPUC/CP/70-61, CPUC/CP/70-62, CPUC/CP/70-75, CPUC/CP/70-76 are complete regular to well preserved phragmocones.

Description: The coiling is evolute, the umbilicus wide and the shell discoidal. The whorl section is rounded-subquadrate. It is slightly wider than high in juvenile stages (D < 35 mm) and changes gradually to higher than wide in adults (D > 35 mm) (figure 4.24). The umbilical shoulder is rounded, flanks are convex and slightly rounded and the venter is narrowly rounded. The maximum width is reached on the middle part of the flank. The sculpture is composed by primary ribs that are slightly flexuous, rursiradiate to prorsiradiate, slightly convex on the dorsolateral and on the middle part of the flank. They bend back to slightly prorsiradiate on the ventrolateral area and cross the venter without interruption. Most ribs are bifurcated on the middle part of the flank and some are trifurcate, while a few remain simple. With increasing diameter, trifurcate ribs are gradually more common. In larger specimens shallow constrictions are present which are rectiradiate to prorsiradiate.

Dimensions

Dimensions	D	W	H	W/H	U	U/D
CPUC/CP/40-04	54.1	17.5	18.8	0.93	23.7	0.44
CPUC/CP/40-05	63.5	21.5	21.2	1.01	27.8	0.44
CPUC/CP/40-14	43.2	14.2	14	1.01	20.2	0.47
CPUC/CP/50-02	49.4	15.7	17.0	0.92	20.4	0.41
CPUC/CP/50-04	52.9	18.0	17.4	1.03	23.0	0.43
CPUC/CP/50-07	47.8	14.6	14.5	1.01	22.6	0.47
CPUC/CP/70-03	41.1	13.8	13.7	1.01	17.9	0.44
CPUC/CP/70-11	44.1	14.8	15.3	0.97	17.4	0.39
CPUC/CP/70-26	28.0	9.8	8.7	1.13	11.7	0.42
CPUC/CP/70-31	32.4	11.5	11.4	1.01	12.3	0.38
CPUC/CP/70-54	36.3	12.8	12.6	1.02	13.8	0.38
CPUC/CP/70-62	47.9	15.7	16.3	0.96	20.4	0.43

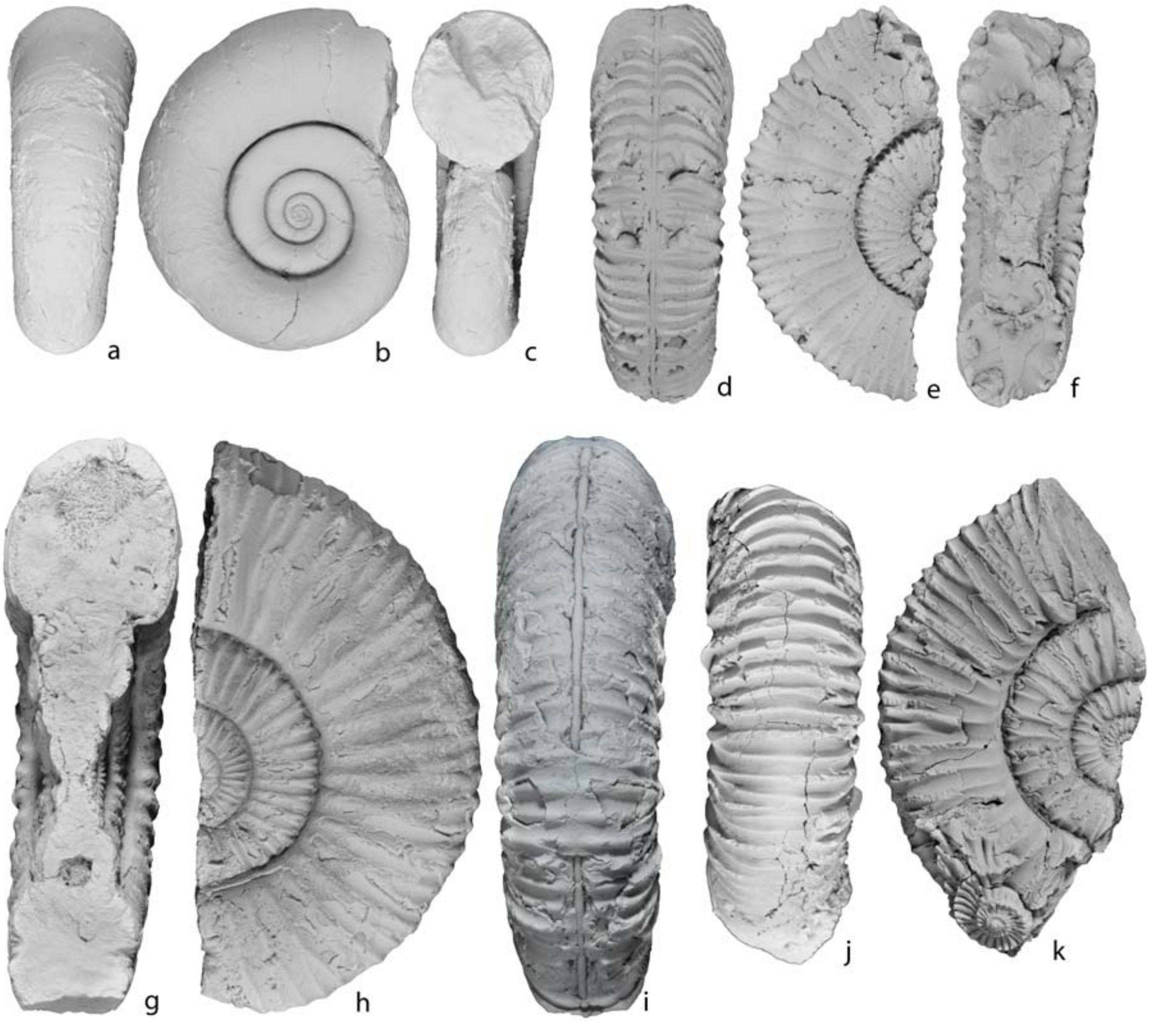


Figure 4.23. a-c: *Pterolytoceras exoticum* (Oppel, 1863) from Lo Valdés Formation. **a-c:** CPUC/CP/60-32 x1. **d-k:** *Aulacosphinctes proximus* (Steuer, 1897) from Lo Valdés Formation. **d-f**: CPUC/CP/70-37 x1; **g-i:** CPUC/CP/40-70-17 x1; **j-k:** CPUC/CP/70-55 x1.

Remarks: *Reineckeia mangaensis* Steuer (1897) was based on a single slightly deformed specimen that differs from *A. proximus* only by a lower section. However, the whorl section of *A. proximus* changes gradually from juvenile to adult stages and also includes other specimens described as *R. mangaensis* (e.g., Burckhardt 1900, Leanza 1945). *R. mangaensis* is thus considered here a synonym of *A. proximus*.

P. colubrinus Steuer (1897) is a large specimen which differs from *A. proximus* only by a wider than high section of the last whorl and by a trifurcated rib. Burckhardt (1900), Weaver (1931) and Corvalán (1959) distinguish *A. colubrinus* also based on a higher density of the ribs. We consider that these differences are within the morphological variability observed in *A. proximus* and the two are here considered to be conspecific.

A. azulensis Leanza (1945) shows a whorl section that is higher than in the lectotype of *A. proximus*, but it is still within the morphological variability between juveniles and adult specimens of *A. proximus* as described here; *A. azulensis* is thus also considered to be conspecific with *A. proximus*.

Juvenile stages of *A. proximus* are closely allied with *C. mendozanum* and *M. vetustum*. In *C. mendozanum* the coiling is more compressed, ribs are more spaced and the whorl section is proportionally higher than in *A. proximus*. In *M. vetustum*, ribs are stronger and spaced, tubercles are present and a smooth furrow characterizes the venter.

Juveniles of *A. proximus* are thus morphologically close to *C. mendozanum* and *M. vetustum*. In *C. mendozanum* the coiling is more compressed, ribs are wider spaced and the whorl section proportionally higher than in *A. proximus*. In *M. vetustum*, ribs are stronger and wider spaced, and a smooth ventral furrow is associated with tubercles on both sides.

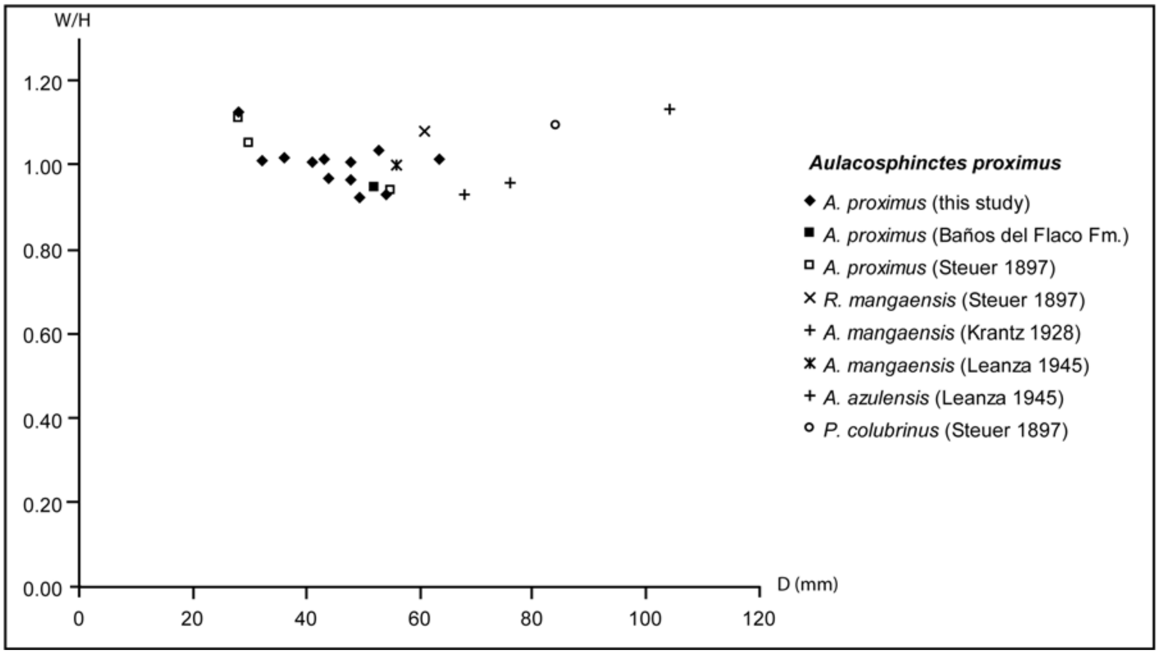


Figure 4.24. Relationship between W/H and D in *Aulacosphinctes proximus* (Steuer, 1897) and the junior synonymies included in this study.

Occurrence: *A. proximus* is present in the Siltstone member at Cajón del Morado, Lo Valdés and Cruz de Piedra (figure 5.6-5.8). Elsewhere in central Chile, *A. proximus* was recorded from the Middle Tithonian of the Baños del Flaco Formation (Corvalán 1959) and from the middle to uppermost Tithonian of the Lo Valdés Formation (Biro 1964, 1980a; Hallam et al. 1986).

A. proximus was recorded from the Upper Tithonian of Perú (Rivera 1951), the Middle-Upper Tithonian of Neuquén and Mendoza in Argentina, (Steuer 1897, Burckhardt 1900, Haupt 1907, Krantz 1928, Weaver 1931, Leanza 1980, Parent 2003a, Aguirre-Urreta & Vennari 2009), the Tithonian of Antarctica (Thompson 1979), the upper part of the Lower Tithonian of Tibet (Yin & Enay 2004) and the Tithonian of Madagascar (Collignon 1960).

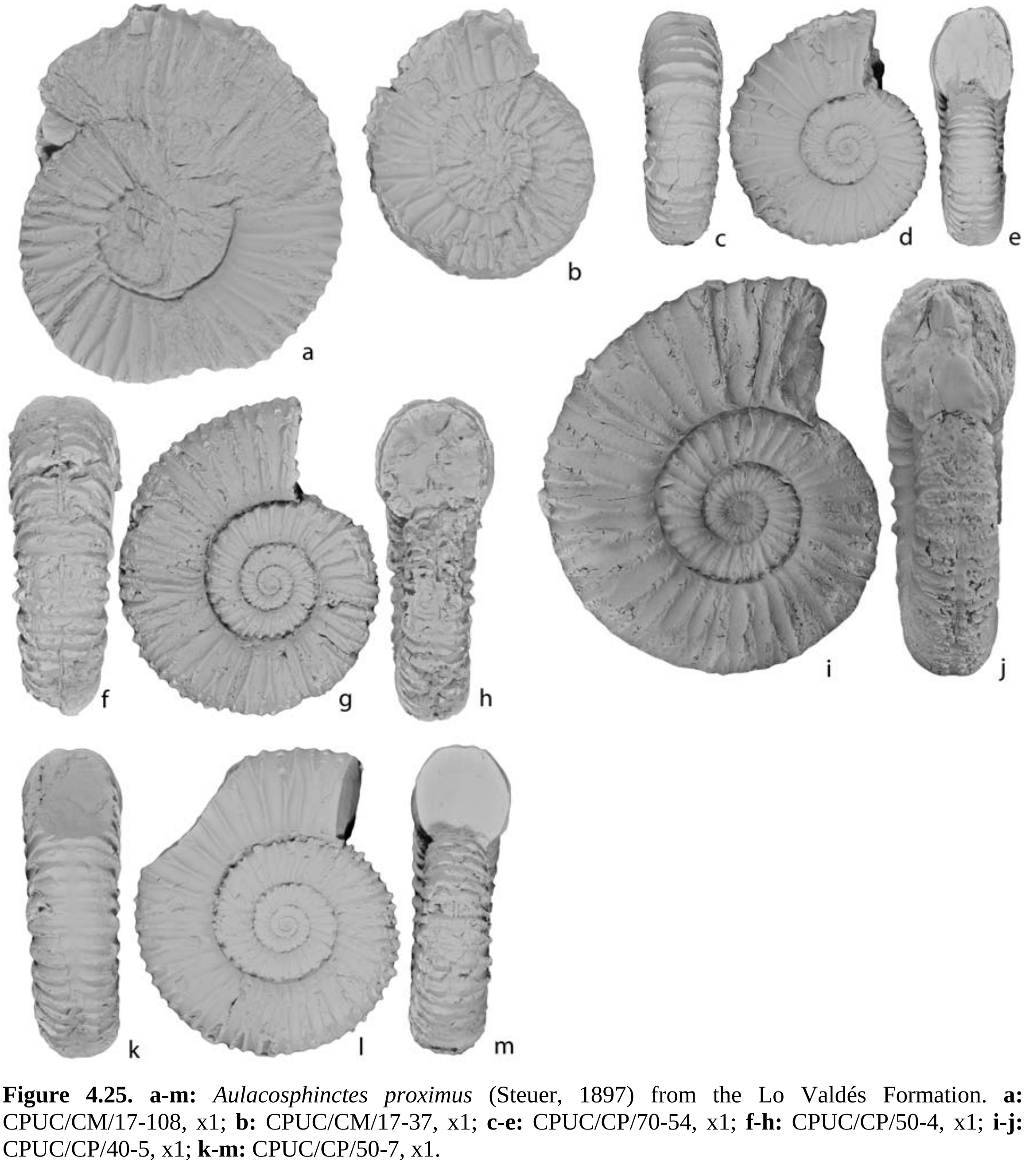


Figure 4.25. a-m: *Aulacosphinctes proximus* (Steuer, 1897) from the Lo Valdés Formation. **a:** CPUC/CM/17-108, x1; **b:** CPUC/CM/17-37, x1; **c-e:** CPUC/CP/70-54, x1; **f-h:** CPUC/CP/50-4, x1; **i-j:** CPUC/CP/40-5, x1; **k-m:** CPUC/CP/50-7, x1.

Genus *Micracanthoceras* Spath, 1925

Type species. *Ammonites microcanthus* Oppel 1865, p. 555 (Zittel, 1868, pl. 17, fig. 3a-b) by original designation of Spath (1925, p. 144).

Description of genus: Evolute, whorl section rounded to elongated. Small tubercles are present on rib bifurcations on the middle flank and on the ventral shoulder. These ribs are interrupted by a smooth furrow on the venter (Spath 1925 and Arkell et al. 1957)

Micracanthoceras microcanthum (Oppel, 1865)

Figure 4.26, 4.27

1865	*Ammonites microcanthus* Oppel, p. 555.
1868	*Ammonites microcanthus* Oppel. Zittel, p. 93, pl. 17, figs. 3, non pl. 17, fig. 1a, 2 (= *Himalayites* sp.), ?pl. 17, fig. 1b, non pl. 17, fig. 4.
1897	*Reineckeia microcantha* (Oppel). Steuer, p. 156, pl. 21, fig. 3-5.
1912	*Hoplites* sp. ind. Burckhardt, p. 142, pl. 36, figs. 4-6.
1919	*Hoplites* aff. *microcanthus* (Oppel). Burckhardt, p. 54.
1921	*Hoplites* aff. *microcanthus* (Oppel). Burckhardt, pl. 18, figs. 5-9.
1921	*Reineckeia microcantha* (Oppel). Steuer, p. 56, pl. 7, figs. 3-5 (= Steuer 1897).
1939	*Micracanthoceras aguajitense* Imlay, p. 43, pl. 14, figs. 5-7.
1939	*Micracanthoceras* cf. *microcanthum* (Oppel). Imlay, p. 45, pl. 7, figs. 2-3.
1939	*Micracanthoceras alamense* Imlay, p. 45, pl. 9, figs. 3-12.
1942	*Micracanthoceras* sp. juv. Imlay, p. 1452, pl. 4, fig. 9-10, 14-16.
1945	*Micracanthoceras tapiai* Leanza A., p. 43, pl. 6, figs. 5-6.
1945	*Himalayites concurrens* Leanza A., p. 46, pl. 3, figs. 5-6 (lectotype).
1945	*Micracanthoceras lamberti* Leanza A., p. 44, pl. 3, figs. 9-10.
1981b	*Micracanthoceras lamberti* Leanza A. Leanza H., p. 570, pl. 3, figs. 5-6 (= Leanza A., 1945).
1981b	*Himalayites concurrens* Leanza A. Leanza H., pl. 3, figs. 9-10.
1981b	*Micracanthoceras tapiai* Leanza A. Leanza H., p. 570, pl. 3, figs. 14-15 (= Leanza A., 1945).
1985	*Micracanthoceras* (*Micracanthoceras*) *microcanthum* (Oppel). Tavera, p. 169-175, pl. 21, figs. 1-4, pl. 22, figs. 1-6.

synonymy).

1989 *Himalayites* (*Micracanthoceras*) cf. *alamense* (Imlay). Myczynski, p. 107, pl. 9, fig. 4.

1990 *Micracanthoceras microcanthum* (Oppel). Fözy, p. 329, pl. 3, fig. 4.

1994 *Himalayites* (*Micracanthoceras*) cf. *alamense* (Imlay). Myczynski, p. 294, pl. 1, fig. 6.

1994 *Micracanthoceras microcanthum* (Oppel). Fözy, p. 138, pl. 21, fig. 7.

1999 *Micracanthoceras* aff. *microcanthum* (Oppel). Fatmy & Zeiss, p. 97, pl. 42, fig. 3.

2004 *Micracanthoceras* aff. *Microcanthum* (Oppel). Shome et al. p. 199, fig. 3, 3b.

2005 *Micracanthoceras concurrens* (A. Leanza). Klein, p. 18.

2005 *Micracanthoceras lamberti* Leanza A. Klein, p. 19.

2005 *Micracanthoceras microcanthum* (Oppel). Klein, p. 19. (with additional synonymy).

2009 *Micracanthoceras* cf. *microcanthum* (Oppel). Shome & Bardhan, p. 6, pl. 4, figs. a-g. (with additional synonymy).

? 2011b *Micracanthoceras* sp.A. Parent et al., p. 75, fig. 29E.

Type: As for the genus.

Material: 21 internal moulds, which are complete and fragmentary phragmocones. Seventeen specimens are from the Lo Valdés section, three from Cajón del Morado and one from Cruz de Piedra. CPUC/LV/3-07, CPUC/LV/3-13, CPUC/LV/3-198, CPUC/LV/3-214, CPUC/LV/3-356, CPUC/LV/3-357, CPUC/CM/16-97, CPUC/CM/16-110, CPUC/CM/16-126, CPUC/CP/0-03 are complete phragmocones and regular to well preserved. CPUC/LV/3-75, CPUC/LV/3-145, CPUC/LV/3-146, CPUC/LV/3-200, CPUC/LV/3-215, CPUC/LV/3-216, CPUC/LV/3-243, CPUC/LV/3-245, CPUC/LV/3-246, CPUC/LV/3-248, CPUC/LV/3-295 are well preserved fragmentary phragmocones.

Description: The coiling is evolute and the umbilicus wide. The whorl section is rounded, wider than high. The umbilical border is rounded; the flanks are convex and the venter rounded. The sculpture consists in simple ribs; most are bifurcated near the middle part of the flank and a few are trifurcated. Some ribs present fine tubercles at the point of bifurcation. In addition, some ribs present fine tubercles on the ventral shoulder. The ribs are interrupted on the venter by a smooth furrow. Juveniles (D<50 mm) are highly variable, but towards adult stages morphology tends to be more homogenous (figure 4.26).

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/3-07	42.6	16.8	13.0	1.29	20.1	0.47
CPUC/LV/3-214	64.6	(15.0)	16.7	(0.90)	34.2	0.53
CPUC/LV/3-356	66.1	21.6	20.3	1.06	29.3	0.44
CPUC/LV/3-357	25.6	10.4	10.2	1.02	8.6	0.34
CPUC/CM/16-110	72.7	(25.5)	26.1	(0.98)	26	0.36
CPUC/CM/16-126	60.9		21.6		26.9	0.44
CPUC/CP/0-03	38.9	16.0	13.0	1.23	16.8	0.43

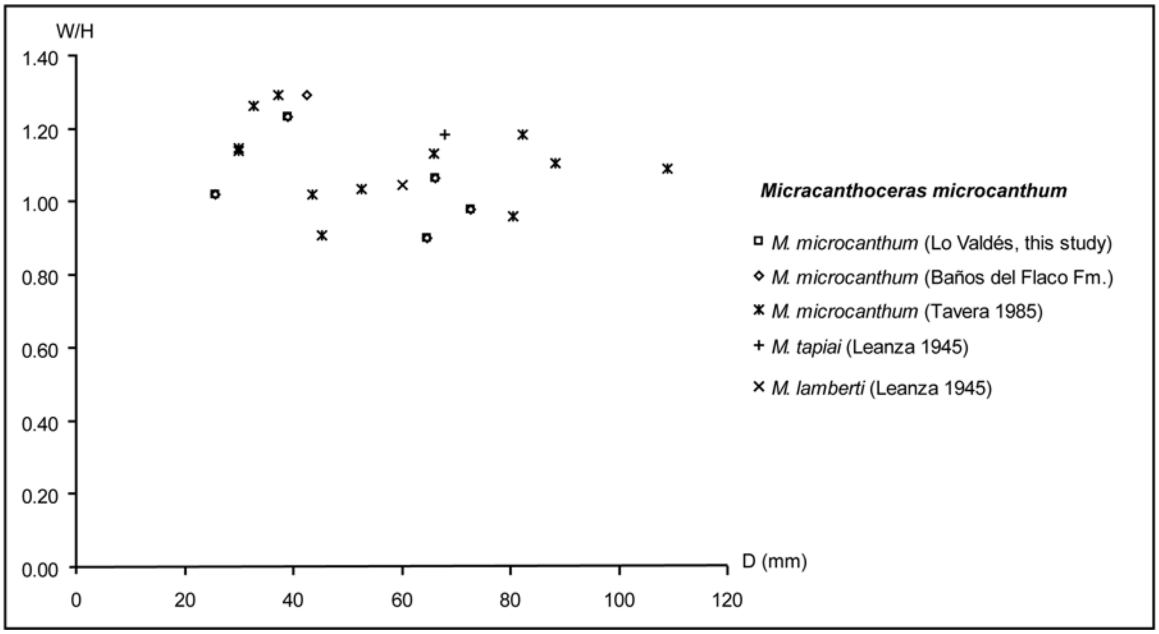


Figure 4.26. Relationship between W/H and D in *Micracanthoceras microcanthum*(Oppel, 1865) and the junior synonymies included in this study.

Remarks: Tavera (1985) gives a full discussion of *Micracanthoceras microcanthum* and considers the wide morphological variation observed in this species. The Mexican *Micracanthoceras aguajitense* was distinguished by Imlay (1939) based on a finer sculpture in the inner whorls, whereas *M. alamense* Imlay (1939) was distinguished based on a less distinct ventral depression, fewer simple ribs and a relatively higher whorl section. However, these differences are within the wide morphological range of *M. microcanthum* and the two Mexican taxa are here considered synonymous with *M. microcanthum.*

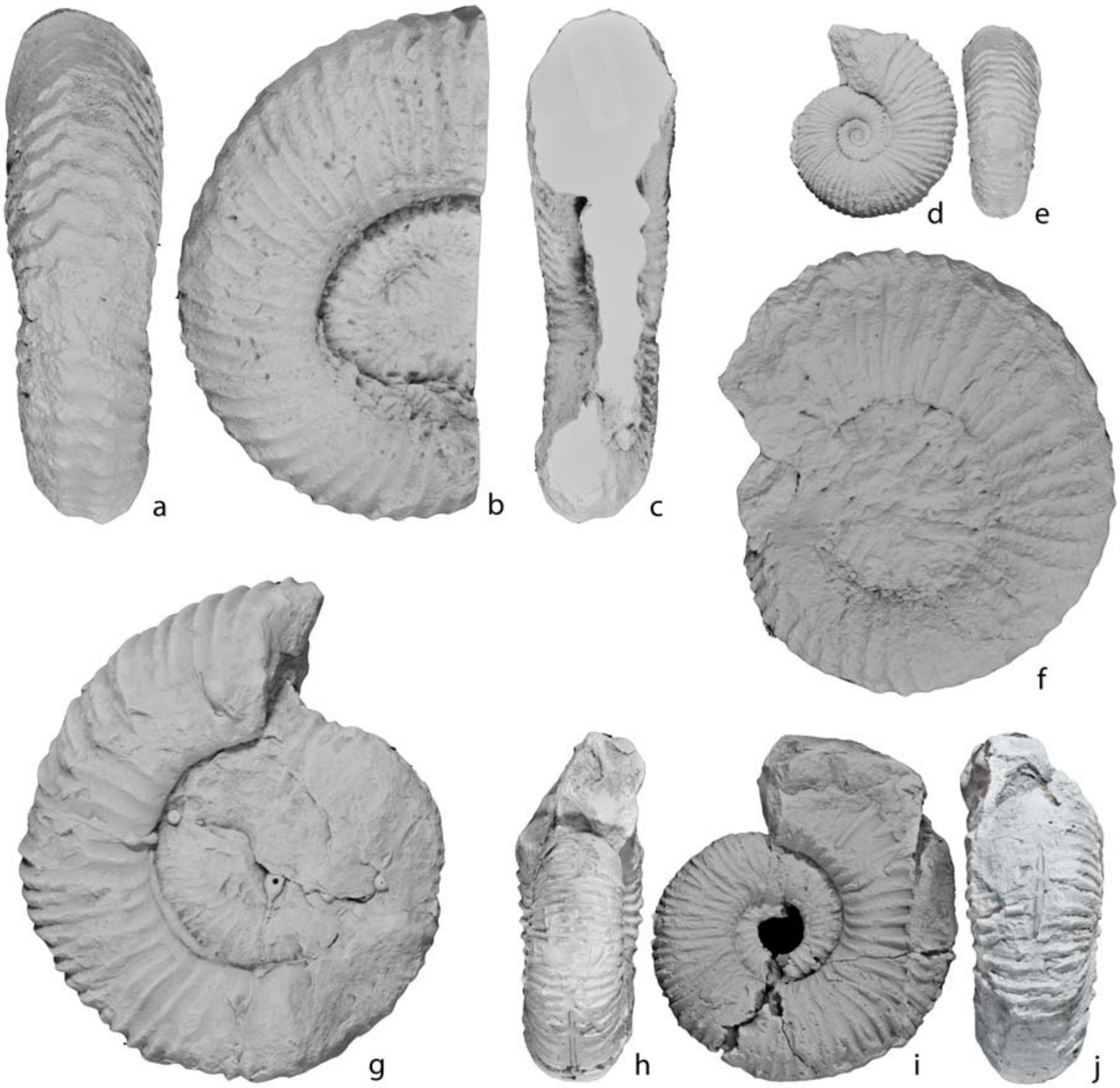


Figure 4.27. a-j: *Micracanthoceras microcanthum*(Oppel, 1865) from the Lo Valdés Formation. **a-c:** CPUC/CM/16-110, x1; **d-e:** CPUC/LV/3-357, x1; **f:** CPUC/CM/16-126, x1; **g:** CPUC/LV/3-356, x1; **h-j:** CPUC/CP/0-3, x1.

Occurrence: In the Lo Valdés Formation, *M. microcanthum* is officially recorded for first time in Chile and is present in the Sandstone member of the Lo Valdés and Cajón del Morado sections (figure 5.6-5.7); at Cruz de Piedra the taxon is present in the lower part of the Siltstone member (figure 5.8). *M lamberti* is here considered to be a synonym of *M. microcanthum* and was registered by Biro (1964) from the Sandstone member of the Lo Valdés Formation. Elsewhere in central Chile, *M. microcanthum* is recorded from the upper Baños del Flaco Formation. The taxon is also present in Argentina (Steuer 1897-1921) and was recorded, as *M. lamberti*, from the Upper Tithonian of the Mendoza area (Leanza 1945). *M. microcanthum* is known to occur in the Upper

Tithonian of Mexico (Burckhardt 1919, Imlay 1939), Cuba (Myczynski 1989, 1994) and western India (Shome & Bardhan 2009). In the Tethys region, *M. microcanthum* is recorded from Stramberg, Germany, the Italian Alps (Zittel 1868), Sicily in Italy (Fözy 1995), south-east France (Mazenot 1939), southern Spain (Tavera 1985), Bulgary (Sapunov 1979), Hungary (Fözy 1990), and Pakistan (Fatmi & Zeiss 1999). The taxon is considered the index of the *M. microcanthum* Zone which defines the base of the Upper Tithonian (Enay & Geyssant 1975, Tavera 1985, Ogg 2004).

Micracanthoceras spinulosum (Gerth, 1925)

Figure 4.28, 4.29

1921 *Berriasella spinulosa* n. sp. Gerth, p. 147 (*nomen nudum*).
1921 *Berriasella inaequicostata* n. sp. Gerth, p. 147 (*nomen nudum*).
1925 *Berriasella spinulosa* n. sp. Gerth, p. 91, pl. 6, figs. 1 and 2-2a.
1925 *Berriasella inaequicostata* n. sp. Gerth, p. 90, pl. 6, figs. 4, 4a-4b.
1928 *Berriasella spinulosa* Gerth. Gerth, p. 475, pl. 19, fig. 11 (= Gerth 1925).
1937 *Berriasella spinulosa* Gerth. Feruglio, p. 65. 8, figs. 7-13.
? 1937 *Berriasella* cf. *inaequicostata* Gerth. Feruglio, p. 69.
1945 *Berriasella inaequicostata* Gerth. A. Leanza, p. 34, pl. 4, fig. 2.
1961 *Berriasella* aff. *spinulosa* Gerth. Bürgl, p. 194, pl. 5, fig. 13.
1964 *Berriasella spinulosa* Gerth. Biro, p. 56.
1964 *Berriasella inaequicostata* Gerth. Biro, p. 101, pl. 2, figs. 1-2.
1967 *Berriasella spinulosa* Gerth. A. Leanza, p.145.
1972 *Micracanthoceras spinulosa* (Gerth). Enay, p. 375.
1983 *Berriasella* (*Malbosiceras*?) *inaequicostata* (Gerth). Geyer, p. 341, text-fig. 3i.
2005 *Micracanthoceras*? *spinulosum* (Gerth). Klein, p. 20.
2005 *Malbosiceras*? *inaequicostatum* (Gerth) Klein, p. 209.
2011b *Steueria alternans* (Gerth). Parent et al., p. 66, figs. 29A-D, 30-31.

Type: Lectotype is STIPB 949, the original of Gerth (1925, p. 91, pl. 6, figs. 1), from the Tithonian of Mendoza, Argentina, and was designated by Salazar & Stinnesbeck (submitted).

Material: 14 specimens. CPUC/LV/5-41 and CPUC/CP/20-01 are complete phragmocones and regular to well preserved. CPUC/LV/3-41, CPUC/LV/3-68, CPUC/LV/3-69, CPUC/LV/3-241, CPUC/LV/3-242, CPUC/CP/0-70 and CPUC/CP/40-20 are well preserved fragmentary phragmocones.

Description: The shell is compressed, the coiling evolute and the umbilicus is wide. The whorl section is rounded, in young specimens (D <30 mm) wider than high, but gradually changing to slightly higher than wide in adult specimens (D > 30 mm) (figure 4.28). The umbilical border is rounded, the flanks are convex and the venter is narrowly rounded with a smooth furrow. The sculpture is composed of rectiradiate ribs that are slightly prorsiradiate in the ventrolateral area. Each rib or every second rib is bifurcated and presents small tubercles at the point of bifurcation (middle flank). These bifurcated ribs have elongated tubercles on the ventral shoulder, on both sides of the ventral furrow.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/3-41		11.0	10.3	1.07		
CPUC/LV/3-68	18.5	8.9	6.0	1.48	7.6	0.4
CPUC/LV/3-69	34.2	13.8	11.2	1.23		
CPUC/LV/5-41	52.0	19.3	18.3	1.05	21.6	0.41
CPUC/CM/17-32	(56.8)				21	(0.36)
CPUC/CM/17-38		21.7	23.7	0.92		
CPUC/CP/0-7		14.2	12.9	1.10	13.2	
CPUC/CP/20-1	58.7	23.3	20.7	1.13	23.6	0.40
CPUC/CP/40-20		19.5	16.0	1.22	20.3	

Remarks: *Micracanthoceras spinulosum* is characterized by an evolute compressed coiling, rounded whorl section, bifurcated ribs and small tubercles at the points of bifurcation and on the ventral shoulder (Gerth 1925). *B. inaequicostata* is regarded conspecific with *M. spinulosum*; the differences inferred by Gerth (1925), such as a slightly higher whorl section and a finer sculpture of inner whorls in *B. inaequicostata,* are the result of a preservational bias in the original described by Gerth (1925).

M. microcanthus and *M. vetustus* are closely related species, but the latter is characterized by wider-spaced ribs and a higher than wide whorl section.

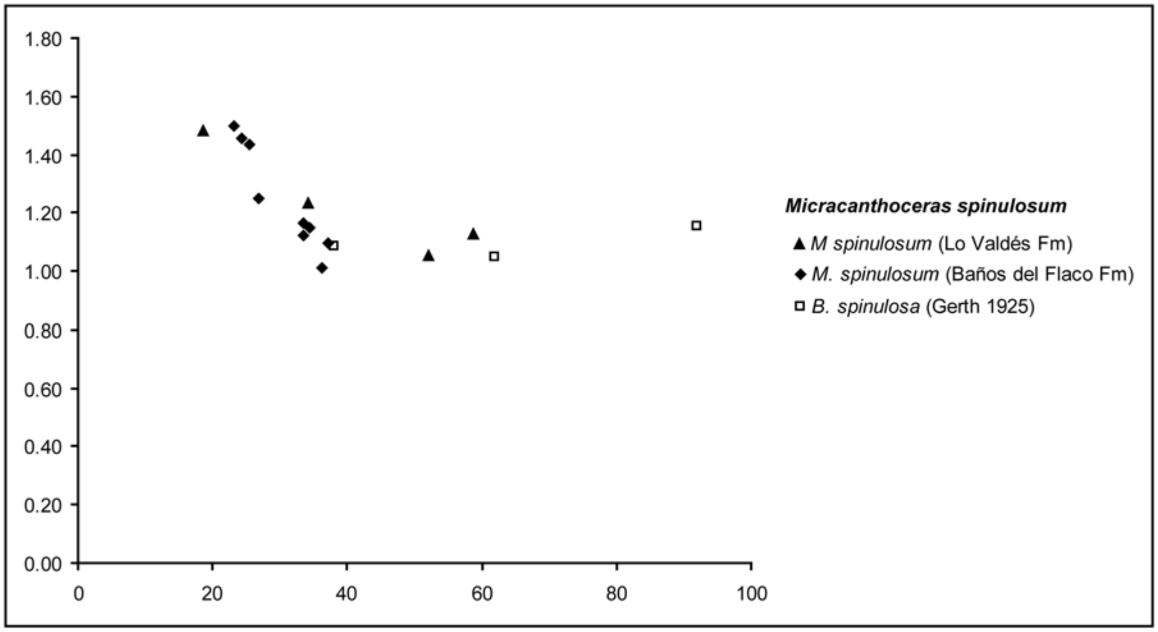


Figure 4.28. Relationship between W/H and D in *Micracanthoceras spinulosum* (Gerth, 1925).

Occurrence: In the Lo Valdés Formation, *M. spinulosum* is registered in the Sandstone and in the lower part of the Siltstone member at Lo Valdés and in the lower part of the Siltstone member at Cajón del Morado and Cruz de Piedra (figure 5.7 and 5.8). Previously Biro (1964) recorded this taxon in the Sandstone member of the Lo Valdés Formation. Elsewhere in Chile *M. spinulosum* was recorded from the upper member of the Baños del Flaco Formation. *B. inaequicostata* and *M. spinulosum* are registered from the Upper Tithonian of Argentina (Gerth 1925, Leanza 1945, Parent et al. 2011) and Perú (Geyer 1983), and the Upper Berriasian of Colombia (Bürgl, 1960).

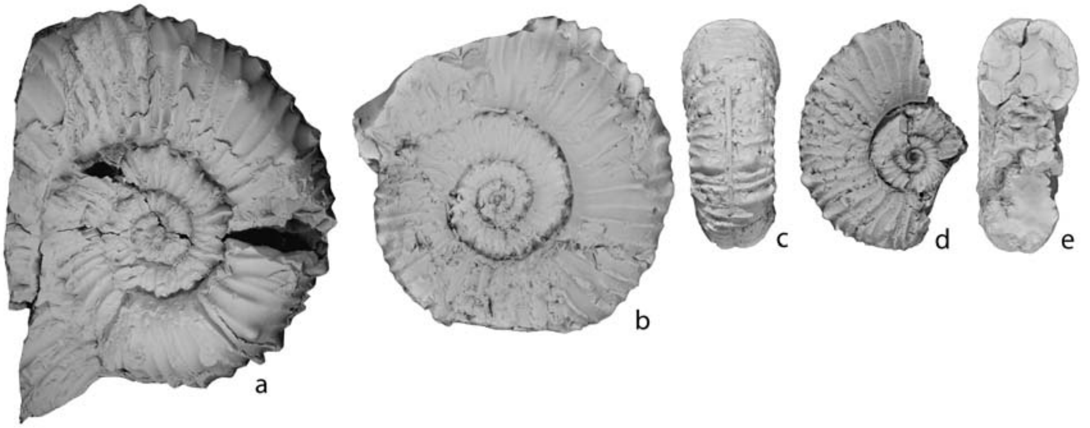


Figure 4.29. a-e: *Micracanthoceras spinulosum* (Gerth, 1925) from the Lo Valdés Formation. **a:** CPUC/CP/20-1, x1; **b:** CPUC/LV/5-41, x1; **c-e:** CPUC/CP/0-7, x1.

Micracanthoceras vetustum (Steuer 1897)

Figure 4.30, 4.31

non 1897 *Reineckeia turgida* n. sp. Steuer, p. 155, pl. 28, figs. 3-4 (= *Corongoceras mendozanum*).

1897 *Hoplites vetustus* n. sp. Steuer. p. 183, pl. 30, figs. 4-10.

1897 *Hoplites subvetustus* n. sp. Steuer. p. 184, pl. 37, figs. 6-8.

1897 *Hoplites Wallichi* (Gray). Steuer, p. 184, pl. 30, figs. 1-3 (non *H. Wallichi*).

? 1908 *Berriasella patagoniensis* n. sp. Favre, p. 622, pl. 33, fig. 5.

1910 *Hoplites Steueri*, Uhlig, p. 188.

non 1921 *Reineckeia turgida* n. sp. Steuer, p. 56, pl. 14, figs. 3-4 (= *Corongoceras mendozanum*).

1921 *Hoplites vetustus* n. sp. Steuer. p. 85, pl. 16, figs. 4-10 (= Steuer 1897).

1921 *Hoplites subvetustus* n. sp. Steuer. p. 86, pl. 23, figs. 6-8 (= Steuer 1897).

1921 *Hoplites Wallichi* (Gray). Steuer, p. 87, pl. 16, figs. 1-3 (= Steuer 1897).

1921 *Acanthodiscus*? *turgidus* (Steuer). Gerth, p. 141.

1925 *Andesites turgidus* (Steuer). Gerth, p. 78.

1926 *Berriasella subprivasensis* Krantz, p. 438.

1926 *Berriasella* (*Riasanites*) *rjasanensoides* n. sp. Krantz. p. 441, pl. 16, figs. 1-2, text-fig. 5.

1926 *Berriasella* (*Riasanites*) aff. *swistowianus* (Nikitin). Krantz, p. 443.

1926 *Berriasella* (*Corongoceras*) *duraznensis* Krantz. p. 445.

1926 *Berriasella subprivasensis* n. sp. Krantz, p. 20, pl. 3, fig. 4.

1928 *Berriasella* (*Riasanites*) *rjasanensoides* n.sp. Krantz. p. 25, pl. 4, fig. 7a-7b, text-fig. 3.

1928 *Berriasella* (*Riasanites*) aff. *swistowianus* (Nikitin). Krantz. p. 27, pl. 4, fig. 8a-8b.

1928 *Berriasella* (*Corongoceras*) *duraznensis* Krantz, p. 29, pl. 4, fig.1.

1931 *Berriasella subprivasensis* Krantz. Weaver, p. 443, pl. 56, figs. 356-357.

? 1937 *Blanfordiceras patagoniensis* (Favre) Feruglio, p. 62, pl. 6, figs. 4-6, 8, pl. 7, figs. 1-2.

non 1937 *Berriasella subvetustus* var. *chomeracensis* Breistroffer. p. 19.

non 1937 *Berriasella subvetustus* var. *Mazenoti* Breistroffer. p. 19.

1939 *Berriasella subvetusta* (Steuer). Mazenot, p. 62, 63, 64, 65, pl. 6, figs. 8-9 (= Steuer 1897).

1945 *Micracanthoceras vetustum* (Steuer). A. Leanza, p. 45, pl. 5, figs. 9-11.

1945 *Riasanites rjasanensoides* (Krantz). A. Leanza, p. 40.

? 1960 *Berriasella privasensis* Pictet. Collignon, fig. 670.

1962 *Blanfordiceras* cf. *wallichi* Gray. Collignon, fig. 679.

? 1960 *Blanfordiceras delgai* n. sp. Collignon, figs. 680-681.

? 1960 *Blanfordiceras acuticosta* Ulig. Collignon, figs. 682-683.

? 1960 *Blanfordiceras* aff. *rotundidoma* Uhlig. Collignon: fig. 684.

? 1960 *Blanfordiceras rotundidoma* Uhlig var. *venusta* n. var.- Collignon: fig. 685.

? 1960 *Blanfordiceras tenuicostatum* n. sp. Collignon: fig. 686.

? 1960 *Corongoceras irregulare* n. sp. Collignon, fig. 690.

? 1960 *Corongoceras fibulatum* n. sp. Collignon, figs. 703-704.

? 1960 *Corongoceras bifurcatum* n. sp. Collignon, fig 706.

? 1960 *Aulacosphinctes mörickei* Oppel var. *alta* n. var.- Collignon: fig. 720.

? 1960 *Aulacosphinctes laxicosta* Steuer. Collignon: fig. 721.

? 1960 *Aulacosphinctes laxicosta* Steuer var. *simplex* n. var.- Collignon: fig. 722.

? 1960 *Aulacosphinctes laxicosta* Steuer var. *ankitokensis* n. var.- Collignon: fig. 724.

? 1979 *Blanfordiceras* aff. *wallichi* (Gray). Thomson, p. 27, pl. 7, figs. b-c (non *B. Wallichi*).

1981 *Blanfordiceras vetustum* (Steuer). H. Leanza, p. 570, pl. 3, figs.3-4 (A. Leanza 1945).

1983 *Micracanthoceras* sp. ex gr. *vetustum* (Steuer). Geyer, p. 341, fig. 2c.

1989 *Blanfordiceras acuticosta* (Uhlig). Howlett, p. 28, pl. 1, fig. 3.

1996 “*Aulacosphinctes” cf. *subvetustus* (Steuer). Enay et al., p. 227.

2005 *Micracanthoceras*? *vetustum* (Steuer). Klein, p. 21.

2005 *Corongoceras duraznense* (Krantz). Klein, p. 23

2005 *Berriasella* (*Berriasella*) *subvetusta* (Steuer). Klein, p. 178.

2005 *Riasanites rjasanensoides* (Krantz). Klein, 197.

2005 *Blanfordiceras* (*Blafordiceras*) *steueri* (Uhlig). Klein, p. 203.

2005 *Argentiniceras turgidum* (Steuer). Klein, p. 250.

non 2011b *Blanfordiceras vetustum* (Steuer), Parent et al., p. 55, pl. 26C-F, 27A-B, =(*Corongoceras mendozanum*)

2011b *Blanfordiceras vetustum* (Steuer), Parent et al., app. 2-D-E. (= Weaver 1931 and Steuer 1897).

Type: Lectotype is specimen GZG 499-141 illustrated by Steuer (1897, pl. 16, figs. 4-5).Parent (2011b) erroneously designated another specimen of the Steuer type collection (p. 94, appendix 2, fig. E), but this is not the specimen that Steuer (1897, pl. 16, figs. 4-5) used for the description and figure.

Material: 43 internal moulds, all from the Cruz de Piedra section. CPUC/CP/40-70-08, CPUC/CP/40-70-31, CPUC/CP/40-70-42, CPUC/CP/50-13, CPUC/CP/60-03, CPUC/CP/60-04, CPUC/CP/60-08, CPUC/CP/60-24, CPUC/CP/60-39, CPUC/CP/60-41, CPUC/CP/60-44, CPUC/CP/60-52, CPUC/CP/70-12, CPUC/CP/70-14, CPUC/CP/70-18 and CPUC/CP/70-28 are regular to well preserved complete phragmocones. CPUC/CP/20-13, CPUC/CP/40-70-02, CPUC/CP/40-70-29, CPUC/CP/50-19, CPUC/CP/50-24, CPUC/CP/50-48, CPUC/CP/50-34, CPUC/CP/50-39, CPUC/CP/50-43, CPUC/CP/60-11, CPUC/CP/60-19, CPUC/CP/60-23, CPUC/CP/60-26, CPUC/CP/60-27, CPUC/CP/60-30, CPUC/CP/60-46, CPUC/CP/60-47, CPUC/CP/60-48, CPUC/CP/60-50, CPUC/CP/60-55, CPUC/CP/60-58, CPUC/CP/60-60 are regular to well preserved fragmentary phragmocones.

Description: The shell is compressed; coiling is evolute and the umbilicus wide (U/D: 0.37-0.48). The whorl section is slightly higher than wide. The umbilical border and the flanks are rounded. The venter is narrowly rounded, except for a median furrow. The sculpture consists of strong rectiradiate to slightly prorsiradiate ribs. Their density changes during ontogeny: spacing in inner whorls is close and progressively changes towards wider spaced ribs in adults. Most ribs are bifurcated ventrolaterally. These bifurcated ribs are intercalated by one or two simple ribs. In the point of bifurcation, ribs present a weak tubercle which is not always well preserved. On the venter, ribs are interrupted by a furrow; small tubercles are present on the ribs on both sides of the furrow.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CP/40-70-08	33.3	9.9	11	0.90	11.7	0.35
CPUC/CP/40-70-42	53.5	17.4	16.2	1.07	25.5	0.48
CPUC/CP/50-13	38.6	(11.3)	13.9	(0.81)	14.1	0.37
CPUC/CP/60-08	39	12.7	13	0.98	16	0.41

CPUC/CP/60-24	38.6	13.5	13.1	1.03	15.1	0.39
CPUC/CP/60-26	39.7	12.4	14	0.89	14.5	0.37
CPUC/CP/60-04	39.3	12	13.7	0.88	15.4	0.39
CPUC/CP/60-41	43.5	13.9	15.5	0.90	18.2	0.42
CPUC/CP/60-44	41.1	14.5	14.8	0.98	15.9	0.39
CPUC/CP/60-52	59.9	(15.8)	19.8	(0.80)	25.2	0.42
CPUC/CP/70-12	45.9	14.8	15.6	0.95	19	0.41
CPUC/CP/70-14	35.3	11.3	10.9	1.04	13.4	0.38
CPUC/CP/70-18	46.2	14.6	15.6	0.94	17.7	0.38
CPUC/CP/70-28	32.8	10.6	11.4	0.93	12.2	0.37

Remarks: *Micracanthoceras* is characterized by evolute coiling, a rounded whorl section, small tubercles on rib bifurcations and on both sides of a ventral furrow (Spath 1925, Arkell et al. 1957). These morphological characteristics indicate assignation within the genus *Micracanthoceras*.

Hoplites wallichi Steuer (1897) was based on a single specimen with wider-spaced ribs than in *M. vetustum*. The taxon was subsequently included in *Hoplites Steueri* by Uhlig (1910) but based on our abundant material we conclude that it corresponds to an adult *M. vetustum*. *Hoplites subvetustus* Steuer (1897) was differentiated by closer-spaced ribs. In his original description, the author suggested that this species represents “transition forms of *H. vetustus*”, but it clearly corresponds to juveniles of *M. vetustum*. Mazenot (1939) and Tavera (1985) included *M. subvetustum* as synonyms of *B. mazenoti*, but the latter European species presents finer and closer-spaced ribs.

B. (*R.*) *rjasanensoides* Krantz (1926) and *B.* (*R.*) aff. *swistowianus* Krantz (1926) are here regarded as juvenile forms of *M. vetustum*. On the other hand, *B.* (*C.*) *duraznensis* corresponds to an adult specimen of *M. vetustum*. Juvenile stages of *Corongoceras mendozanum* are similar to *M. vetustum* (figure 4.30), but are more compressed, the whorl section is higher and ribs are denser.

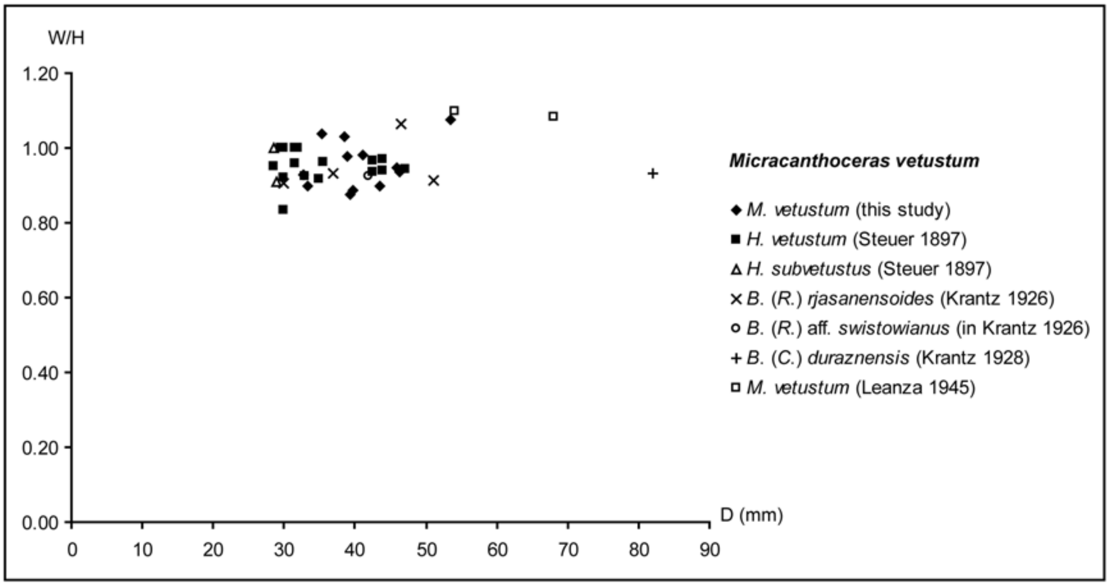


Figure 4.30. Relationship between W/H and D in *Micracanthoceras vetustum* (Steuer, 1897) and the junior synonymies included in this study.

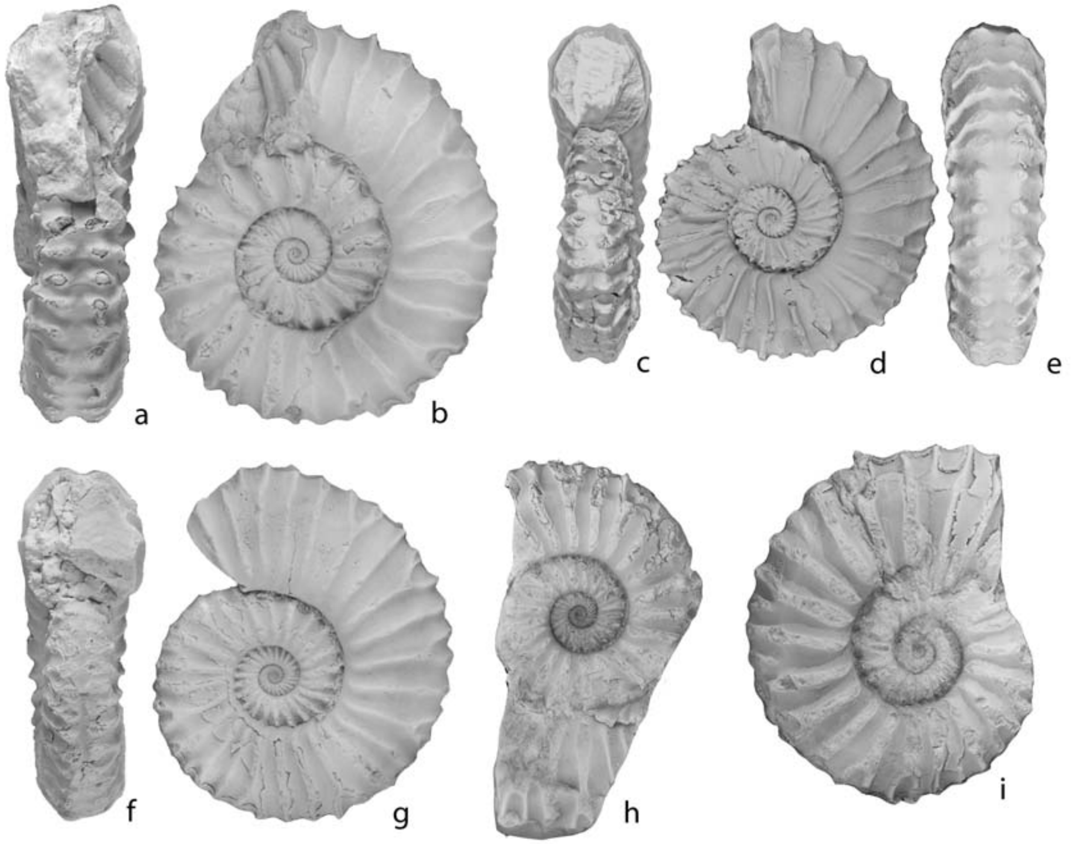


Figure 4.31. a-i: *Micracanthoceras vetustum* (Steuer, 1897) from the Lo Valdés Formation. **a-b:** CPUC/CP/40-70-42, x1; **c-e:** CPUC/CP/60-41, x1; **f-g:** CPUC/CP/70-18, x1; **h:** CPUC/CP/60-39, x1; **i:** CPUC/CP/60-44, x1.

Occurrence: In the Lo Valdés Formation, the taxon is abundant at Cruz de Piedra and occurs in the middle part of the Siltstone member (figure 5.8). This is the first record in Chile. *M. vetustum* is registered for the Upper Tithonian of Argentina (Steuer 1897, Krantz 1926, A. Leanza 1945 and H. Leanza 1981) and also occurs in Perú (Welter 1913, Geyer 1983) and in Antarctica (Thomson 1979, Howlett 1989).

Genus *Corongoceras* Spath, 1925

Type species. *Corongoceras lotenoense*, pro *Hoplites köllikeri* (Oppel, 1863), *sensu* Haupt (1907, pl. 9, fig. 7a-b), STIPB 201, by subsequent designation of Spath (1925, p. 144). This genus was discussed by Parent (2001).

Description of the genus: Inner whorls show bifurcated ribs with lateral and ventral tubercles bordering a smooth concave venter. Ribs on outer whorls are strong and distant, bituberculated, with lateral and ventral tubercles, and some secondary ribs which are looped or zigzag; ventral tubercles may be spinous (Spath 1925 and Arkell et al. 1957). Complementary description: In juveniles the venter is rounded or flat and gradually to nearly flat in adult outer whorls.

Corongoceras alternans (Gerth 1925)

Figure 4.32, 4.33

1900b *Reineckeia Koellikeri* (Oppel). Burckhardt, p. 16, pl. 20, figs.14-15, pl. 21, fig. 1.
1900b *Reineckeia microcantha* (Oppel). Burckhardt, p. 16, pl. 20, fig. 16-17 (?= *Corongoceras alternans*).
1921 *Berriasella alternans* Gerth, p. 147 (*nomen nudum*).
1925 *Berriasella alternans* Gerth, p. 89, pl. 6, figs. 3, 3a.
1928 *Berriasella alternans* Gerth. Gerth p. 474, pl. 19, figs. 10, 10a (= Gerth 1925).
1931 *Berriasella alternans* Gerth. Windhausen, pl. 30, fig. 6 (= Gerth 1925).
non 1937 *Berriasella alternans* (n var.?) Gerth. Feruglio, p. 70, pl. 8, fig. 6 (= *Lytohoplites burckhardti*).
1945 *Berriasella pastorei* n. sp. A. Leanza, p. 33, pl. 3, figs. 12-13.

non 1945 *Berriasella groeberi* n. sp. A. Leanza, p. 37, pl. 4 (holotype by monotype) (= *Corongoceras mendozanum*).

non 1945 *Berriasella* (?) *delhaesi* n. sp. A. Leanza, p. 39, pl. 6, figs. 1-2 (holotype by monotype) (= *Corongoceras mendozanum*).

non 1945 *Himalayites concurrens* n. sp. A. Leanza, p. 46, pl. 3, figs. 5-6 (= *Micracanthoceras microcanthum*).

1945 *Corongoceras alternans* (Gerth). Leanza A., p. 47, pl. 1, fig. 2-3.

1945 *Corongoceras rigali* n. sp. A. Leanza, p. 48, pl. 6, figs. 3-4.

1958 *Corongoceras alternans* (Gerth). Corvalán & Pérez, p. 46, pl. 13, fig. 32a-b (= Gerth 1925).

1964 *Corongoceras alternans* (Gerth). Biro, p. 103, pl. 24, figs. 1a-b, 2a-b, 3a-b, pl. 25, figs. 1a-b, 2a-b.

1966 *Berriasella* cf. *alternans* Gerth. Fuenzalida, p. 135, figs. 24-26.

1973 *Blanfordiceras* aff. *pastorei* (A. Leanza). Geyer, p. 83, text-fig. 29.

1981 *Berriasella pastorei* A. Leanza. H. Leanza, pl. 3, figs. 13-14.

non 1981 *Himalayites concurrens* A. Leanza. H Leanza, pl. 3, figs. 9-10 (= *Micracanthoceras microcanthum*).

2001 *Corongoceras* cf. *alternans* (Gerth). Parent, p. 32, figs. 5F, 8K, 8L.

2001 *Corongoceras alternans* (Gerth). Parent, fig. 9D-E (= Gerth 1925).

non 2005 *Micracanthoceras concurrens* (A. Leanza). Klein, p. 18 (= *Micracanthoceras microcanthum*).

2005 *Corongoceras alternans* (Gerth). Klein, p. 22.

non 2005 *Berriasella* (*Berriasella*)? *delhaesi* A. Leanza. Klein, p. 169 (= *Corongoceras mendozanum*).

non 2005 *Berriasella* (*Berriasella*) *groeberi* A. Leanza. Klein, p. 170 (= *Corongoceras mendozanum*).

2005 *Blanfordiceras* (*Blanfordiceras*) *pastorei* (A. Leanza). Klein, p. 202.

non 2011b *Steueria alternans* (Gerth). Parent et al., p. 66, figs. 29A-D, 30-31 (= *Micracanthoceras spinulosum*).

Type: The holotype was defined by monotypy. It is STIPB 939, the original of Gerth (1925, p. 89, pl. 6, figs. 3, 3a), from the Tithonian of Mendoza, Argentina.

Material: 71 specimens, representing complete and fragmentary phragmocones. CPUC/LV/3-138, CPUC/LV/3-194, CPUC/LV/3-217, CPUC/LV/3-218, CPUC/LV/3-379, CPUC/LV/3-401, CPUC/CM/16-20, CPUC/CM/16-95 are complete and well preserved phragmocones.

Description: The shell is compressed and evolute, with a wide umbilicus. The whorl section in juveniles (D < 30 mm) is slightly wider than high and gradually changes to higher than wide in adult specimens (D > 30 mm) (figure 4.32). Sculpture consists of strong ribs which are slightly prorsiradiate and convex. Their density changes during ontogeny: they are closely-spaced in inner whorls and progressively wider-spaced towards adult stages. Almost all ribs bifurcate on the middle flank, at a prominent tubercle at the point of bifurcation. A few intercalated ribs remain single; they are closely spaced and parallel to other single ribs. Ribs end at a narrow smooth furrow on the venter, forming spine-like tubercles on both sides of the furrow.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/3-138	49.2	13.6	15.1	0.90	22.9	0.47
CPUC/LV/3-21	44.7	(13.0)	13.4	(0.97)		
CPUC/LV/3-218	(45.9)	14.4	(14.9)	(0.97)	(20.5)	(0.45)
CPUC/LV/3-379	37.6	11.2	12.4	0.90	17.7	0.47
CPUC/LV/3-401	24.7	8.8	8.0	1.10	10.9	0.44
CPUC/CM/16-1	24.4		8.2		10.6	0.43
CPUC/CM/16-15	37.1	(10.5)	12.8	(0.82)	15.3	0.41
CPUC/CM/16-21	24.0		8.9		10.2	0.43
CPUC/CM/16-23	35.7	(11.0)	11.9	(0.92)	16.7	0.47
CPUC/CM/16-57	(32.2)		10.8		14.9	(0.46)
CPUC/CM/16-77	29.9				12.7	0.42
CPUC/CM/16-95	(29.8)	(11.2)	(11.6)	(0.97)	(11.0)	0.37

Remarks: *Corongoceras* is characterized by widely spaced ribs on the outer and closely-spaced ribs on inner whorls; ribs are bifurcated, with tubercles at the point of bifurcation and on both sides of the ventral furrow. *C. alternans* differs from other *Corongoceras* by evolute coiling, a whorl section which gradually changes ontogenetically from wider than high to higher than wide, and by ribs which are closely spaced in juveniles and distant in adults. *C. evolutum* and *C. lotenoense* are closely related species, but their whorl sections are wider than high, coiling is more evolute and ribs are denser.

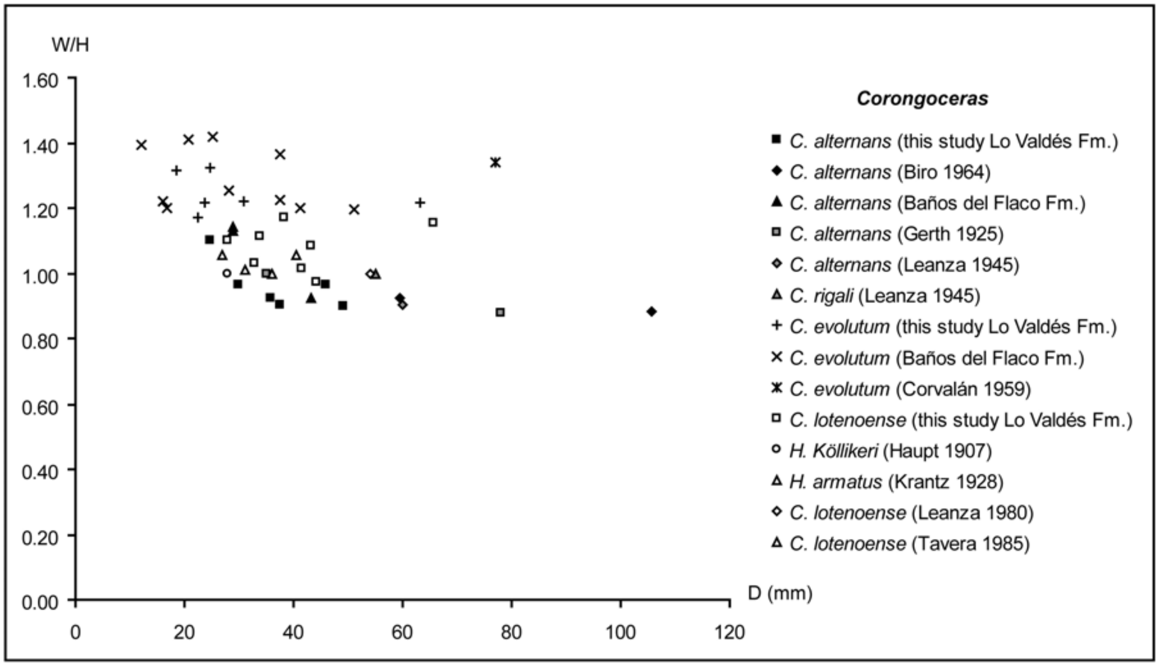


Figure 4.32. Relationship between W/H and D in *Corongoceras* from in Lo Valdés Formation.

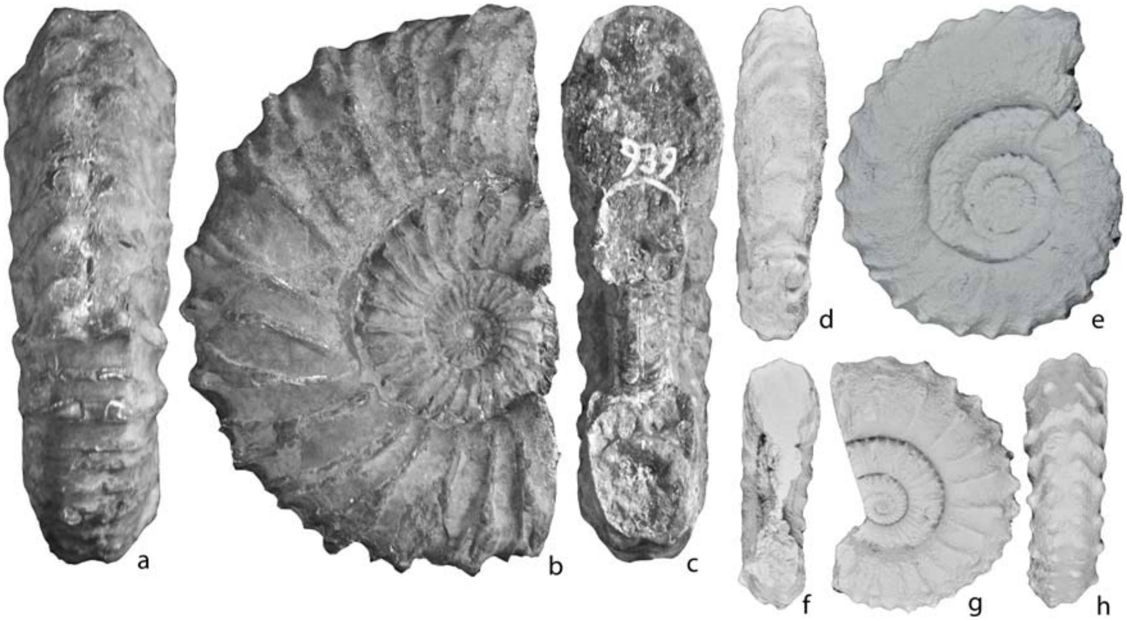


Figure 4.33. a-h: *Corongoceras alternans* (Gerth, 1925). **a-c:** Lectotype STIPB 939, x1. **d-h:** *Corongoceras alternans* (Gerth, 1925) from the Lo Valdés Formation. **d-e:** CPUC/LV/3-194, x1; **f-h:** CPUC/LV/3-379, x1.

Occurrence: At Cajón del Morado and Lo Valdés, the taxon is recorded from the lower to middle part of the Sandstone member (figure 5.6 and 5.7). *C. alternans* was recorded by Biro (1964) from the middle Upper Tithonian at Lo Valdés, corresponding to the Sandstone member of the Lo Valdés Formation, from the Upper Tithonian of the Baños del Flaco Formation (see chapter 5), and from the Upper Tithonian of Alto Palena (Fuenzalida 1966). In Argentina, the taxon was recorded from the lower Upper Tithonian of Mendoza (Gerth 1925, Leanza 1945, Parent 2001).

Corongoceras evolutum Corvalán, 1958

Figure 4.16, 4.32, 4.34

1958 *Corongoceras evolutum* Corvalán. In Corvalán & Pérez, p. 43, pl. 10, fig. 21a-b.
1959 *Corongoceras evolutum* n. sp. Corvalán., p. 18, pl. 7, figs. 25-26.
1964 *Corongoceras evolutum* Corvalán. Biro, p. 104, pl. 26, fig. 1a-d.
1994 *Corongoceras evolutum* Corvalán. Pérez & Reyes, p. 50.
2005 *Corongoceras evolutum* Corvalán. Klein, p. 23.

Type: Holotype is SNGM 7001 (= IIG 133) by monotypy. It is the original from Corvalán & Pérez (1958) and figured by Corvalán (1959, p. 18, pl. 7, figs. 25-26), from the Upper Tithonian of Rio Leñas (Chile).

Material: Eigth specimens. CPUC/LV/3-30, CPUC/LV/3-50, CPUC/LV/3-57, CPUC/LV/3-73, CPUC/LV/3-388, CPUC/LV/3-392 and CPUC/LV/3-408 are complete phragmocones and regular to well preserved. CPUC/LV/3-51 is a small fragment.

Description: The coiling is evolute and the umbilicus wide (U/D: 0.36-0.55). The whorl section is characteristically sub-hexagonal, wider than high (figure 4.16, 4.32). The umbilical border is vertical, flanks are convex, and the venter is wide and presents a well-marked wide and smooth furrow (figure 4.16). Ribs are strong; they are rectiradiate on the umbilical shoulder. Primaries bifurcate on the middle part of the flank, presenting fine tubercles at the point of bifurcation. Secondaries remain strong, but end in fine tubercles on both sides of a ventral furrow. CPUC/LV/3-30 (D: 103.1) shows five constrictions on the last whorl. Simple ribs dominate in this specimen; every one or two simple ribs are intercalated by a bifurcated rib with tubercles at the point of bifurcation.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/3-30	103.1		27.8		56.5	0.55
CPUC/LV/3-50	63.3	(21.2)	(17.4)	(1.22)	(28.1)	(0.44)
CPUC/LV/3-57	24.6	9.8	8.2	1.20	11.0	0.45
CPUC/LV/3-73	18.6	7.5	5.7	1.32	8.7	0.47
CPUC/LV/3-388	30.8	12.1	9.9	1.22	12.3	0.40
CPUC/LV/3-392	22.5	9.5	8.1	1.17	8.0	0.36
CPUC/LV/3-408	23.7	9.0	7.4	1.22	9.3	0.39

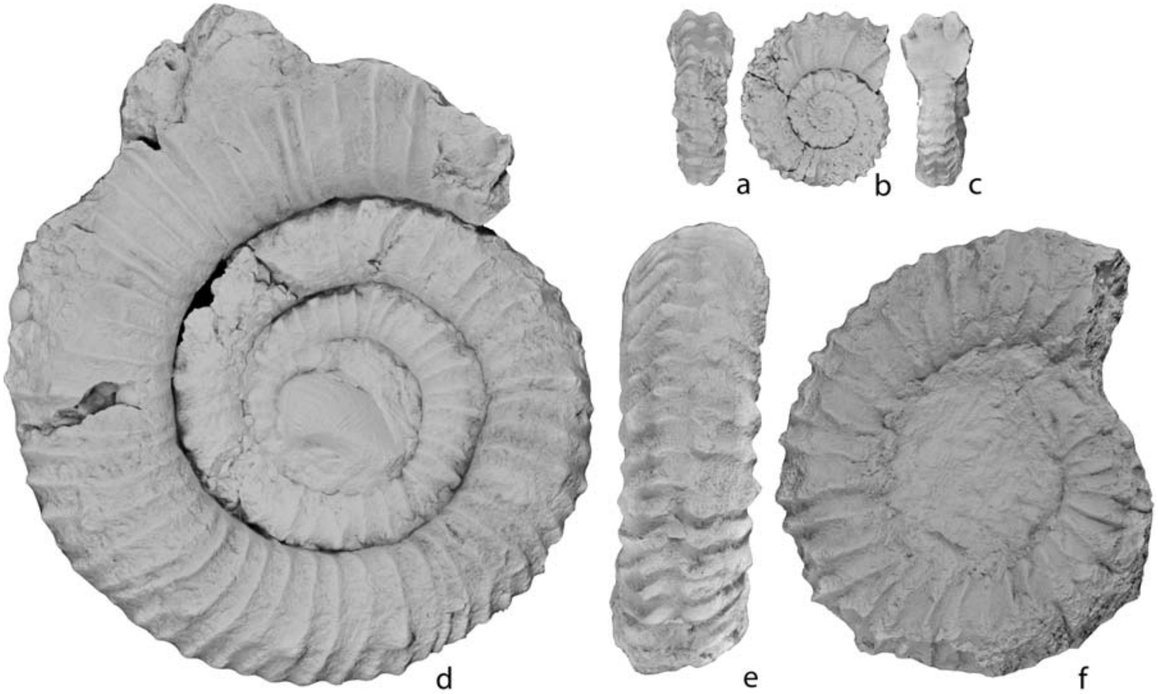


Figure 4.34. a-f: *Corongoceras evolutum* Corvalán (1959) from the Lo Valdés Formation.. **a-c:** CPUC/LV/3-37, x1; **d:** CPUC/LV/3-30, x 0.75; **e-f:** CPUC/LV/3-50, x1.

Remarks: *C. evolutum* is differentiated from other species of *Corongoceras* by a wide umbilicus, strong ribs, and a wide venter with a well-marked wide and smooth furrow (Corvalán 1959). *C. involutum*, *C. alternans* and *C. lotenoense* are closely related species. However, coiling is more compressed in *C. involutum*, the whorl section is higher than wide and flanks are convex (figure 4.16). In *C. alternans* ribs are wider spaced and the whorl section changes gradually from wider than high to higher than wide (figure 4.16). *C. lotenoense* is more compressed, ribs are wider spaced, tubercles are stronger and the whorl section is more rounded (figure 4.16).

Occurrence: *C. evolutum* is endemic to central Chile. In the Lo Valdés Formation at Lo Valdés, *C. evolutum* is recorded in the lower to middle part of the Sandstone member (Biro, 1964 and figure 5.6). The taxon also occurs in the Upper Tithonian at Rio Leñas (Corvalán, 1959) and in the Upper Tithonian of the Baños del Flaco Formation (see chapter 5).

Corongoceras involutum Biro, 1980

Figure 4.35

1964	*Corongoceras involutum* Biro, p. 105, pl. 27, figs. 1a, 1b, 2a, 2b, 2c, pl. 28, figs. 1a, 1b. (*nomen nudum*).
1980b	*Corongoceras involutum* n. sp. Biro, p. 233, pl. 7, figs. 7a-7b, 8a-8b, 9a-9b. (= Biro 1964).
2005	*Corongoceras involutum* Biro. Klein, p. 24.

Type: Holotype is CPUC/III/1, the original of Biro (1980b, p. 233, fig. 7a-7b); this holotype is lost. Neotype is CPUC/LV/3-129 designated here from the type section of the Lo Valdés Formation at Lo Valdés. Paratypes designated here are CPUC/LV/3-53, CPUC/LV/3-55 and CPUC/LV/3-116.

Material: 50 specimens, twenty-seven of which are from the Lo Valdés section (LV) and sixteen from Cajón del Morado (CM). CPUC/LV/3-53, CPUC/LV/3-55 and CPUC/LV/3-129 are well preserved complete phragmocones. CPUC/LV/3-103, CPUC/LV/3-109, CPUC/LV/3-114, CPUC/LV/3-115, CPUC/LV/3-116, CPUC/LV/3-117, CPUC/LV/3-120, CPUC/LV/3-121, CPUC/CM/14-01, CPUC/CM/14-05 and CPUC/CM/14-14 are well to regularly preserved fragmentary phragmocones, whereas CPUC/CM/14-06 is a poorly preserved fragmentary phragmocone.

Description: Moderately involute, whorl section discoidal, higher than wide, umbilical shoulders rounded, flanks almost flat and parallel and the venter rounded. The sculpture consists in primary ribs which initiate slightly concave on the umbilical border and are rectiradiate on the flanks. Most primaries bifurcate into secondary ribs half way up the flank at a fine tubercle. A second row of fine tubercles is present on the ventral shoulder. The venter is rounded-flat.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/3-129 (Neotype)	(30.8)	8.2	12.0		9.4	
CPUC/LV/3-53	(32.0)	10.2	12.8		11.3	
CPUC/LV/3-55	21.1	7.0	8.3		8.5	
CPUC/LV/3-116	30.8	(7.3)	11.1		10.1	
CPUC/LV/3-121	31.7	(6.0)	12.4		10.5	
CPUC/CM/14-14	52.2		21.4		17.4	

Remarks: *Corongoceras involutum* is characterized by moderately involute coiling, a discoidal, higher than wide whorl section, and ribs which are bifurcated on the middle part of the flank. *C. evolutum* is more involute and the whorl section is subhexagonal (figure 4.16). Coiling in *C. alternans* is evolute, the whorl section changes from wider than high to higher than wide (figure 4.16) and the ribs are progressively wider spaced. *C. lotenoense* is more compressed, ribs are wider spaced, tubercles are stronger and the section is better rounded (figure 4.16). *C. mendozanum* is closely related to *C. involutum,* but the ribs are more prominent, bifurcation of the ribs is on the middle part of the flank and the whorl section is thin.

Occurrence: *C. involutum* is an endemic species recorded only for central Chile. In the Lo Valdés Formation the taxon is registered in the lower part of the Sandstone member at Cajón del Morado and at Lo Valdés (figure 5.6 and 5.7, also see Biro 1964).

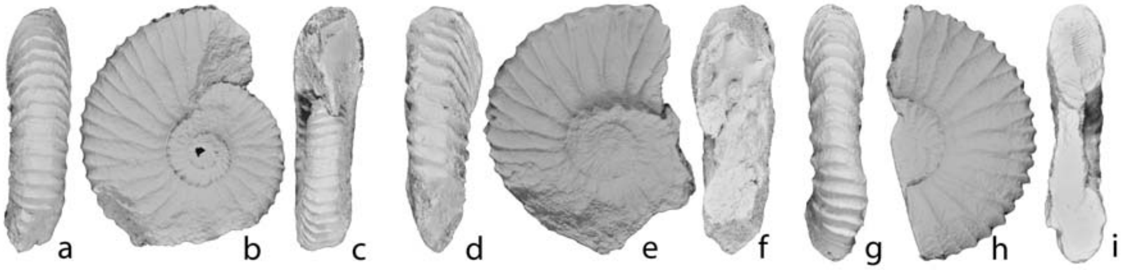


Figure 4.35. a-i: *Corongoceras involutum* Biro (1980) from the Lo Valdés Formation. **a-c:** CPUC/LV/3-129, x1; **d-f:** CPUC/LV/3-53, x1; **g-i:** CPUC/LV/3-116, x1.

Corongoceras cf. *koellikeri* (Oppel, 1865)

Figure 4.36

1865 *Ammonites Köllikeri* Oppel, p. 555.

1868 *Ammonites Köllikeri* Oppel. Zittel, p. 95, pl. 18, fig. 1a, 1b, 1c. Non pl. 18, fig. 2a, 2b (= *Corongoceras rhodanicum*).

1886 *Perisphinctes Köllikeri* (Oppel). Vicolis & Parona, p. 77, pl. 4, fig. 6.

non 1890 *Hoplites Koellikeri* (Oppel). Toucas, p. 607, pl. 18, fig. 11A, 11B (= *Corongoceras rhodanicum*).

1891 *Hoplites Köllikeri* (Oppel). Behrendsen, p. 401.

1897 *Reineckeia Koellikeri* (Oppel). Steuer, p. 31, pl. 22, figs. 5-6.

non 1900b *Reineckeia Koellikeri* (Oppel). Burckhardt, p. 16, pl. 20, figs. 14, 15, pl. 21, fig. 1 (= *Corongoceras alternans*).

1921 *Reineckeia Koellikeri* (Oppel). Steuer, p. 57, pl. 8, figs. 5-6 (= Steuer 1897).

1922 *Hoplites Köllikeri* (Oppel). Behrendsen, p. 183 (= Behrendsen 1891).

1928 *Ammonites Köllikeri* Oppel. Krantz, p. 28, pl. 3, fig. 1a, 1b. (= Zittel 1868).

1931 *Berriasella Koellikeri* (Oppel). Windhausen, pl. 29, fig. 4, 7.

non 1936 *Himalayites* (*Corongoceras*) *Kollikeri* (Oppel). Roman, p. 27, pl. 4, fig. 19, 19a, 20. (= *Corongoceras rhodanicum*).

1939 *Micracanthoceras* n. sp. aff. *koellikeri* (Oppel). Imlay, p. 44, pl. 17, figs. 2, 3, 4.

1976 *Himalayites* cf. *Kollikeri* (Oppel). Khimshiashvili, p. 118, pl. 11, fig. 3.

1985 "*Corongoceras*" *köllikeri* (Oppel). Tavera, p. 194, pl. 28, fig. 2, text-fig. 17G.

1997 "*Corongoceras*" *köllikeri* (Oppel). Benzaggagh & Atrops, p. 158, pl. 7, fig. 3.

2005 *Aulacosphinctes*? *koellikeri* (Oppel). Klein, p. 14.

Type: Holotype is the original of Oppel (1865) from Stramberg Germany, designated and illustrated by Zittel (1868, p. 95).

Material: Seven internal moulds, which are fragmentary phragmocones. CPUC/CM/17-87, CPUC/LV/5-21, CPUC/LV/5-40, CPUC/LV/5-55, CPUC/LV/5-58, CPUC/CP/90-11 and CPUC/CP/90-12 are regular to poorly preserved.

Description: The whorl section is higher than wide, with a rounded umbilical shoulder, convex flanks and a rounded and arched venter. Sculpture consists in slightly prorsiradiate and flexuous ribs, which are bifurcated on the middle part of the flank. Acute tubercles are present at the bifurcation points.

Figure 4.36. a-d: *Corongoceras* cf. *koellikeri* (Oppel, 1865) from Lo Valdés Formation. **a-c:** Biro`s collection CPUC/LV/III-34, x1; **d:** CPUC/CP/90-12, x1.

Remarks: The specimens here described correspond to fragmentary phragmocones of which the preservation is regular to poor. Assignation of the material to *Corongoceras* is based on the original description of this genus, which emphazises distant primary ribs, bifurcation with a tubercle at the point of bifurcation and a second row of ventrolateral tubercles (Spath 1925, Arkell et al. 1957). *C. koellikeri* is close related to *C. alternans* and *C. lotenoense*. In *C. alternans* ribs are wider separated and coiling is more evolute. In *C. lotenoense* ribs are also wider spaced and the whorl section is rounded.

Occurrence: In the Lo Valdés Formation *C. koellikeri* is present in the lower Siltstone member of Lo Valdés, Cajón del Morado and Cruz de Piedra (figures 5.6, 5.7 and 5.8). Biro (1964) also registered the taxon from this unit. In Argentina *C. koellikeri* is recorded from the Upper Tithonian (Behrendsen, 1891-1922, Steuer 1897-1922, Krantz 1928 and Windhausen 1931). A similar stratigraphic range is observed in Mexico (Imlay 1939) and in the Caucasus (Khimshiashvili 1976). In southern Spain and the Rif mountains of Morocco the species was recorded from the Lower Berriasian *Berriasella jacobi* zone (Tavera 1985, Benzaggagh & Atrops 1997).

Corongoceras lotenoense Spath, 1925

Figure 4.16, 4.32, 4.37

1891 *Hoplites Köllikeri* (non Oppel), Behrendsen, p. 401.
1897 *Reineckeia Köllikeri* (non Oppel), Steuer, p. 31, pl. 22, figs. 5-6.
1907 *Hoplites Köllikeri* (non Oppel) Haupt, p. 201, pl. 9, figs. 7a, 7b, 7c, 7d, 7e.
1922 *Reineckeia Köllikeri* (non Oppel), Steuer, p.57, pl. 8, figs. 5-6 (= Steuer 1897).
1922 *Hoplites Köllikeri* (non Oppel), Behrendsen, p. 183 (= Behrendsen 1891).
1925 *Corongoceras lotenoense* Spath, p. 144.
1926 *Hoplites armatus* Krantz. p. 437, pl. 17, fig. 3.
1926 *Berriasella* (*Corongoceras*) *lotenoensis* (Spath). Krantz, p. 444.
1928 *Hoplites armatus* Krantz. p. 19, pl. 4, fig. 5. (= Krantz 1926).
1928 *Ammonites Köllikeri* (non Oppel) Krantz, p. 28, pl. 3, fig. 1a-1b.
1928 *Berriasella* (*Corongoceras*) *lotenoensis* (Spath). Krantz, p. 28.
1931 *Berriasella* cf. *koellickeri* (Oppel) Steuer. Weaver, p. 444.

1938 *Corongoceras loetonense* (Spath). Roman, p 312, pl. 31, fig. 301, 301a, text-fig. 301 (=Haupt 1907).
1957 *Corongoceras lotenoense* Spath. Arkell et al., p. L356, fig. 468: 6a, 6b (=Haupt, 1907)
1960 *Corongoceras lotenoense* Spath var. *fortior* Collignon, pl. 167, fig. 687.
? 1969 *Corongoceras* aff. *lotenoense* Spath. Helmstaed, p. 78.
1979 *Corongoceras* cf. *lotenoense* Spath. Thomson, p. 30, pl. 6, fig. g.
1980 *Corongoceras lotenoense* Spath. H. Leanza, p. 45, pl. 6, fig. 6a, 6b, txt-fig. 10c.
1983 *Corongoceras lotenoense* Spath. Matsumoto & Sakai, p. 79, pl. 8, fig. 2a, 2b, 2c.
1985 *Micracanthoceras* (*Corongoceras*) *lotenoense* (Spath). Tavera, p. 176-178, pl. 23, figs. 11, 12, 13, tex-fig. 14K, 14J.
1992 *Corongoceras lotenoense* Spath. Riccardi in Westermann et al., pl. 81, 4a, 4b.
1996 *Corongoceras* sp. cf. *lotenoense* Spath. Enay et al. p. 227.
2001 *Corongoceras lotenoense* Spath. Parent, p. 32, fig. 9A, 9B (=Haupt 1907).
2005 *Corongoceras lotenoense* Spath. Klein, p. 24.

Type: Lectotype is STIPB 201, the original of Haupt (1907, pl. 9, fig. 7a-b), described as *Hoplites köllikeri* (Oppel, 1863), by subsequent designation of Spath (1925, p. 144).

Material: Thirty-five specimens. CPUC/CM/15-3, CPUC/CM/16-25, CPUC/CM/16-61, CPUC/CM/16-78, CPUC/CM/16-90, CPUC/LV/3-2, CPUC/LV/3-61, CPUC/LV/3-200 CPUC/LV/3-375 are well preserved complete phragmocones. CPUC/CM/14-21, CPUC/CM/15-1, CPUC/CM/16-9, CPUC/CM/17-91, CPUC/LV/3-263, CPUC/LV/3-267, CPUC/LV/3-269, CPUC/LV/3-319, CPUC/LV/3-325, CPUC/LV/3-327, CPUC/LV/3-328, CPUC/LV/3-329, CPUC/LV/3-366, CPUC/LV/3-387, CPUC/LV/3-391 and CPUC/LV/3-399 are fragmentary phragmocones which are well to regularly preserved. CPUC/LV/3-219, CPUC/LV/3-220, CPUC/LV/3-266, CPUC/LV/3-260, CPUC/LV/3-262, CPUC/LV/3-283, CPUC/LV/3-322, CPUC/LV/3-331, CPUC/LV/3-359 and CPUC/LV/3-261 are poorly preserved or small fragments of the phragmocone. Twenty-seven specimens are from Lo Valdés (LV) and eight specimens from Cajón del Morado (CM).

Description: Evolute, whorl section rounded, as high as wide, flanks convex and venter rounded (figure 4.16). The sculpture consists of strong primary ribs, that are prorsiradiate and slightly convex on the ventrolateral part of the flank. Most primary ribs bifurcate, with acute tubercles at the point of bifurcation. Ventrolaterally, resulting secundaries are prorsiradiate and a second row of acute tubercles is present. Ribs are weakened on the venter. Simple ribs also present two rows of tubercles. Some of these simple ribs are paralleled by closely spaced other primaries.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/14-21	108.0		33.9		51.7	0.48
CPUC/CM/15-01	38.3	14.3	12.2	1.17	13.5	0.35
CPUC/CM/16-61	32.8	(10.6)	10.3	(1.03)	17.3	0.53
CPUC/CM/16-90	33.9	12.8	11.5	1.11	12.3	0.36
CPUC/LV/3-2	65.6	22.5	19.5	1.15	31.6	0.48
CPUC/LV/3-61	44.3	14.7	15.1	0.97	18.8	0.42
CPUC/LV/3-263	41.4	(12.8)	12.6	(1.02)	21.2	0.51
CPUC/LV/3-300	43.1	15.3	14.1	1.09	19.3	0.45
CPUC/LV/3-329	27.9	10.7	9.7	1.10	11.1	0.40
CPUC/LV/3-366	35.7	(12.8)	14.3	(0.90)	(15.6)	(0.44)

Remarks: *Corongoceras lotenoense* is characterized by evolute coiling, rounded whorl section, strong bifurcated ribs and acute tubercles at the point of bifurcation and on the ventral border. The taxon is closely related to *C. involutum*, *C. evolutum*, *C. alternans* and *C. mendozanum*. *C. involutum* differs by a higher degree of involution and a stronger discoidal whorl section. *C. evolutum* is more evolute and the whorl section subhexagonal (figure 4.16). *C. alternans* is evolute, with a whorl section that gradually changes from wider than high to higher than wide (figure 4.16); ribs are progressively more spaced. *C. mendozanum* differs by a higher degree of involution, closer-spaced ribs and a higher than wide whorl section (figure 4.16).

Occurrence: *C. lotenoense* is here recorded for the first time in Chile. At Lo Valdés and Cajón del Morado the taxon is present in the lower to middle part of the Sandstone member (figure 5.6-5.7); at Cajón del Morado, a single specimen was also discovered in the uppermost part of the Sandstone member (figure 5.7). *C. lotenoense* was also recorded for the Middle-Upper Tithonian of Argentina (Behrendsen 1891-1922, Steuer 1897-1922, Haupt 1907, Krantz 1926-1928, Weaver 1931, H. Leanza 1980), the Upper Tithonian of Perú (Enay et al. 1996), the Upper Tithonian of Antarctica (Thompson 1979), the Tithonian of Nepal (Matsumoto & Sakai 1983, Helmstaed 1969), and the Upper Tithonian of South Spain (Tavera 1985).

Figure 4.37. a-o: *Corongoceras lotenoense* Spath (1925) from Lo Valdés Formation. a-c: CPUC/LV/3-2, x1; d-f: CPUC/CM/16-61, x1; g-i: CPUC/CM/16-90, x1; j-l: CPUC/LV/3-320, x1; m: CPUC/CM/14-21, x1; n-o: CPUC/CM/15-3, x1.

Corongoceras mendozanum (Behrendsen 1891)

Figure 4.38, 4.39

1891 *Hoplites mendozanus* n. sp. Behrendsen, p. 399, pl. 25, fig. 2.

1897 *Reineckeia turgida* n. sp. Steuer, p. 155, pl. 28, figs. 3-4 (non *Micracanthoceras vetustus*).

1897 *Hoplites mendozanus* Behrendsen. Steuer, p. 185, pl. 28, fig 4.

1921 *Acanthodiscus*? *turgida* Steuer. Gerth, p. 141.

1921 *Berriasella mendozana* (Behrendsen). Gerth, p. 147.

1921 *Reineckeia turgida* n. sp. Steuer, p. 56, pl. 14, figs. 3-4 (non *Micracanthoceras vetustus*).

1921 *Hoplites mendozanus* Behrendsen. Steuer, p.88, pl. 24, fig. 4 (= Steuer 1897).

1922 *Hoplites mendozanus* n. sp. Behrendsen, p. 181, pl. 2, fig. 4 (= Behrendsen 1891).

1925 *Andesites turgidus* Steuer. Gerth, p. 78

non 1926 *Berriasella* (*Corongoceras*) *duraznensis* n. sp. Krantz, p. 445 (= *Micracanthoceras vetustum*).

1926 *Berriasella* (*Corongoceras*) *mendozana* (Behrendsen). Krantz, p. 446.

1926 *Berriasella* (*Corongoceras*) *submendozana* Krantz, p.446.

non 1926 *Berriasella* (*Riasanites*) *rjasanensoides* n. sp. Krantz, p. 441, pl. 17, figs. 1-2 (= *Micracanthoceras vetustum*).

1928 *Berriasella* (*Corongoceras*) *duraznensis* Krantz, p. 29, pl. 4, fig.1 (= *Micracanthoceras vetustum*).

1928 *Berriasella* (*Corongoceras*) *mendozana* (Behrendsen). Krantz, p. 29, pl. 4, fig. 3-4.

1928 *Berriasella* (*Corongoceras*) *submendozana* n. sp. Krantz, p. 30, pl. 4, fig. 6.

non 1928 *Berriasella* (*Riasanites*) *rjasanensoides* n. sp. Krantz, p. 25, pl. 4, figs. 7 (= *Micracanthoceras vetustum*).

1931 *Berriasella mendozana* (Behrendsen). Windhausen, pl. 29, fig. 2. (= Steuer 1897).

1937 *Berriasella* (*Corongoceras*) *mendozana* (Behrendsen). Feruglio, p. 64.

1945 *Aulacosphinctes* sp. indet. A. Leanza, p. 22, pl. 3, figs. 7-8.

1945 *Berriasella krantzi* A. Leanza. p. 32, pl. 6, fig. 7,8.

1945 *Berriasella groeberi* n. sp. A. Leanza, p. 37, pl. 4.

1945 *Berriasella* (?) *delhaesi* n. sp. A. Leanza, p. 39, pl. 6, fig. 1-2.

? 1953 *Berriasella* cf. *mendozana* (Behrendsen). Arnould-Saget, p. 31, pl. 3, fig. 8, 10.

non 1960 *Blanfordiceras acuticosta* Ulig. Collignon, figs. 682-683 (= *Micracanthoceras vetustum*?).

non 1960 *Corongoceras irregulare* n. sp. Collognon, fig. 690 (= *Micracanthoceras vetustum*?).

non 1960 *Corongoceras fibulatum* n. sp. Collignon, figs. 703-704. (lectotype) (= *Micracanthoceras vetustum*?).

non 1960 *Corongoceras bifurcatum* n. sp. Collignon, fig 706 (holotype) (= *Micracanthoceras vetustum*?).

1967 *Corongoceras mendozanum* (Behrendsen). A. Leanza, pl. 2, fig. 1. (= Feruglio 1937).

? 1973 *Corongoceras mendozanum* (Behrendsen). Verma & Westermann, p. 247, pl. 54, fig. 2, text-fig. 28A.

1976 *Corongoceras* aff. *mendozanum* (Behrendsen). Cantú-Chapa, pl. 2, fig. 16a.

non 1979 *Blanfordiceras* aff. *wallichi* (Gray). Thomson, p. 27, pl. 7, figs. b-c (= *Micracanthoceras vetustum*?).

non 1980 *Corongoceras involutum* n. sp. Biro. P. 233, pl. 7, figs. 7-9.

1981 *Berriasella krantzi* A. Leanza. H. Leanza, pl. 3, fig. 1, 2 (= A. Leanza, 1945).

1985 *Micracanthoceras* (*Corongoceras*) *mendozana* (Behrendsen). Tavera, p. 186, pl. 25, fig. 3, text-fig. 14G.

non 1989 *Blanfordiceras acuticosta* (Uhlig). Howlett, p. 28, pl. 1, fig. 3 (= *Micracanthoceras vetustum*?).

? 2004 *Corongoceras* sp. C. Yin & Enay, fig 10 (8).

2005 *Berriasella* (*Berriasella*)? *delhaesi.* A. Leanza. Klein, p. 169.

2005 *Berriasella* (*Berriasella*) *groeberi* A. Leanza. Klein, p. 170.

2005 *Corongoceras mendozanum* (Behrendsen). Klein, p. 25.

2005 *Corongoceras submendozanum* (Krantz). Klein, p. 26.

? 2009 *Aulacosphinctes proximus* (Steuer). Aguirre-Urreta & Vennari, p. 39, figs. 5r-t.

non 2011b *Blafordiceras vetustum* (Steuer), Parent et al., p. 55, pl. 26C-F, 27A-B, (= *Corongoceras mendozanum*).

Type: Lectotype is GZG 497-139 designated here by monotypy. It is the original of Behrendsen (1891, p. 399, pl. 25, fig. 2).

Material: Fourty-one specimens. CPUC/LV/3-368, CPUC/LV/3-370, CPUC/CP/0-05, CPUC/CP/20-09, CPUC/CP/40-70-36, CPUC/CP/60-12, CPUC/CP/70-51, CPUC/CP/50-01, CPUC/CP/50-12, CPUC/CP/60-13 are well preserved complete phragmocones. CPUC/LV/3-362, CPUC/LV/3-363, CPUC/LV/3-369, CPUC/CP/0-01, CPUC/CP/0-02, CPUC/CP/20-04, CPUC/CP/20-06, CPUC/CP/20-14, CPUC/CP/20-15, CPUC/CP/40-13, CPUC/CP/40-14, CPUC/CP/40-16, CPUC/CP/40-70-06, CPUC/CP/40-70-07, CPUC/CP/40-70-11, CPUC/CP/40-70-14, CPUC/CP/50-04, CPUC/CP/50-15, CPUC/CP/50-30, CPUC/CP/50-32, CPUC/CP/60-02, CPUC/CP/70-02 and CPUC/CP/70-71 are well to regularly preserved fragmentary phragmocones. CPUC/LV/3-23, CPUC/LV/3-364, CPUC/LV/3-365, CPUC/CP/0-13, CPUC/CP/20-02, CPUC/CP/20-12, CPUC/CP/40-24, CPUC/CP/50-08 and CPUC/CP/50-27 are poorly preserved fragmentary phragmocones or small fragments.

Description: Moderately evolute. The whorl section in juveniles is almost as high as wide but progressively changes through ontogeny to higher than wide (figure 4.38). The flanks are slightly convex and the venter is smoothly rounded. The sculpture consists in rectiradiate ribs. Most are bifurcated above the middle part of the flank, with a tubercle at the point of bifurcation, but simple ribs also present tubercles. A second row of acute tubercles is present on the ribs ventrolaterally. All ribs are weakened on the venter.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/3-362	46.2	14.0	16.0	0.88	18.5	0.40
CPUC/LV/3-368	41.4	13.0	14.6	0.89	15.9	0.38
CPUC/LV/3-369	31.9	10.3	12.3	0.84	12.5	0.39
CPUC/LV/3-370	33.0	10.8	13.2	0.82	13.1	0.40
CPUC/CP/0-05	38.7	13.4	13.9	0.96	15.4	0.40
CPUC/CP/20-09	28.5	10.0	10.5	0.95	11.2	0.39
CPUC/CP/40-16	49.5	16.7	19.8	0.84	18.1	0.37
CPUC/CP/40-70-06	34.7	11.0	11.9	0.92	14.5	0.42
CPUC/CP/40-70-36	(44.9)	15.6	18.6	0.84	13.2	0.29
CPUC/CP/50-01	64.0	21.0	23.3	0.90	22.0	0.34
CPUC/CP/50-12	72.8	23.6	27.0	0.87	25.1	0.34
CPUC/CP/60-13	107.5	31.8	36.2	0.88	44.4	0.41
CPUC/CP/70-02	37.9	12.7	14.3	0.89	12.1	0.32
CPUC/CP/70-51	60.8	18.6	22.3	0.83	23.8	0.39
GZG-497-139 Behrendsen 1891	57.0	19.0	22.0	0.86	20	0.35
GZG-499-135 Steuer 1897	62.0	18.5	21.0	0.88	27.5	0.44
GZG-499-136 Steuer 1897	57.0	16.0	19.0	0.84	26.0	0.46

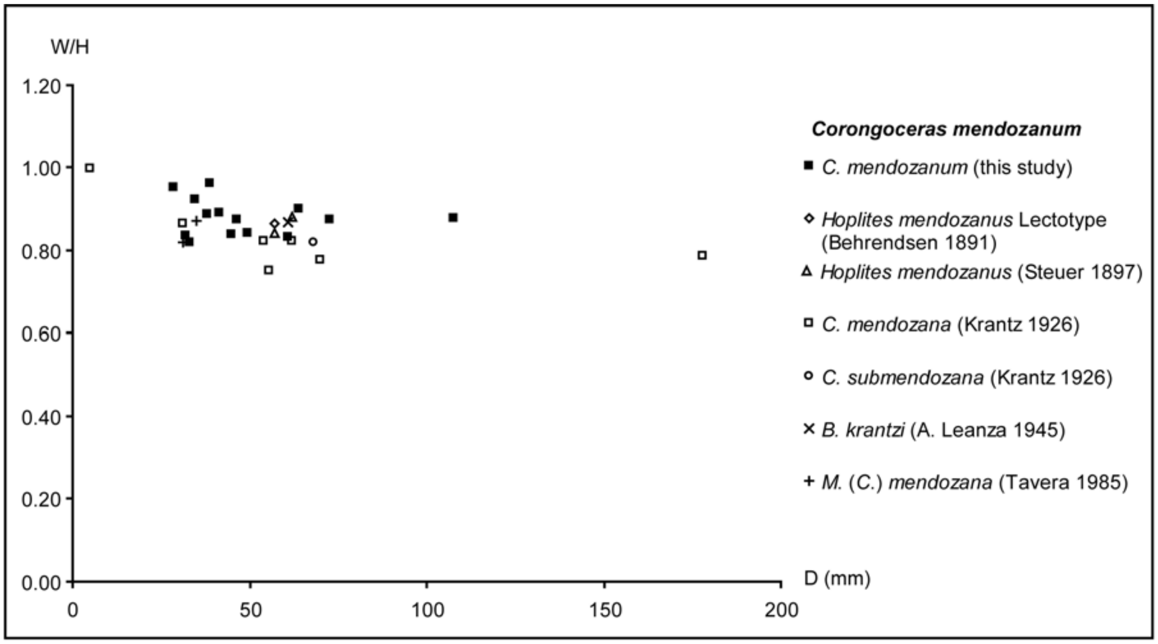


Figure 4.38. Relationship between W/H and D in *Corongoceras mendozanum* (Behrendsen 1891) and the junior synonymies included in this study.

Remarks: The presence of tubercles in the present material as well as on the lectotype and paratypes of *Corongoceras mendozanum* largely depends on a good preservation of these specimens. *C. mendozanum* is characterized by a whorl section that is higher than wide; ribs are denser than in other species of *Corongoceras*. Tavera (1985) suggested an assignation of the species to *Micracanthoceras*, but the rounded whorl section and the smooth venter (Spath 1925 and Arkell et al. 1957) suggest that this taxon is better referred to *Corongoceras*. *C. mendozanum* is closely related with *C. alternans* and *C. lotenoense*. In *C. alternans*, ribs are wider spaced and coiling is evolute. *C. lotenoense* differs by evolute coiling and a rounded, slightly wider than high whorl section. *Corongoceras mendozanum* is easily confused with *Micracanthoceras vetustum*, but clearly differs from the latter by denser ribbing and a homogenous distribution of ribs, a higher whorl section and sub-parallel flanks.

Occurrence: *C. mendozanum* is here registered in Chile for the first time. In the Lo Valdés Formation, the taxon is detected in the lower part of the Sandstone member at Lo Valdés (figure 5.6) and in the lower to middle part of the Siltstone member at Cruz de Piedra section (CP) (figure 5.8). *C. mendozanum* was previously registered in the Tithonian of Peru (Stappenbeck 1929, Steinmann 1929), the Middle-Upper Tithonian of Argentina (Behrendsen 1891-1922, Steuer 1897-1922, Gerth 1921, Krantz 1926-1928, A. Leanza 1945), the Upper Tithonian of

Tunisia (Arnould-Saget 1953), the Tithonian of México (Verma & Westermann 1973) and the Upper Tithonian of South Spain (Tavera 1985).

Figure 4.39. a-p: *Corongoceras mendozanum* (Behrendsen 1891) from Lo Valdés Formation. a-c: CPUC/CP/40-70-36, x1; d-f: CPUC/LV/3-368, x1; g-i: CPUC/LV/3-370, x1; j-l: CPUC/CP/50-12, x1; m-n: CPUC/CP/40-16, x1; o-p: CPUC/CP/60-13, x1.

Family OLCOSTEPHANIDAE Haug, 1910

Subfamily SPITICERATINAE Stah, 1924

Genus *Spiticeras* Uhlig, 1903

Type species: *Ammonites spitiense* Blanford (1864, p. 131, pl. 2, fig. 4a-b), by subsequent designation of Roman (1938, p. 380).

Genus description: Inner whorls and section are inflated, and the sculpture consists of ribs which branch from midlateral tubercles. Later whorls are inflated to compressed or subquadrate, with fine ribs branching from umbilical tubercles, but some species tend to become smooth and generally present curved constrictions (Uhlig 1903, Arkell et al. 1957, Wright et al. 1996).

Spiticeras acutum Gerth (1925)

Figure 4.40, 4.41, 4.42

? 1921	*Spiticeras groeberi* Gerth, p. 140 (*nomen nudum*).
1921	*Spiticeras acutum* Gerth, p. 147 (*nomen nudum*).
1921	*Spiticeras Hauthali* Gerth, p. 147 (*nomen nudum*).
1925	*Spiticeras acutum* n. sp. Gerth, p. 63, pl. 3, fig. 1, 1a, text-fig. 2.
1925	*Spiticeras Hauthali* n. sp. Gerth. P. 65, pl. 1, fig. 8, pl. 2, fig. 5, text-fig. 3.
? 1925	*Spiticeras groeberi* n. sp. Gerth, p. 70, pl. 1, fig. 6.
1925	*Spiticeras laeve* Burckhardt. Gerth, p. 69, pl. 2, fig. 6.
1928	*Spiticeras acutum* Gerth. Gerth, p. 466, pl. 19, fig. 2 (= Gerth 1925).
1928	*Spiticeras Hauthali* Gerth. Gerth, p. 466.
1928	*Spiticeras Burckhardti* n. sp. Gerth, p. 467, pl. 19, fig. 1, (= Gerth 1925, *S. laeve*).
1928	*Spiticeras groeberi* Gerth. Gerth, pl. 18, fig. 3 (= Gerth 1925).
non 1937	*Spiticeras* aff. *groeberi* Gerth. Feruglio, p. 46, pl. 4, fig. 7 (= *Pseudosimoceras patagonicum*).
non 1937	*Spiticeras* sp. (gruppo sp. *acutum*). Feruglio, p. 47, pl. 4, fig. 8 (= *Himalayites peregrinus*).
1945	*Spiticeras andinum* n. sp. A. Leanza, p. 79, pl. 15, figs. 5, 8.

1945 *Spiticeras mammatum* n. sp. A. Leanza, p. 80, pl. 15, figs. 2a, 3, pl. 19, figs. 5, 6, text-fig. 9.
1945 *Spiticeras* cf. *acutum* Gerth. A. Leanza, p. 81, pl. 5, fig. 3.
1945 *Spiticeras stultum* n. sp. A. Leanza, p. 82, pl. 20, fig. 5, 6.
2005 *Spiticeras*? *acutum* Gerth. Klein, p. 50.
2005 *Spiticeras andinum* A. Leanza. Klein, p. 51.
2005 *Spiticeras burckhardti* Gerth. Klein, p. 51.
? 2005 *Spiticeras groeberi* Gerth. Klein, p. 53.
2005 *Spiticeras hauthali* Gerth. Klein, p. 53.
2005 *Spiticeras mammatum* A. Leanza. Klein, p. 55.
2005 *Spiticeras stultum* A. Leanza. Klein, p. 60.

Type: Lectotype is specimen STIPB-961, designated here. It is the original figured by Gerth (1925, p. 63, pl. 3, figs. 1, 1a) from the province of Mendoza, Argentina. STIPB-1025, the original of Gerth (1925), is a paralectotype.

Material: Two specimens. CPUC/CP/100-17 is a well preserved phragmocone, while CPUC/LV/6-06 is a regular to well preserved fragmentary phragmocone.

Description: Coiling is involute in juvenile stages (D < 30mm), with a wide umbilicus. Adult specimens (D > 30 mm) are gradually more evolute and the umbilicus is wider (U/D: 0.34 – 0.54). The whorl section of inner whorls is slightly wider than high and the venter is smoothly rounded; progressively the whorl section changes to higher than wide; flanks become gradually flatter and the venter is increasingly acute (figure 4.40). Sculpture consists of strong elongate umbilical tubercles which give rise to one, two or three ribs. One or two simple ribs are intercalated between each tubercle. Tubercles in adult specimens are stronger than in juveniles. Two to three shallow constrictions are present per whorl. They are rectiradiate and parallel the ribs.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CP/100-17	89.3	29.8	30.1	0.99	30.7	0.34
S. acutum (Gerth 1925) Lectotype	80.0	20.0	21.0	0.95	29.0	0.36
S. acutum (Gerth 1925) Paralectotype	35.0	11.0	9.0	1.22	15.0	0.43
	20.0	7.0	5.0	1.40	8.0	0.40

	10.5	4.0	2.5	1.60	4.0	0.38
S. hauthali (Gerth 1925)	59.0	20.0	17.0	1.18	21.0	0.36
S. laeve (Gerth 1925)	72.0	23.0	24.0	0.96	31.0	0.43
S. mammatum (A. Leanza 1945)	59.0	20.0	17.0	1.18	29.0	0.49

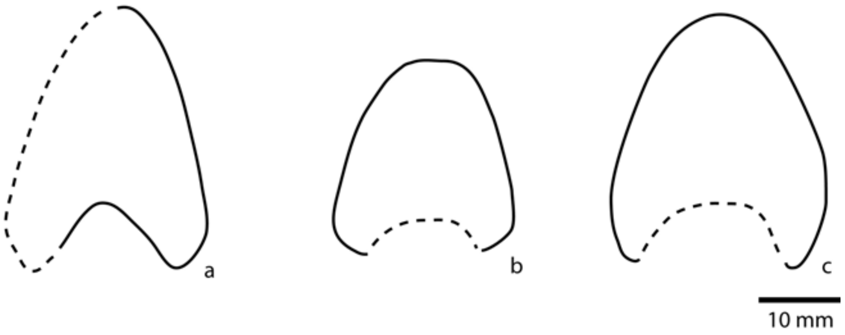


Figure 4.40. Whorl section of *Spiticeras acutum* Gerth (1925). **a:** STIPB-961, Lectotype of *Spiticeras acutum*. **b:** STIPB-963 (= S. "*hauthali*") from Gerth`s collection. **c:** CPUC/CP/100-17 from Lo Valdés Formation.

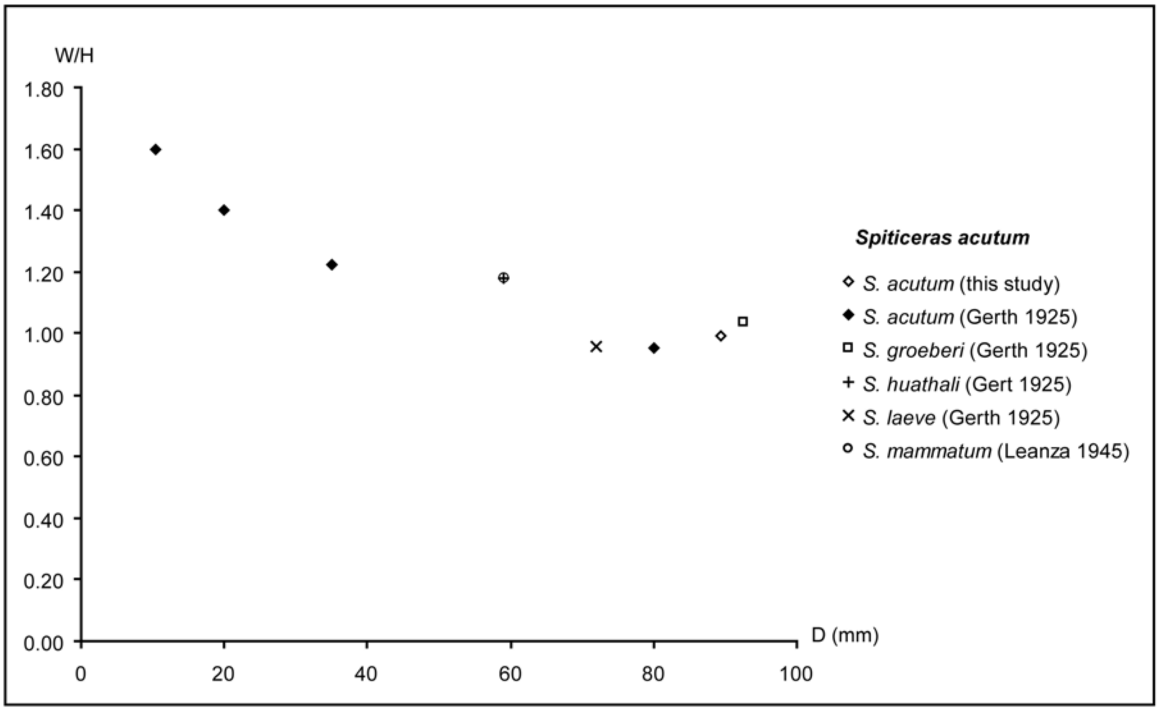


Figure 4.41. Relationship between W/H and D in *Spiticeras acutum* Gerth (1925) and the junior synonymies included in this study. There are marked by gradual change of the whorl section from wider than high to higher than wide.

Remarks: The lectotype of *Spiticeras acutum* (STIPB-961)has a deformed whorl section. *Spiticeras acutum* is described here as a morphologically variable species. Coiling, whorl section and sculpture change gradually from juvenile to adult specimens. Figure 4.41 shows the gradual change of the whorl section from wider than high to higher than wide.

Spiticeras groeberi, *Spiticeras hauthali*, *Spiticeras burckhardti* (*Spiticeras laeve*), *Spiticeras andinum*, *Spiticeras mammatum*, *Spiticeras burckhardti*, *Spiticeras groeberi, Spiticeras hauthali* and *Spiticeras stultum* are within the morphological range of the taxon and are here considered conspecific with *Spiticeras acutum* for the following reasons:

Spiticeras groeberi Gerth (1925) was based on a single adult specimen (D: 92.5 mm) with a deformed whorl section. All morphological elements correspond to an adult *Spiticeras acutum*.

Spiticeras hauthali Gerth (1925) is also based on a single well preserved specimen that corresponds to a juvenile *Spiticeras acutum*.

Gerth (1925) also describes *Spiticeras burckhardti* (*Spiticeras laeve*); the single specimen is an internal mould of regular preservation, without ribs and with a deformed whorl section. The differences in morphology are here regarded as a result of preservation and the taxon is considered a junior synonym of *Spiticeras acutum*.

Spiticeras andinum A. Leanza (1945) was described as a close relative of *Spiticeras burckhardti* and ontogenetically transitional between a juvenil and adult. Leanza (op.cit.) suggested that the coiling is slightly more evolute than in *S. burckhardti*, with a whorl section almost as high as wide. Regarding the high morphological variability of *S. acutum*, the taxon is here considered synoymous.

A. Leanza (1945) considered *Spiticeras mammatum* and *Spiticeras stultum* as close relatives of *S. acutum*. *S. mammatum* was distinguished based on a wider than high whorl section and more evolute coiling, while *S. stultum* was suggested to differ by a higher whorl section and stronger umbilical tubercles. They are also considered synonyms of *S. acutum*.

Occurrence: *S. acutum* is here recorded for the first time in Chile. At Cruz de Piedra and Lo Valdés, the taxon is registered for the upper Siltstone member (figures 5.6 and 5.8). In Argentina the taxon is registered from the Uppermost Tithonian to Uppermost Berriasian (Gerth 1921, 1925, A. Leanza 1945).

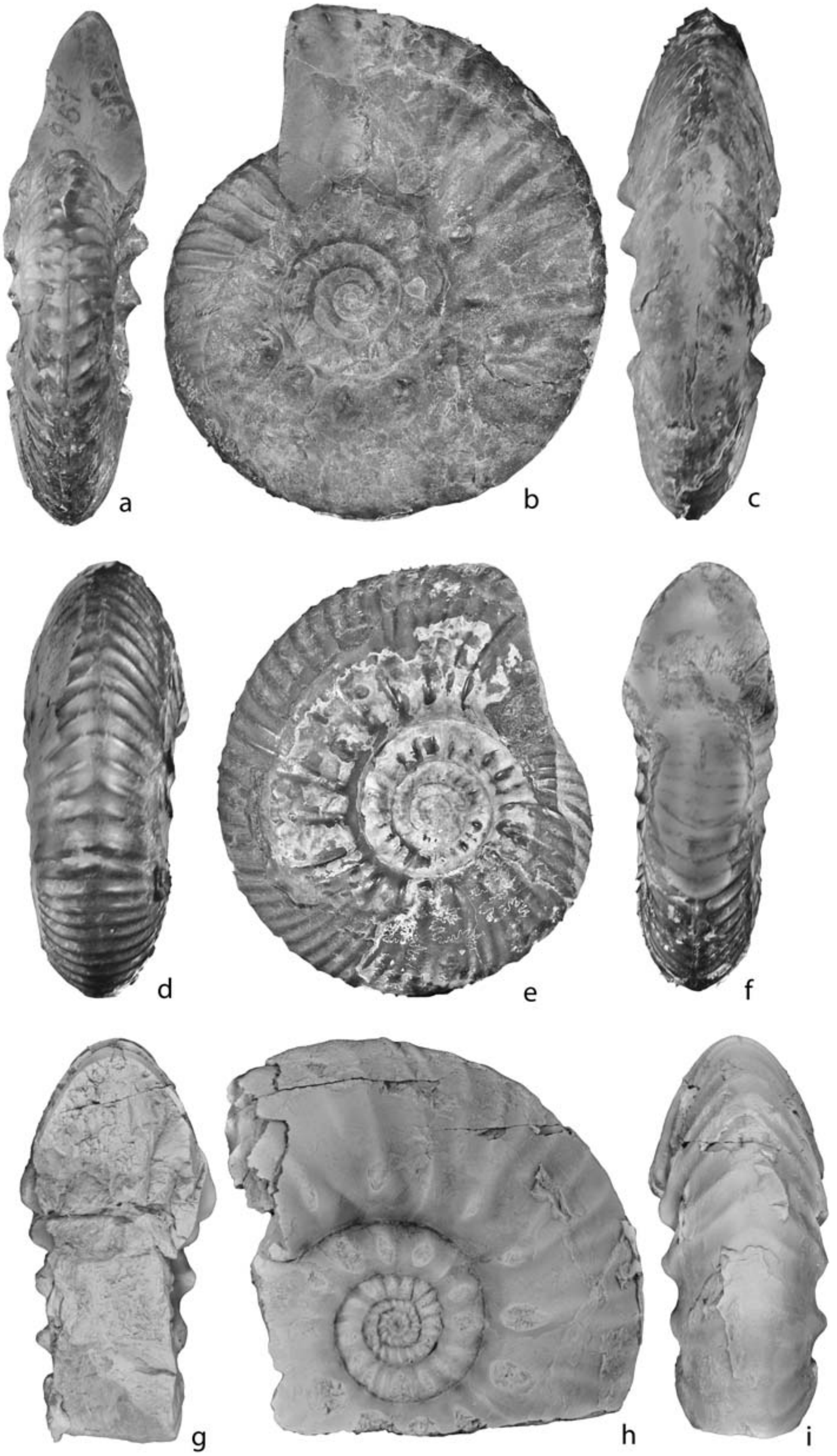


Figure 4.42. a-i: *Spiticeras acutum* Gerth (1925). **a-c:** STIPB-961 (Lectotype) from Gerth`s collection, x1; **d-f:** STIPB-963 (= S. "*hauthali*") from Gerth`s collection, x1; **g-i:** CPUC/CP/100-17 from Lo Valdés Formation, x1.

Spiticeras pricei Howarth (1998)

Figure 4.43a-b

1998 *Spiticeras* (*Spiticeras*) *pricei* n. sp. Howarth, p. 81, pl. 16, fig. 6, pl. 17, figs. 2, 4, 6, pl. 18, figs. 1-2.
2005 *Spiticeras pricei* Howarth. Klein, p. 57.

Type: Holotype is CA666, *Spiticeras* (*Spiticeras*) *pricei* Howarth (1998, p. 81, pl. 16, fig. 6.) by original designation.

Material: One specimen. CPUC/CM/18-77 is a fragmentary phragmocone.

Description: Evolute, with triagonal whorl section and a steep umbilical wall; flanks converge towards the arched venter. The sculpture consists of rounded-elongated umbilical tubercles.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/18-77		30.8	45.1	0.68		

Remarks: The single fragmentary mould presents all morphological characteristics of the taxon described by Howarth (1998), with the exception of fine ribs. Howarth (op. cit.) gives a full description and discussion.

Occurrence: *Spiticeras pricei* is recorded for the first time in Chile and occurs in the upper part of the Siltstone member at Cajón del Morado (figure 5.7). Elsewhere, *S. pricei* is registered from Yemen where it occurs in the Occitanica Zone of the Berriasian (Howarth 1998).

Spiticeras spitiense (Blanford, 1864)

Figure 4.43c-e, 4.44

1864 *Ammonites spitiense* Blanford, p. 131, pl. 2, fig. 4.
1903 *Holcostephanus* (*Spiticeras*) *spitiense* (Blanford). Uhlig, p. 89, pl. 8, figs, 1, 2, figs. 3a, 3c (= Blanford 1864), figs. 3b, 3d, 3e.

? 1945 *Spiticeras obliteratum* A. Leanza, p. 78, pl. 17, fig. 8.

? 1945 *Spiticeras* (*Negreliceras*) *singulare* A. Leanza, p. 79, pl. 15, fig. 1, 6, pl. 17, fig. 1, 6, 7, 9.

1970 *Spiticeras* (*Spiticeras*) cf. *spitiensis* (Blanford). Tavera, p. 182, pl. 4, figs. 12-13, pl. 5, fig. 15.

1979 *Spiticeras* (*Spiticeras*) aff. *spitiensis* (Blanford). Thomson, p. 24, pl. 6, fig. f, text-fig. 6a.

1992 *Spiticeras* (*Spiticeras*) *spitiense* (Blandorf). Howarth, p. 620, pl. 5, figs. 1, 4.

1998 *Spiticeras* (*Spiticeras*) *spitiensis* (Blanford). Howarth, p. 81, pl. 17, fig. 1.

? 1999 *Spiticeras* (*Spiticeras*) sp. Aguirre-Urreta & Alvarez, p. 29, pl. 3, figs. 4-6.

2005 *Spiticeras spitiense* (Blanford). Klein, p. 59 (with additional synonymy).

? 2005 *Spiticeras obliteratum* A. Leanza. Klein, p. 56.

? 2005 *Negreliceras singulare* (A. Leanza). Klein, p. 68.

Type: Lectotype is the original illustrated by Blandford (1864, p. 131, pl. 2, fig 4), by subsequently designated by Uhlig (1903).

Material: Four specimens, one from Lo Valdés and three from Cajón del Morado. CPUC/LV/3-23 is a complete well preserved phragmocone. CPUC/CM/18-110, CPUC/CM/18-13 and CPUC/CM/18-374 are fragmentary phragmocones which are regular to well preserved.

Description: Moderately involute. On the last whorl, the section is oval to inflated, slightly triagonal, higher than wide. Umbilical borders are rounded to steep, the dorsolateral shoulder is rounded, flanks converge and the venter is bluntly angled. Sculpture consists of 7 to 9 elongated tubercles per half whorl, which are present on the umbilical border. Four to five ribs diverge from each tubercle; and one to three ribs are intercalated between them. The ribs are prorsiradate, slightly concave; they cross the venter without interruption.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/8-23	54.1	22.2	20.9	1.06	15.7	0.29
CPUC/CM/18-110	105.5	36.6	30.3	1.21	51.6	0.49
CPUC/CM/18-213		28.8	30.4	0.95		

Remarks: Uhlig (1903) gives a full description and discussion of this taxon. *Spiticeras spitiense* is considered to be highly variable, with major morphological changes from juvenile to adult stages (Uhlig 1903).

Spiticeras obliteratum and *Negreliceras singulare* described by A. Leanza (1945) are weakly sculptured, possibly due to a preservational bias; these taxa appear to be closely related with *Spiticeras spitiense* and could be conspecific.

Kilianiceras damesi also resembles *Spiticeras spitiense*. *Kilianiceras damesi* is characterized by a rounded whorl section; ribs are apparently interrupted on the venter. *Spiticeras bodenbenderi* Behrendsen (1892) was based on only two adult specimens. They resemble *Kilianiceras damesi* and may also be conspecific.

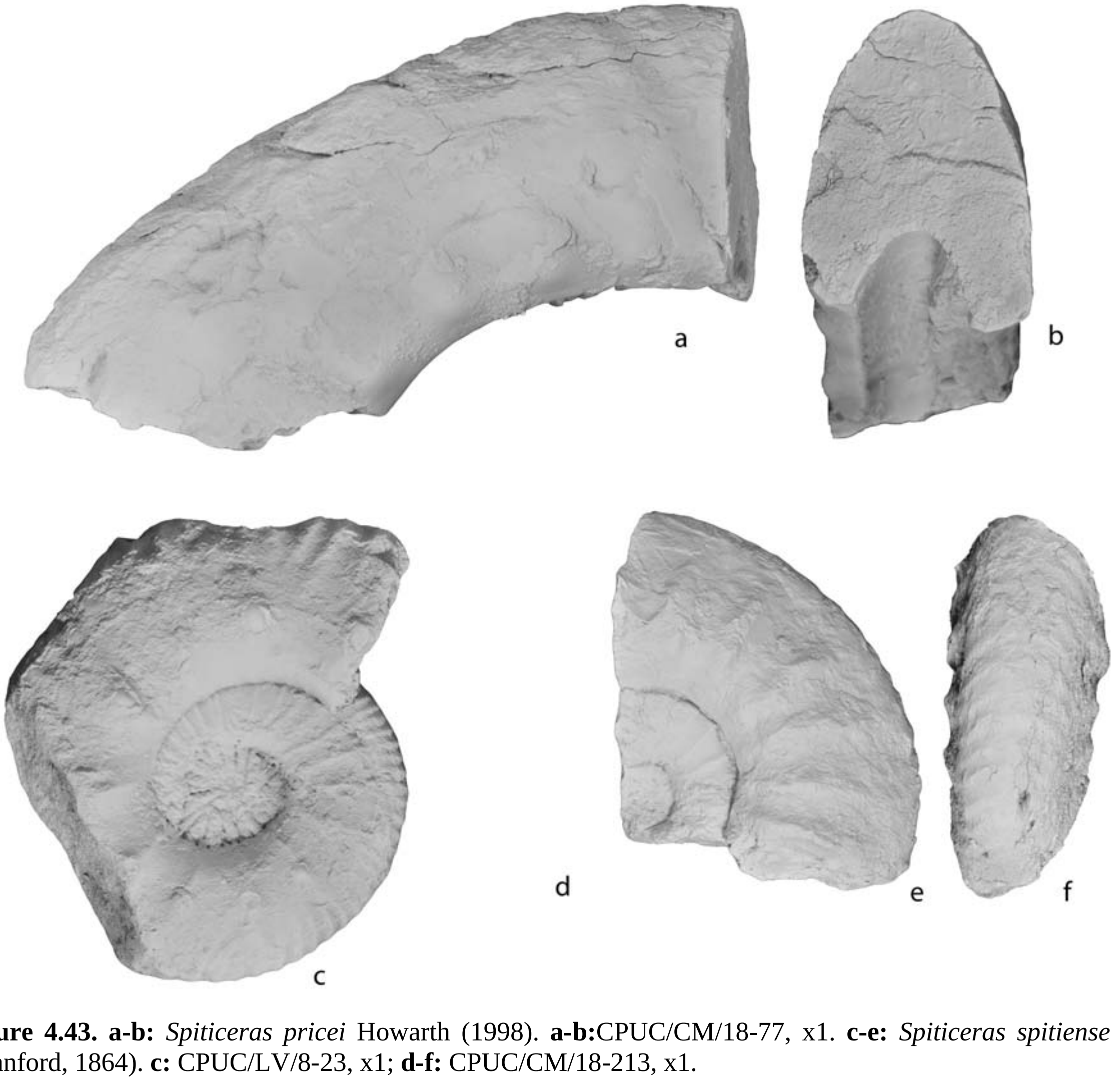


Figure 4.43. a-b: *Spiticeras pricei* Howarth (1998). **a-b:**CPUC/CM/18-77, x1. **c-e:** *Spiticeras spitiense* (Blanford, 1864). **c:** CPUC/LV/8-23, x1; **d-f:** CPUC/CM/18-213, x1.

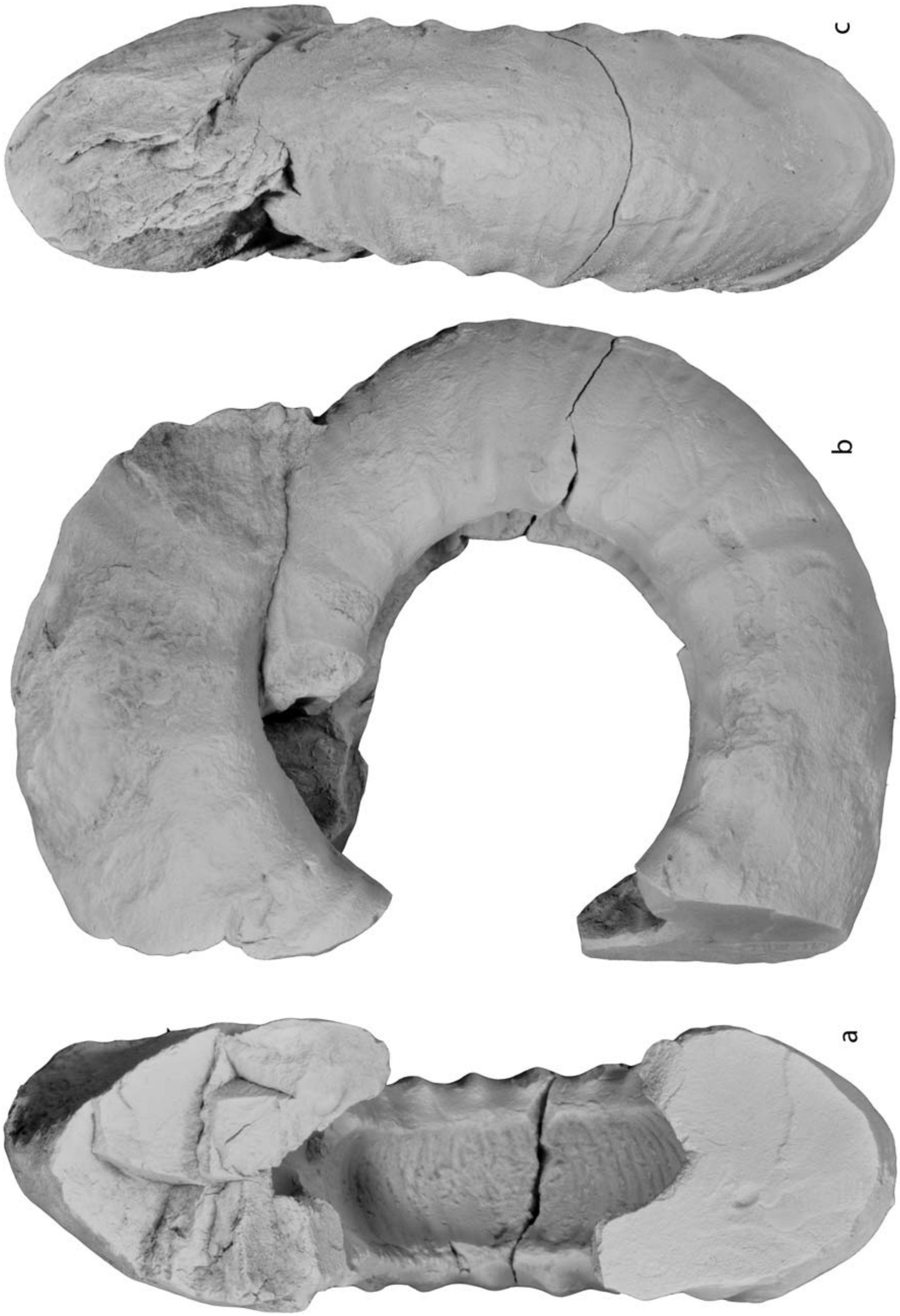


Figure 4.44. a-c: *Spiticeras spitiense* (Blanford, 1864). **a-c:** CPUC/CM/18-110, x1.

Occurrence: *S. spitiense* is here recorded for the first time in Chile. It is present in the upper part of the Siltstone member at Lo Valdés (figure 5.6) and in the lower part of the Limestone member at Cajón del Morado (figure 5.7). *S. spitiense* is considered an index fossil of the Berriasian and was recorded from this stage in the Himalayas and Tibet (Blanford 1864, Uhlig 1903, Chao 1976, Liu 1988, Takei et al. 2004), China (Grabau 1928), Ucraina (Karakash 1907, Kvantaliani 1999), Italy (Rossi 1984, Marino et al. 2004), South France (Djanélidzé 1922), Iraq (Howarth 1992), Tunisia (Arnould-Saget 1953), South Yemen (Howarth 1998), and the South Shetlands and Alexander Island in Antarctica (Tavera 1970, Thomson 1979).

Spiticeras tripartitum (Hupé 1854)

Figure 4.45, 4.46, 4.47, 4.48.

1854 *Ammonites tripartitus* Hupé, p. 35, pl. 1, fig. 2.
1867 *Ammonites tripartitus* Hupé. Rémond de Corbineau, p. 105.
1897 *Stephanoceras Damesi* n. sp. Steuer, p. 193, pl. 20, figs. 1-4.
1921 *Stephanoceras Damesi* n. sp. Steuer, p. 96, pl. 6, figs. 1-4 (= Steuer 1897).
1921 *Spiticeras Damesi* (Steuer). Gerth, p. 147.
1922 *Spiticeras* (*Kilianiceras*) *damesi* (Steuer). Djanélidzé, p. 193.
1925 *Spiticeras Damesi* (Steuer). Gerth, p. 66, text-fig. 4.
1928 *Spiticeras damesi* (Steuer). Gerth, p. 466.
? 1931 *Spiticeras damesi* (Steuer). Weaver, p. 427.
1931 *Spiticeras Damesi* (Steuer). Windhausen, pl. 32, fig. 1 (= Steuer 1897).
? 1938 *Spiticeras* (*Kilianiceras*) *Damesi* (Steuer). Roman, pl. 38, fig. 363, text-fig. 363 (= Steuer 1897).
? 1945 *Spiticeras* (*Kilianiceras*) *damesi* (Steuer). A. Leanza, p. 73, pl. 15, figs. 4, 7, pl. 17, figs. 4, pl. 20, figs. 7, pl. 22, figs. 1-2.
1964 *Spiticeras tripartitus tripartitus* (Hupé). Biro, p. 95, pl. 18, fig. 2, pl. 19, figs. 1-3, pl. 20, fig. 1, fig. 2 (= Hupé 1854).
1964 *Spiticeras tripartitus lovaldensis* Biro, p. 99, pl. 21, fig. 1 (*nomen nudum*).
1970 *Spiticeras* (*Kilianiceras*) *damesi* (Steuer). Tavera, p. 181, pl. 4, figs. 10-11, 14.
1980 *Spiticeras tripartitus tripartitus* (Hupé). Biro, p. 229, pl. 3, figs. 1, 2a-b (= Biro 1964, pl. 18, fig. 2, pl. 19, fig. 1), fig. 3 (= Hupé 1854), pl. 4, figs. 4-6 (= Biro 1964, pl. 20, fig. 1, pl. 19, figs. 3, 6.

1980 *Spiticeras tripartitus lovaldensis* n. ssp. Biro, p. 231, pl. 5, figs. 1-2 (= Biro 1964, pl. 21, figs. 1-2), pl. 6, figs. 3-4, pl. 7, figs. 5-6 (= Biro 1964, pl. 22, figs. 1-2).

? 1981 *Spiticeras damesi* (Steuer). H. Leanza, pl. 5, fig. 7 (= A. Leanza 1945).

? 1988 *Spiticeras damesi* (Steuer). Riccardi, pl. 3, figs. 5-6.

? 1993 *Spiticeras damesi* (Steuer). Aguirre-Urreta, pl. 1, fig. 6.

1996 *Spiticeras* (*Kilianiceras*) *damesi* (Steuer). Wright et al., p. 43, fig. 31, 2a,b (= Steuer 1897).

2005 *Spiticeras*? *tripartitum* (Hupé). Klein, p. 61.

2005 *Spiticeras*? *tripartitum lovaldensis* Biro. Klein, p. 61.

2005 *Kilianiceras damesi* (Steuer). Klein, p. 63.

Type: Holotype is the original described by Hupé (1854, p. 35, pl. 1, fig. 2).

Material: 143 regular to well preserved specimens, most of which are deformed. CPUC/LV/7-2 and CPUC/LV/8-62 are complete phagmocones. CPUC/LV/6-22, CPUC/CM/18-108, CPUC/CM/18-167, CPUC/CM/18-174, CPUC/CM/18-184, CPUC/CM/18-420 and CPUC/CM/18-444 are fragmentary phragmocones.

Description: Evolute and compressed. The whorl section is sub-rounded to rounded, wider than high, except for a few specimens in which it is slightly higher than wide. The umbilical shoulder is rounded, flanks in the dorsolateral area are rounded to sub-parallel; they converge ventrolaterally towards the arched venter. The sculpture consists of prorsiradiate primary ribs, which initiate as small elongated tubercles on the umbilical border. On the dorsolateral part of the flank ribs form a second row of prominent elongate spinous tubercles, or prominent spines, but this is recognized only in some well preserved specimens. Secondaries initiate at mid-flank, branching off from these spines. The number of secondary ribs varies between two and five, and occasionally even six. These ribs are prorsiradiate and slightly concave and cross the venter without interruption. An additional one to three unbranched primary ribs are intercalated between them and parallel the branched secondaries. Some specimens preserve small irregular tubercles on the ventral border.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/7-2	173.9	49.8	46.6	1.07	91.8	0.53
CPUC/LV/8-62	108.3	37.2	30.2	1.23	52.8	0.49

Remarks: The holotype of *S. tripartitum*, the single specimen described and illustrated by Hupé (1854), presents secondary ribs, that are grouped in three. Biro (1964, 1980) gives a full description of this taxon based on fifty-two specimens; he indicates that *Spiticeras tripartitum* is a variable species. *Spiticeras tripartitum lovaldensis* described by Biro (1964, 1980) was based on 103 specimens. The author suggests that this taxon differs from the nominal species *S. tripartitum* by a slightly wider than high whorl section, by the presence of ventral tubercles and a slightly more evolute coiling. Nevertheless, we consider these morphological elements as within the morphological variability of *S. tripartitum*, where the ventral tubercles are preserved in some specimens and the whorl section is as wide as high, but also including specimens with a slightly wider, or higher, whorl section.

Spiticeras damesi described originally by Steuer (1897, 1921) was based on a single specimen, an adult with a diameter of approx. 150 mm. The author indicates that his description is based mainly on the last whorl, whereas inner whorls were not available for study then. The morphological elements described for *S. damesi* by Steuer (1897, 1921) correspond to those for adults of *S. tripartitum* as given by Biro (1964, 1980) and here. Hence, *S. damesi* is considered a junior synonym of *S. tripartitum*. Few authors cite *S. damesi* (see synonymy list) and most of them refigure the specimen described and illustrated by Steuer (1897, 1921), or discuss the genus. Weaver (1931) gives a complementary description of a single specimen of *S. damesi*, but without illustration. Riccardi (1988) and Aguirre-Urreta (1993) both illustrate single specimens without description or discussion of the species. According to the illustrations, these specimens should be assignated to *S. tripartitum.*

A. Leanza (1945) presents five specimens of *S. damesi*, one of which is an adult (D= 146 mm) and a second the holotype of *S. damesi* figured by Steuer (1897, 1921), which corresponds to *S. tripartitum*. Three other specimens (pl. 15, figs. 4, 7, pl. 17, fig. 4, pl. 20, fig. 7) correspond to juveniles; their umbilical and dorsolateral tubercles appear to be fused, although this may be the result of a preservational bias. For the moment, their assignation to *S. tripartitum* remains doubtful.

S. tripartitum is closely related with *Argentiniceras bituberculatum* A. Leanza (1945) and *Argentiniceras noduliferum* (Steuer 1897). In *A. bituberculatum* the ribs are closer-standing; both the umbilical and middle flank tubercles are prominently rounded. *A. noduliferum* is presently based on five specimens described by Steuer (1897, 1921), A. Leanza (1945) and Aguirre-Urreta (1993). The taxon presents elongated umbilical tubercles and the primaries are bifurcated.

Figure 4.45. a-e: *Spiticeras tripartitum* (Hupé 1854) from Lo Valdés Formation. **a:** CPUC/CM/18-188, x1; **b:** CPUC/CM/19-59, x1; **c-e:** CPUC/CM/17-111, x1.

Figure 4.46. a-b: *Spiticeras tripartitum* (Hupé 1854) from Lo Valdés Formation. **a:** CPUC/CM/18-174, x0.75; **b:** CPUC/LV/8-62, x0.75.

Figure 4.47. a-b: *Spiticeras tripartitum* (Hupé 1854) from Lo Valdés Formation. **a-b:** CPUC/CM/18-444, x1.

Occurrence: In the Lo Valdés Formation *S. tripartitum* is present at Lo Valdés in the upper part of the Siltstone member and the lowermost part of Limestone member (figure 5.6). At Cajón del Morado the taxon is present in the upper part of the Siltstone member (figure 5.7).

In his description of the Lo Valdés section, Biro (1964, 1980) recorded a range of *S. tripartitum* from the Uppermost Tithonian to the Berriasian, with a major abundance for the Upper Berriasian. It must be noted, however, that the Tithonian record was based on a single specimen which was not collected *in situ*. In Argentina both *S. tripartitum* and *S. damesi* are regarded index fossils of the Upper Berriasian by A. Leanza (1945), H. Leanza (1981), Riccardi (1988) and Aguirre-Urreta (1993), whereas earlier authors, among them Steuer (1897, 1921) and Weaver (1931), recorded this taxon for the Valanginian.

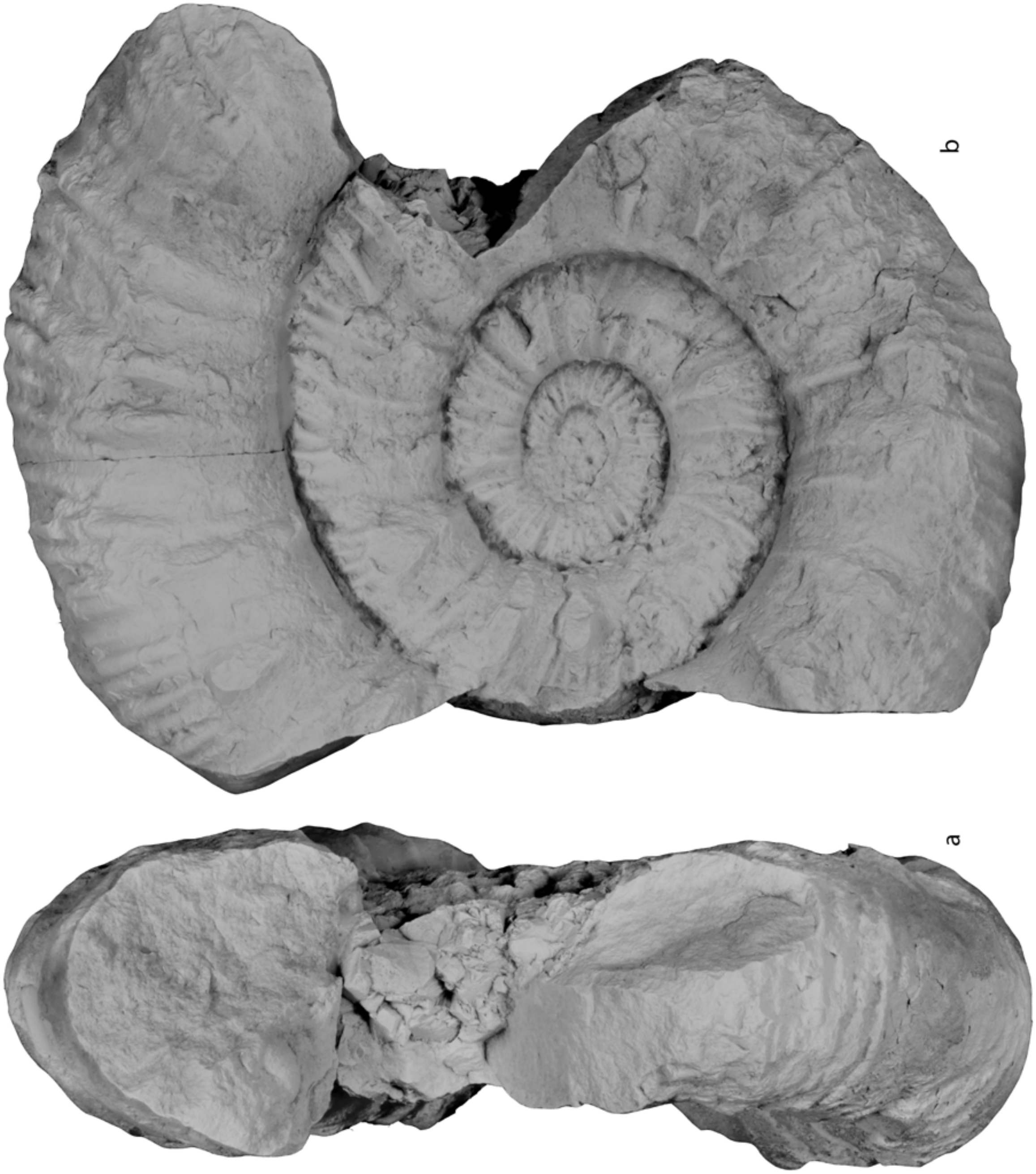


Figure 4.48. a-b: *Spiticeras tripartitum* (Hupé 1854) from Lo Valdés Formation. **a-b:** CPUC/LV/7-2, x1.

Genus *Groebericeras* A. Leanza, 1945

Type species: *Groebericeras bifrons* A. Leanza (1945, p. 82, pl. 18, fig. 1), by original designation (= *Ammonites rocardi* Pomel, 1889).

Groebericeras rocardi (Pomel, 1889)

Figure 4.49, 4.50, 4.51

1889 *Ammonites rocardi* Pomel, p. 65, pl. 8, figs. 3-5.

1945 *Groebericeras bifrons* n. sp. A. Leanza, p. 82, pl. 17, figs. 2-5, pl. 18, fig 1, pl. 19, figs. 1-2, 7, text-fig. 11.

1957 *Groebericeras bifrons* A. Leanza. Arkell et al., p. L347, fig. 454: 5a-5b (= A. Leanza 1945).

1981a *Groebericeras bifrons* A. Leanza. H. Leanza, pl. 4, fig. 1-2 (= A. Leanza 1945).

1982 *Spiticeras* (*Groebericeras*) *rocardi* (Pomel). Hoedemarker, p. 35.

1982 *Spiticeras* (*Groebericeras*) aff. *bifrons* (A. Leanza). Hoedemarker, p. 39, 41, pl. 4, fig. 3

1992 *Groebericeras rocardi* (Pomel). Howarth, p. 626, pl. 4, figs. 3-4, pl. 5, figs. 5-6, pl. 6, figs. 1-4, text-fig. 6D, 6E, 7.

1993 *Groebericeras bifrons* A. Leanza. Aguirre-Urreta, p. 67, pl. 1, figs. 2-3.

1994 *Groebericeras* aff. *bifrons* A. Leanza. Covacevich et al., p. 428, fig. 2a.

1996 *Groebericeras rocardi* (Pomel). Wright et al., p. 43, fig. 43, fig. 31: 4a-4b (= A. Leanza 1945).

1999 *Groebericeras bifrons* A. Leanza. Aguirre-Urreta & Alvarez, p. 19, pl. 1, figs. 1-2 (= A. Leanza 1945), figs. 3-5, figs. 6-7 (= Aguirre-Urreta 1993), figs. 8-9, pl. 2, figs. 1-4, pl. 3, figs. 1-3, text-fig. 3.

2005 *Groebericeras bifrons* A. Leanza. Klein, p. 69.

2005 *Groebericeras rocardi* (Pomel). Klein, p. 70.

Type: The holotype of A*mmonites* (=*Groebericeras) rocardi* described by Pomel (1889, p. 65, pl. 8, figs. 3-5) is lost. Lectotype is specimen SEGEMAR 8067 figured by Leanza (1945, pl. 19, figs. 1-2), designated by Howarth (1992, p. 626-630). This author also presents a full discussion.

Material: Thirty-one specimens. CPUC/CM/18-42, CPUC/CM/18-57, CPUC/CM/18-58, CPUC/CM/18-67 and CPUC/LV/6-67 are largest and correspond to well preserve complete and fragmentary phragmocones. CPUC/CM/18-36, CPUC/CM/18-41, CPUC/CM/18-56 and CPUC/CM/18-331 are well preserved complete and fragmentary phragmocones.

Description: Most specimens described here are large, from 84 to 282 or even reaching 463 mm in diameter. The smaller specimens (D< 100) are evolute and present a whorl section which is higher than wide and discoidal. The umbilical border is rounded, the flanks are flat to slightly convex and the venter is arched and acute. The sculpture consists of very fine prorsiradiate ribs on the ventrolateral area and the venter, and three to four constrictions on the last whorl, which are gently prorsiradiate and concave. In the largest specimens (D>100 mm.) coiling is more evolute and the umbilicus wide. Ribs are observed only in a single specimen (CPUC/LV/6-67); they are fine and prorsiradiate and restricted to the ventral border.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/18-56	83.8	19.8	25.2	0.79	38.1	0.45
CPUC/CM/18-331	140.1	34.5	48.1	0.72	57.7	0.41
CPUC/CM/18-36	148.6	34.4	51.6	0.67	70.5	0.47
CPUC/CM/18-41	171.5		54.3		71.1	0.41
CPUC/CM/18-42	179.1				79.3	0.44
CPUC/CM/18-57	203.2		67.6		89.0	0.44
CPUC/CM/18-67	282.1		94.7		115.7	0.41
CPUC/LV/6-67	(463.1)		152.9			

Remarks: Howarth (1992, p. 624-630) gives a full description and discussion of *Groebericeras* and of *Groebericeras rocardi,* in which he points to the morphological similarities between this latter species and *G. bifrons* A. Leanza (1945), which he considered synonymous with "*Ammonites*" *rocardi*. Subsequently, Aguirre-Urreta & Alvarez (1999) suggested retaining both taxa as valid species, based on a higher evolution, stronger ribbing and a complete lack of tubercles of *G. bifrons*. Howarth (1992), on the other hand, emphasized the morphological variablility of *G. rocardi.* In addition to the variable umbilical diameter, internal moulds of *G. rocardi* frequently do not show any sculpture and tubercles frequently disappear at about 25 mm shell diameter. Considering these characteristics, we agree with the discussion of Howarth (1992,

p. 624-630) and consider *G. bifrons* as a junior synonym of *G. rocardi*; the lectotype is specimen SEGEMAR 8067 figured by Leanza (1945, pl. 19, figs. 1-2).

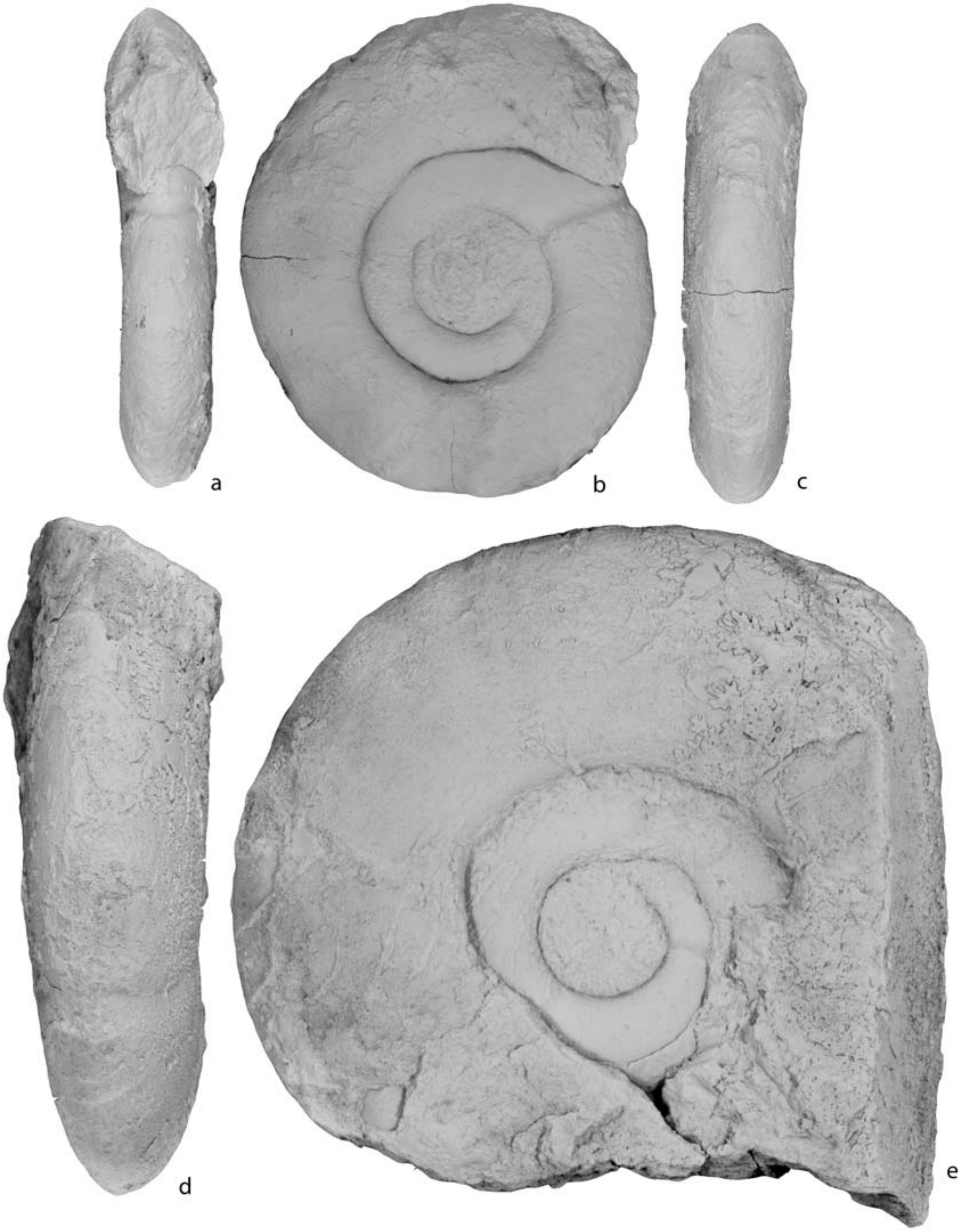


Figure 4.49. a-e: *Groebericeras rocardi* (Pomel, 1889) from Lo Valdés Formation. **a-c:** CPUC/CM/18/56, x1; **d-e:** CPUC/CM/18-331, x1.

Figure 4.50. a-b: *Groebericeras rocardi* (Pomel, 1889) from Lo Valdés Formation. **a-b:** CPUC/CM/18-58, x0.75.

Occurrence: *Groebericeras rocardi* is here documented for the first time in Central Chile. In the Lo Valdés Formation it is present in the upper part of the Siltstone member at Lo Valdés and at Cajón del Morado (figure 5.6-5.7). In Argentina *Groebericeras rocardi* (= *G. bifrons*) is registered for the ?Lower Berriasian (Leanza 1945, Aguirre-Urreta & Alvarez 1999). Outside South America *Groebericeras rocardi* is well recorded for the Upper Berriasian of Algeria

(Pomel 1889), south-east Spain (Hoedemaeker 1982), ?Nepal, western Canada and Iraq (Howarth 1992).

Figure 4.51. a: *Groebericeras rocardi* (Pomel, 1889) from Lo Valdés Formation. **a:** CPUC/CM/18-42, x1.

Family NEOCOMITIDAE Salfeld, 1921
Subfamily BERRIASELLINAE Spath, 1922
Genus *Berriasella* Uhlig, 1905
Subgenus *Berriasella* Uhlig, 1905

Type species: *Ammonites privasensis* Pictet (1867, p. 84, pl. 18, figs. 1a, 1b) by subsequent designation of Roman (1938, p. 324) for the genus and subgenus.

Berriasella (*Berriasella*) *jacobi* Mazenot (1939)
Figure 4.52

1890 *Hoplites Calisto* (Orbigny). Toucas, p. 600, pl.17, fig. 3.
1897 *Reineckeia fraudans* n. sp. Steuer, p. 35, pl. 9, figs. 4-6.
? 1897 *Odontoceras fallax* n. sp. Steuer, p. 52, pl. 14, figs. 1-2.
1921 *Berriasella fraudans* (Steuer). Gerth, p. 147.
1921 *Reineckeia fraudans* Steuer, p. 61, pl. 9, figs. 4-6 (= Steuer 1897).
? 1921 *Odontoceras fallax* n. sp. Steuer, p. 80, pl. 14, figs. 1-2 (= Steuer 1897).
1925 *Thurmannia fraudans* (Steuer). Gerth, p. 96, text-fig. 9.
1926 *Berriasella Steinmanni* n. sp. Krantz, p. 439, pl. 14, figs. 3-4, text-fig. 4.
1926 *Andiceras acuticostum* n. sp. Krantz, p. 452, pl. 15, figs. 7-8.
1928 *Berriasella Steinmanni* n. sp. Krantz, p. 22, pl. 1, fig. 3, text-fig. 2 (= Krantz 1926).
1928 *Andiceras acuticostum* n. sp. Krantz, p. 38, pl. 2, figs. 2, text-fig. 11 (= Krantz 1926).
? 1930 *Andiceras fallax* (Steuer). Burckhardt, table 11.
1939 *Berriasella Jacobi* Mazenot, p. 54, pl. 4, figs. 1-4, non fig. 5 (= *Lemencia subjacobi*).
1945 *Berriasella fraudans* var. *inflata* (Steuer). A. Leanza, p. 31, pl. 1, fig. 1.
? 1951 *Berriasella curvicostata* n. sp. Rivera, p. 32, pl. 1, figs. 1-2.
1951 *Berriasella peruviana* n. sp. Rivera, p. 31, pl. 1, figs. 4-7.
1953 *Berriasella Jacobi* Mazenot. Arnould-Saget, p. 33, pl. 3, fig. 11, pl. 4, fig. 1.
1960 *Berriasella jacobi* Mazenot. Collignon, p. CLXV, figs. 668-669.

1968 *Berriasella jacobi* Mazenot. Hégarat & Remane, p. 25, pl. 5, fig. 1, fig. 2.
1979 *Berriasella* (*Berriasella*) *jacobi* Mazenot. Sapunov, p. 173, pl. 55, fig. 3.
1983 *Berriasella* (*Hegaratella*) cf. *jacobi* Mazenot. Geyer, p. 343, fig. 3g.
1985 *Berriasella* (*Berriasella*) *jacobi* Mazenot. Tavera, p. 238, pl. 33, fig. 7-11, text-fig. 19B.
1987 *Berriasella jacobi* Mazenot. Liu & Wang, pl. 1, fig. 6, pl. 2, fig. 7.
1989 *Berriasella jacobi* Mazenot. Khimshiashvili, p. 9, pl. 4, fig. 3-4.
1990 *Berriasella* ex gr. *jacobi* Mazenot. Sey & Kalacheva, pl. 1, figs. 1-6.
1992 *Berriasella* (*Berriasella*) *jacobi* Mazenot. Howarth, p. 631, pl. 4, fig. 5.
1992 *Berriasella* (*Berriasella*) *jacobi* Mazenot. Wierzbowski & Remane, p. 874, pl. 1-4.
1999 *Berriasella* (*Berriasella*) *jacobi* Mazenot. Kvantaliani, p. 89, pl. 10, figs. 4-7.
? 2005 *Berriasella* (*Berriasella*)? *curvicostata* Rivera. Klein, p. 169.
2005 *Berriasella* (*Berriasella*) *fraudans* (Steuer). Klein, p. 169.
2005 *Berriasella* (*Berriasella*) *jacobi* Mazenot. Klein, p. 171 (with aditional synonymy).
2005 *Berriasella* (*Berriasella*) *peruviana* Rivera. Klein, p. 174.
2005 *Berriasella* (*Berriasella*) *steinmanni* Krantz. Klein, p. 177.
2005 *Andiceras acuticostatum* Krantz. Klein, 193.
? 2005 *Parandiceras*? *fallax* (Steuer). Klein, 194.

Type: *Berriasella jacobi* Mazenot (1939, p. 54, pl. 4, figs. 1a-1b) by original designation, from South-East France, deposited in the collection of the Faculté des Sciences, Lyon, France.

Material: Fifty-two regular to well specimens, that correspond to complete and fragmentary phragmocones. CPUC/CP/20-3, CPUC/CP/40-11, CPUC/CP/40-6, CPUC/CP/40-70-1, CPUC/CP/40-70-3, CPUC/CP/50-20, CPUC/CP/50-28, CPUC/CP/50-29, CPUC/CP/50-33, CPUC/CP/50-40, CPUC/CP/60-29, CPUC/CP/60-34 are CPUC/LV/5-57 are well preserved complete phragmocones.

Description: The coiling is evolute with a wide umbilicus. The whorl section is discoidal, higher than wide. The umbilical border is rounded, flanks are slightly convex and the venter is rounded. The maximum width of the whorl section is dorsolaterally. The sculpture consists of dense ribs that are rectiradiate and slightly flexuous. Most are bifurcated irregularly on the middle part of the flank, while others remain simple. Ribs initiate on the umbilical wall, where they are slightly concave on the flanks. On the venter they are interrupted by a tenuous discontinuity. Occasional 2-3 shallow prorsiradiate constrictions are present per whorl; they interrupt the ribs.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CP/20-3	33.8	11.2	12.1	0.93	14.7	0.43
CPUC/CP/40-11	45.2	16.9	18.4	0.92	17.5	0.39
CPUC/CP/40-6	28.7	8.5	10.7	0.79	10.8	0.38
CPUC/CP/40-70-1	37.8	11.0	14.3	0.77	15.5	0.41
CPUC/CP/40-70-3	46.8	13.5	16.6	0.81	19.7	0.42
CPUC/CP/50-20	51.3	15.8	19.2	0.82	20.3	0.40
CPUC/CP/50-28	28.8	8.5	10.6	0.80	11.2	0.39
CPUC/CP/50-29	28.4	8.9	10.6	0.84	10.8	0.38
CPUC/CP/50-33	30.3	8.6	10.4	0.83	11.4	0.38
CPUC/CP/50-40	42.2	12.7	13.9	0.91	18.2	0.43
CPUC/CP/60-29	37.4	10.0	12.0	0.83	16.3	0.44
CPUC/CP/60-34	54.2	15.4	19.5	0.79	22.1	0.41
CPUC/LV/5-57	36.0	9.7	12.5	0.78	15.5	0.43

Remarks: In South America, the taxon was previously described as *Berriasella fraudans* by Steuer (1897) and as the variety *inflata* by Leanza (1945). Both are based on single adult specimens (D> 60 mm) that show a slightly wider umbilicus and lower whorl section than the holotype of *Berriasella jacobi* described by Mazenot (1939), which is based on a juvenile specimen; similar material described by Arnould-Saget (1953) and Tavera (1985) also corresponds to juveniles (D< 60 mm). All morphological elements and sculpture of *B. fraudans* described here agree with the characteristics described for *Berriasella jacobi* Mazenot (1939) from the the Lowermost Berriasian of Southern Europe, which should therefore be considered to be a junior synonym of *B. fraudans*. Nevertheless, *B. jacobi* is an index marker taxon for the base of the Berriasian which is widely used internationally for the recognition of the base of the Cretaceous (e.g. Ogg 2004). The name should rather be kept. We suggest that the question of how to maintain *B. jacobi* as a valid taxon should be solved through a query to the Bulletin of Zoological Nomenclature. In the meantime we suggest continuing use *B. jacobi,* giving it preference over *B. fraudans*.

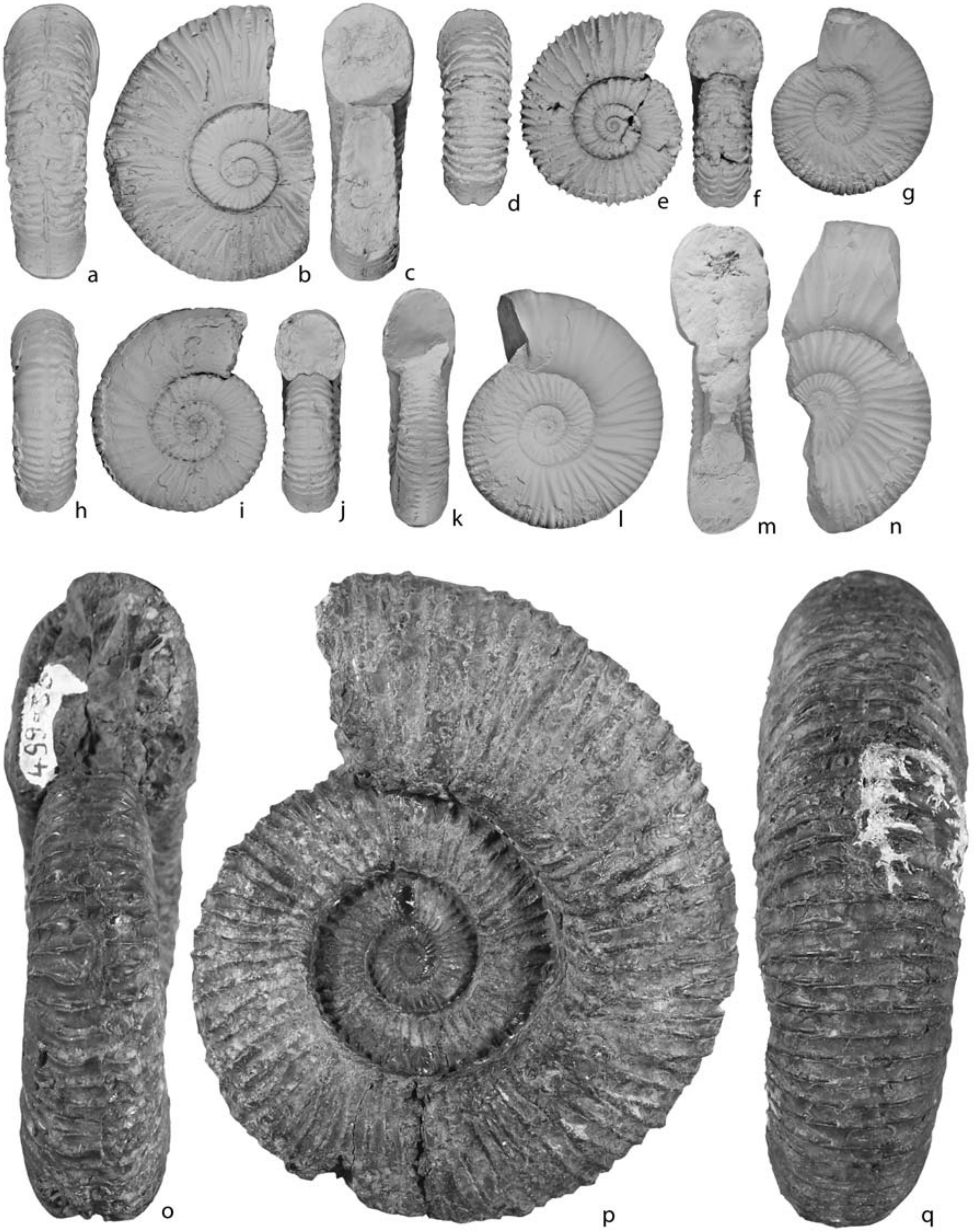


Figure 4.52. a-n: *Berriasella* (*Berriasella*) *jacobi* Mazenot (1939) from Lo Valdés Formation. **a-c:** CPUC/50-20, x1; **d-f:** CPUC/CP/20-3, x1; **g:** CPUC/CP/50-33, x1; **h-j:** CPUC/CP/40-11, x1; **k**-*l:* CPUC/40-70-1, x1; *m-n:* CPUC/CP/60-56, x1. **o-q:** *Berriasella* (*B.*) *jacobi* Mazenot (1939) (= *Berriasella fraudans* Steuer 1897), GZG 499-33, x1.

In Perú, *Berriasella peruviana* Rivera (1951) is morphologically indistinguishable from *B. jacobi* and the taxon is also considered to be a junior synonym. *Berriasella curvicostata* Rivera (1951) also resembles *B. jacobi*, but differs by a narrower umbilicus.

Berriasella (*B.*) *mazenoti* (Breistroffer 1937) is characterized by a maximum width of the whorl section on the middle part of the flank and a narrow venter; most ribs are simple and bifurcation is rare. *Berriasella* (*B.*) *callisto* (D`Orbigny 1850) and *Berriasella* (*B.*) *privasensis* (Pictet 1867) are distinguished from the present material by a higher flexuosity of ribs and a stronger sculpture.

Occurrence: *B. jacobi* is here recorded for the first time in Chile. In the Lo Valdés Formation the taxon is present in the Siltstone member at Cajón del Morado, Lo Valdés and Cruz de Piedra (figure 5.6, 5.7 and 5.8). Previously Biro (1964) registered *B. fraudans* (= *B. jacobi*) for the lower part of the Siltstone member. In Argentina *B. fraudans* (= *B. jacobi*) was recorded for the Upper Tithonian by Steuer (1897, 1921 and A. Leanza (1945). *B. jacobi* is also known from the Upper Tithonian of Perú (Geyer 1983) and Madagascar (Collignon 1960). *Berriasella* (*B.*) *jacobi* is present in the Lowermost Berriasian of the Tethys where it is considered an index fossil of the Lower Berriasian (Ogg 2004), with records in South France (Mazenot 1939, Hégarat & Remane 1968), Spain (Barthel et al. 1966, Hoedemarker 1982, Tavera 1985), Tunisia (Arnould-Saget 1953, Memmi 1967), Bulgary (Sapunov 1979), Poland (Wierzbowski & Remane 1992), Hungary (Horvath & Knauer 1986), Tibet (Liu & Wang 1987), the Caucasus (Khimchiashvili 1989, Kvantaliani 2000), Far East Russia (Sey & Kalacheva 1990) and Iraq (Horwarth 1992).

Genus *Substeueroceras* Spath, 1923c

Type species: *Odontoceras koeneni* Steuer (1897, p. 45, pl. 17, figs. 1-3), by subsequent designation of Spath (1923c, p. 305). The generotype is lost, but a plaster copy of this specimen (GZG 499-57), the original of Steuer (1897), still exists.

Genus A neotype is designated here. It is specimen GFZ 499-58, illustrated as *Odontoceras koeneni* Steuer (1897, p. 45, pl. 17, figs. 4-5).

Substeueroceras calistoide (Behrendsen 1891)

Figure 4.53, 4.54. 4.55, 4.56

1891 *Hoplites calistoides* n. sp. Behrendsen, p. 402, pl. 23, fig. 1.

? 1897 *Reineckeia incerta* n. sp. Steuer, p. 37, pl. 12, figs. 1-4.

1897 *Odontoceras callistoides* (Behrendsen) enmend. Steuer, p. 41, pl. 17, figs 13 (= Behrendsen 1891), 14-16.

1897 *Odontoceras Beneckei* n. sp. Steuer, p. 42, pl. 17, figs. 6-12.

1897 *Odontoceras subcallisto* (Toucas). Steuer, p. 44, pl. 18, figs. 10-12 (non *Berriasella* (*B.*) *subcalisto*).

1897 *Odontoceras intercostatum* n. sp. Steuer, p. 46, pl. 22, figs. 1-5.

1897 *Odontoceras ellipsostomum* n. sp. Steuer, p. 50, pl. 21, figs. 1-2, pl. 22, fig. 12.

1897 *Odontoceras nodulosum* n. sp. Steuer, p. 52, pl. 15, figs. 3-5.

1900b *Odontoceras nodulosum* Steuer. Burckhardt, p. 17, pl. 21, figs. 2-3.

1906 *Hoplites* cfr. *calistoides* (Behrendsen). Burckhardt, p. 139, pl. 39, figs. 6, non 5.

1910 *Necomites nodulosus* (Steuer). Kilian, p. 221.

1912 *Berriasella* cf. *calistoides* (Behrendsen). Burckhardt, p. 162, pl. 39, fig. 7.

1919 *Berriasella* cf. *calistoides* (Behrendsen). Burckhardt, p. 57, pl. 19, fig. 9, pl. 20, fig. 1-3.

1921 *Steueroceras ellipsostomum* (Steuer). Gerth, p. 84.

1921 *Berriasella calistoides* (Behrendsen). Gerth, p. 147.

1921 *Berriasella Beneckei* (Steuer). Gerth, p. 147.

? 1921 *Reineckeia incerta* n. sp. Steuer, p. 65, pl. 12, figs. 1-4 (= Steuer 1897).

1921 *Odontoceras callistoides* (Behrendsen) enmend. Steuer, p. 69, pl. 17, figs 13 (=Behrendsen 1891), 14-16 (= Steuer 1897).

1921 *Odontoceras Beneckei* n. sp. Steuer, p. 70, pl. 17, figs. 6-12 (= Steuer 1897).

1921 *Odontoceras subcallisto* (Toucas). Steuer, p. 72, pl. 18, figs. 10-12 (= Steuer 1897), (non *Berriasella* (*B.*) *subcalisto*).

1921 *Odontoceras intercostatum* n. sp. Steuer, p. 74, pl. 22, figs. 1-5 (= Steuer 1897).

1921 *Odontoceras ellipsostomum* n. sp. Steuer, p. 78, pl. 21, figs. 1-2, pl. 22, fig. 12 (= Steuer 1897).

1921 *Odontoceras nodulosum* n. sp. Steuer, p. 80, pl. 15, figs. 3-5 (= Steuer 1897).

1922 *Hoplites calistoides* n. sp. Behrendsen, p. 402, pl. 23, fig. 1 (=Behrendsen 1891.

? 1925 *Steueroceras*? *incertum* (Steuer). Gerth, p. 85.

1925 *Beriasella Beneckei* (Steuer). Gerth, p. 89.

1926 *Beriasella Beneckei* (Steuer). Gerth, p. 474

1945 *Parodontoceras calistoides* (Behrendsen). A. Leanza, p. 41, pl. 5, figs. 5-6.
1951 *Berriasella callistoides* (Behrendsen). Rivera, p. 30, pl. 4, fig. 1.
1967 *Parodontoceras* aff. *callistoides* (Behrendsen). Cantú-Chapas, p. 10, pl. 5, figs. 2, 8.
1973 *Parodontoceras* sp. ex gr. *calistoides* (Behrendsen). Geyer, p. 85.
1983 *Parodontoceras* cf. *beneckei* (Steuer). Geyer, p. 341.
1988 *Parodontoceras calistoides* (Behrendsen). Riccardi, pl. 3, figs. 3-4.
2005 *Berriasella* (*Berriasella*)? *nodulosa* (Steuer). Klein, p. 173.
2005 *Parodontoceras beneckei* (Steuer). Klein, p. 180.
2005 *Parodontoceras calistoides* (Behrendsen). Klein, p. 180 (with additional synonymy).
2005 *Substeueroceras ellipsostomum* (Steuer). Klein, p. 189.
? 2005 *Substeueroceras incertum* (Steuer). Klein, p. 189.
2005 *Substeueroceras intercostatum* (Steuer). Klein, p. 189.
2011b *Parodontoceras calistoides* (Behrendsen). Parent et al., p. 54, figs. 23A-B, 25A.

Type: The lectotype is designed here and corresponds to specimen GZG 499-63 described as *Odontoceras calistoides* by Behrendsen (1891, p. 402, pl. 23, fig. 1). It was enmended and refigured by Steuer (1897, p. 41, pl. 17, figs).

Material: Fifty-one specimens of which only the best-preserved were measured and are listed here. CPUC/LV/3-3, CPUC/CM/14-23, CPUC/CM/14-15-5, CPUC/CM/14-16-2, CPUC/CM/17-11, CPUC/CP/0-6, CPUC/CP/20-17, CPUC/CP/40-70-25, CPUC/CP/40-70-41, CPUC/CP/50-9, CPUC/CP/50-14, CPUC/CP/60-16, CPUC/CP/50-50 are well preserved complete and fragmentary phragmocones.

Description: Coiling is involute, even though the umbilicus widens towards adult stages (D>50 mm). The whorl section is sub-oval; in juvenile stages (D< 50mm) it is only slightly higher than wide, but towards adult stages, it clearly changes towards higher than wide (figure 4.53). Flanks are convex and converge towards the venter, with the widest part dorsolaterally close to the umbilical shoulder. The venter is subrounded to tabulate. 40-50 ribs are present on the last whorl in both juvenile and adult specimens. They are dense in inner and gradually more distant in outer whorls. Ribs are rectiradiate to prorsiradiate and flexuous. They initiate on the umbilical border where they are concave. A slightly convex curvature and strong prorsiradiate direction are observed on the dorsolateral part of the flank. Most ribs are bi- and some are trifurcated on the middle of the flank, while others remain simple. Ventrolaterally ribs are again gently concave but flex back to a prorsiradiate direction on both sides of the venter. The venter itself is crossed without an inclination, but ribs weaken and a smooth narrow strip may even be present when the shell is not preserved.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CP/0-6	64.0	19.8	27.2	0.73	16.4	0.26
CPUC/CP/20-17	33.0	12.1	12.4	0.98	13.1	0.40
CPUC/CP/40-70-41	56.9?	29.6	36.1	0.82	26.2	0.46
CPUC/CP/60-16	90.4	31.2	40.2	0.78	25.7	0.28

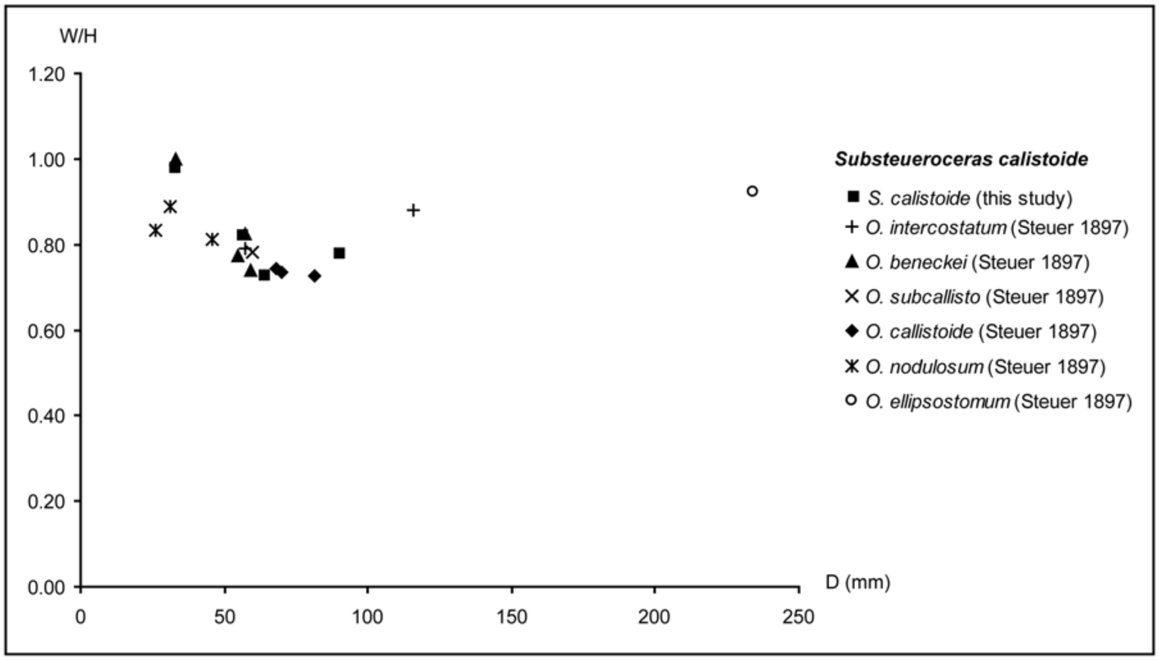


Figure 4.53. Relationship between W/H and D in *Substeueroceras calistoide* (Behrendsen 1891) and the junior synonymies included in this study. There are marked by gradual change of the whorl section from wider than high to higher than wide.

Remarks: *Substeueroceras* is characterized by fine and dense sinuous ribs, bi- or trifurcation on the middle part of the flank and continuity of ribs on the tabulate venter (Wright et al. 1996). The taxon *calistoides* in the enmendation of Steuer (1897) was considered as *Odontoceras calistoides*. Later Spath (1923) assigned the taxon *calistoides* as the generotype of *Parodontoceras*. Verma & Westermann (1973) considered *Substeueroceras* and *Parodontoceras* as synonymous. Wright et al. (1996) included *Parodontoceras* as a junior synonym of *Berriasella*. Parent et al. (2011b) considered *Parodontoceras* as an Andean lineage of Berriasellinae. Nevertheless, characteristics described here of the taxon *calistoides* agree with the diagnosis for *Substeueroceras*, according to the discussion of Verma & Westermann (1973).

Our assignation of the present abundant material to *Substeueroceras calistoides* is also based on a revision of the type material of Behrendsen (1891) and Steuer (1897). Our specimens are characterized by involute coiling, a high whorl section, subrounded to tabulate venter, dense and closely standing ribs that are gradually more spaced, and ribs divided on the middle part of the flank. These morphological characteristics allow for an assignation to *Substeueroceras*. *Parodontoceras* is here considered a junior synonym of *Substeueroceras*.

Substeueroceras intercostatum, *S. incertum*, *S. ellipsostomum*, *Parodontoceras beneckei* and *Berriasella* (*B.*?) *nodulosa* described by Steuer (1897) were revised in the collection in GZG. They all range within the variability of *S. calistoides.* Minor differences are interpreted as a result of ontogeny (juveniles vs. adult specimens) and biased by preservation. *Reineckeia incerta* (Steuer 1897) is similar to *S. calistoides,* but the whorl section of *R. incerta* is narrower.

Parent et al. (2011b) considered *Tirnovella*? *kayseri* and *Tirnovella*? *tenera* as synonyms of *S. callistoides,* but coiling is more involute in *kayseri* and *tenera*, the whorl section is thin and the venter more narrow.

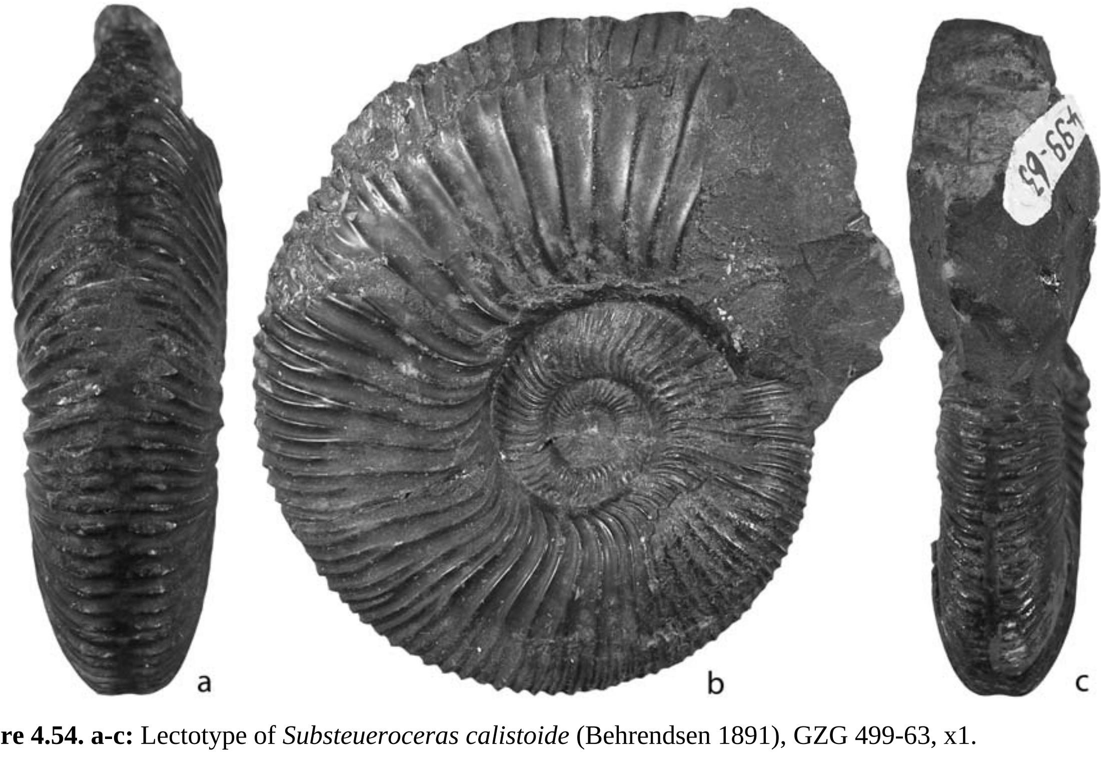


Figure 4.54. a-c: Lectotype of *Substeueroceras calistoide* (Behrendsen 1891), GZG 499-63, x1.

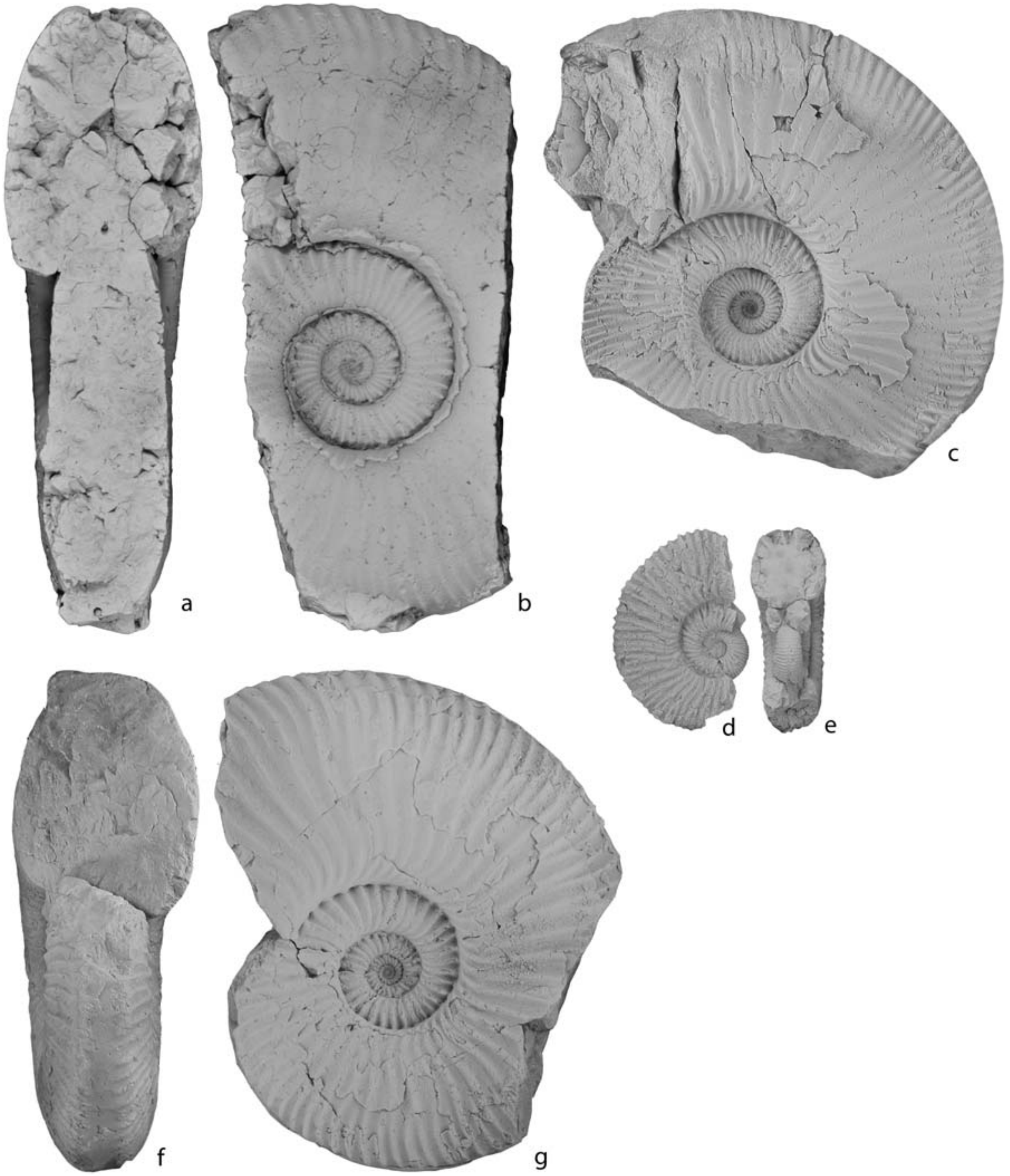


Figure 4.55. a-g: *Substeueroceras calistoide* (Behrendsen 1891) from Lo Valdés Formation. **a-b:** CPUC/CP/50-31, x1; **c:** CPUC/CP/40-70-41, x1; **d-e:** CPUC/CP/20-17, x1; **f-g:** CPUC/CP/60-16, x1.

Occurrence: In the Lo Valdés Formation *Substeueroceras callistoides* is present in the Sandstone member and lower part of the Siltstone member (figure 5.6, 5.7 and 5.8). Previously Biro (1964) recorded this taxon for the Siltstone member. In Argentina *S. callistoides* was registrated for the Upper Tithonian to Berriasian? (Steuer 1897, Gerth 1921, Leanza 1945, Riccardi 1988 and Parent et al. 2011b). In Colombia and Perú it was recorded for the Upper Tithonian (Geyer 1983, Rivera

1951); in Mexico *S. callistoides* in known for the Tithonian to Portlandian (Berriasian) (Burckhardt, 1912, 1919).

Figure 4.56. a-c: *Substeueroceras calistoide* (Behrendsen 1891) from Lo Valdés Formation. **a-c:** CPUC/CM/17-30, x0.75.

Substeueroceras koeneni (Steuer 1897)

Figure 4.57, 4.58, 4.59, 4.60, 4.61, 4.62

1897 *Odontoceras Koeneni* n. sp. Steuer, p. 45, pl. 17, figs. 1-5.

1897 *Odontoceras fasciatum* n. sp. Steuer, p. 46, pl. 32, fig. 1-3.

1897 *Odontoceras subfaciatum* n. sp. Steuer, p. 47, pl. 33, figs. 1-3.

1897 *Odontoceras permulticostatum* n. sp. Steuer, p. 56, pl. 37, figs. 1-2.

1900a *Odontoceras permulticostatum* Steuer. Burckhardt, p. 47, pl. 27, fig. 4.

? 1903 *Perisphinctes permulticostatum* (Steuer). Burckhardt, p. 59.

1906 *Perisphinctes* cfr. *Koeneni* (Steuer). Burckhardt, p. 137, pl. 39, fig. 1.

? 1906 *Perisphinctes* cfr. *permulticostatum* (Steuer). Burckhardt, p. 138, pl. 39, fig. 2.

1912 *Steuroceras lamellicostatum* n. sp. Burckhardt, p. 167, pl. 40, fig. 1-4, 6.

1912 *Steueroceras durangense* n. sp. Burckhardt, p. 168, pl. 40, fig. 5, 7-10.

1921 *Steueroceras Koeneni* (Steuer). Gerth, p. 147.

1921 *Odontoceras Koeneni* n. sp. Steuer, p. 73, pl. 17, fig. 1-5 (= Steuer 1897).

1921 *Odontoceras fasciatum* n. sp. Steuer, p. 74, pl. 18, fig. 1-3 (= Steuer 1897).

1921 *Odontoceras subfaciatum* n. sp. Steuer, p. 75, pl. 19, figs. 1-3 (= Steuer 1897).

1921 *Odontoceras permulticostatum* n. sp. Steuer, p. 84, pl. 23, fig. 1-2 (= Steuer 1897).

1923a *Substeueroceras koeneni* (Steuer). Spath, p. 305.

1925 *Steueroceras Koeneni* (Steuer). Gerth, p. 83, pl. 6, fig. 6.

1925 *Steueroceras subfasciatum* (Steuer). Gerth, p. 84, pl. 6, fig. 5.

1925 *Steueroceras permulticostatum* (Steuer). Gerth, 85.

1925 *Steueroceras Steueri* Gerth, p. 86, pl. 5, fig. 4, text-fig. 7.

1925 *Steueroceras rotundatum* Gerth, p. 87, pl. 5, fig. 6.

1928 *Steueroceras Steueri* Gerth, p. 473, pl. 18, fig. 4.

1930 *Steueroceras durangense* Burckhardt. Burckhardt, p. 63, 71.

1931 *Steueroceras Koeneni* (Steuer). Windhausen, pl. 30, fig. 2 (= Steuer 1897).

1931 *Steueroceras subfasciatum* (Steuer). Windhausen, p. 31, fig. 1 (= Steuer 1897).

1931 *Steueroceras permulticostatum* (Steuer). Windhausen, pl. 31, fig. 2 (= Steuer 1897).

? 1937 *Steueroceras subfasciatum*? (Steuer). Feruglio, p. 72.

1939 *Substeueroceras* n. sp. aff. *subfasciatum* (Steuer). Imlay, p. 50, pl. 15, fig. 9.

1939 *Substeueroceras kelluni* Imlay, p. 50, pl. 14, fig. 1-4.

1945 *Substeueroceras koeneni* (Steuer). A. Leanza, p. 28, pl. 5, figs. 7-8, pl. 7, fig. 4.

? 1945 *Substeueroceras disputabile* A. Leanza, p. 29, pl. 7, fig. 3, pl. 8, fig. 3, pl. 9, fig. 1.

1945 *Berriasella storrsi* Anderson, p. 980, pl. 7, fig. 1.

1951 *Substeueroceras köneni* (Steuer). Rivera, p. 34, pl. 3, fig. 2.

1951 *Substeueroceras permulticostatum* (Steuer). Rivera, p. 35, pl. 3, figs. 3, 5.

1951 *Substeueroceras steueri* (Gerth). Rivera, p. 35, pl. 4, fig. 4-5.

? 1956 *Argentiniceras disputabile* (A. Leanza). Arkell, p. 138.

Figure 4.62. a-b: *Substeueroceras koeneni* (Steuer 1897) from Lo Valdés Formation. **a:** CPUC/LV/6-63, x0.75. **b:** CPUC/LV/6-62, x1.

1957 *Substeueroceras koeneni* (Steuer). Arkell, et al., p. 352, fig. 462: 1a-1b (= Steuer 1897).

1958 *Substeueroceras koeneni* (Steuer). Corvalán & Pérez, p. 43, pl. 9, fig 19 (= Steuer 1897).

1958 *Substeueroceras subfasciatum* (Steuer). Corvalán & Pérez, p. 46, pl. 14, fig. 33 (= Steuer 1897).

1959 *Substeueroceras koeneni* (Steuer). Corvalán, p. 20, pl. 7, fig. 27.

1960 *Substeueroceras permulticostatum* (Steuer). Haas, p. 25, fig. 52.

1970 *Substeueroceras* cf. *S. kelluni* Imlay. Imlay & Jones, p. B42, pl. 10, fig. 19 (= Anderson 1945).

1973 *Substeueroceras* sp. ex. gr. *koeneni* (Steuer). Geyer, p. 84, pl. 5, fig. 6-7.

1973 *Substeueroceras koeneni* (Steuer). Verma & Westermann, p. 240.

1973 *Substeueroceras koeneni tabulatum* Verma & Westermann, p. 240, pl. 48, fig. 5, pl. 49, figs. 1-2.

1981b *Substeueroceras koeneni* (Steuer). H. Leanza, pl. 3, fig. 11 (= A. Leanza 1945).

1982 *Substeueroceras koeneni* (Steuer). Nikolov, p. 206, pl. 71, fig. 2 (Steuer 1897).

? 1983 *Substeueroceras disputabile* A. Leanza. Geyer, p. 341, fig. 3c.

1983 *Substeueroceras koeneni* (Steuer). Geyer, fig. 2g.

1988 *Substeueroceras koeneni* (Steuer). Riccardi, pl. 3, fig. 1, 2.

1990 *Substeueroceras koeneni* (Steuer). Aguirre-Urreta & Charrier, p. 266, pl. 1, fig. 3.

1992 *Substeueroceras koeneni* (Steuer). Howarth, p. 638, pl. 1, figs. 9-10, pl. 2, figs. 3, 10.

1992 *Substeueroceras koeneni* (Steuer). Riccardi, in Westermann et al., pl. 81, fig. 5 (= Riccardi 1988), pl. 82, fig. 3.

1994 *Substeueroceras koeneni* (Steuer). Pérez & Reyes, p. 58.

1996 *Substeueroceras koeneni* (Steuer). Wright et al. p. 50, fig. 36: 4 (= Steuer 1897).

1998 *Substeueroceras koeneni* (Steuer). Howarth, p. 91, pl. 19, fig. 5.

1998 *Substeueroceras lamellicostatum* Burckhardt. Furrazola-Bermúdez et al., p. 17.

1998 *Substeueroceras* aff. *subfasciatum* (Steuer). Furrazola-Bermúdez et al., p. 17.

1999 *Substeueroceras* aff. *tabulatum* Verma & Westermann. Fatmi & Zeiss, p. 94, pl. 42, figs. 1, 5.

1999 *Substeueroceras koeneni* (Steuer). Fatmi & Zeiss, p. 95, pl. 42, fig. 4.

1999 *Substeueroceras* cf. *kelluni* Imlay. Sey & Kalacheva, p. 84, pl. 1, fig. 1.

2001 *Substeueroceras* cf. *kelluni* Imlay. Sey & Kalacheva, p. 1095, pl. 1, fig. 1 (= Key & Kalacheva 1999).
2005 *Substeueroceras durangense* (Burckhardt). Klein, p. 188.
2005 *Substeueroceras fasciatum* (Steuer). Klein, p. 189.
2005 *Substeueroceras kelluni* Imlay. Klein, p. 190.
2005 *Substeueroceras koeneni* (Steuer). Klein, p. 190.
2005 *Substeueroceras lamellicostatum* (Burckhardt). Klein, p. 191.
2005 *Substeueroceras permulticostatum* (Steuer). Klein, p. 191.
2005 *Substeueroceras rotundatum* (Gerth). Klein, p. 191.
2005 *Substeueroceras steueri* (Gerth). Klein, p. 192.
2005 *Substeueroceras subfasciatum* (Steuer). Klein, p. 192.

Type. The lectotype of the genus is designated here and corresponds to GZG 499-57, defined as *Odontoceras koeneni* by Steuer (1897, p. 45, pl. 17, figs. 1-3); this lectotype is lost, only a gypsum copy exists. A neotype is designated here: specimen GZG 499-58 was illustrated as *Odontoceras koeneni* Steuer (1897, p. 45, pl. 17, figs. 4-5).

Material: 102 well preserved complete and fragmentary phragmocones. Only the best-preserved specimens were measured and are listed here. CPUC/CP/40-70-37, CPUC/CP/70-16, CPUC/CP/70-17, CPUC/CP/70-70, CPUC/CP/70-64, CPUC/CP/80-17, CPUC/CP/80-24, CPUC/LV/3-332, CPUC/LV/3-341, CPUC/LV/3-343 and CPUV/LV/6-63 are complete well preserved phragmocones.

Description: Involute in juveniles, but with a gradually widening umbilicus in adults (D > 70 mm), leading to a relationship of U/D between 0.19 and 0.42 (figure 4.57). The whorl section is discoidal in juveniles, higher than wide. Through ontogeny it gradually changes towards a whorl section which is as wide as high (figure 4.58). The umbilical border is nearly vertical, flanks are sub-parallel, slightly convex towards the venter which is narrowly rounded to almost flat. Fine and dense flexuous ribs initiate slightly rursiradiate to concave on the umbilical shoulder; they are prorsiradiate and slightly convex on the dorsolateral part of the flank and prorsiradiate and with concave bending ventrolaterally. Ribs cross the venter without interruption. Ribs are commonly divided into two or three secundaries on the umbilical border and on the middle part of the flank.

Dimensions	D	W	H	W/H	U	U/D

CPUC/CP/40-70-37	63.8	20.9	29.8	0.70	14.7	0.23
CPUC/CP/70-16	52.8	16.5	23.6	0.70	15.7	0.30
CPUC/CP/70-17	37.2	14.2	17.1	0.83	9.1	0.24
CPUC/CP/70-70	50.3	16.7	25.0	0.67	10.3	0.20
CPUC/CP/70-64	48.1	16.5	22.6	0.73	10.4	0.22
CPUC/CP/80-17	35.0	13.7	17.4	0.79	7.4	0.21
CPUC/CP/80-24	41.0	13.2	19.5	0.68	7.9	0.19
CPUC/LV/3-332	50.9	14.7	20.9	0.70	10.6	0.21
CPUC/LV/3-341	40.9	13.5	18.8	0.72	9.0	0.22
CPUC/LV/3-343	41.7	13.5	20.0	0.68	11.2	0.27
CPUV/LV/6-63	158.9	60.0	60.6	0.99	66.5	0.42

Remarks: The Neotype (GFZ 499-58) corresponds to a juvenile specimen.

Substeueroceras fasciatum and S. *subfasciatum*, established by Steuer (1897), are close relatives of *S. koeneni*. According to Steuer (op. cit.) their ribs are slightly stronger and bi- or trifurcated on the middle part of the flank. Our revision of the original collection of Steuer (1897) in the GFZ at Göttingen suggests, nevertheless, that the types of *S. fasciatum* and *S. subfasciatum* are within the morphological range of *S. koeneni* and correspond to specimens in the transition between juveniles and adults.

S. permulticostatum was defined by Steuer (1897) based on a single incomplete specimen. Subsequently, only single fragmentary specimens were described by Burckhardt (1900a), Rivera (1951) and Haas (1960). According to Steuer (1897), *S. permulticostatum* differs from *S. koeneni* by a higher whorl section and a wider umbilicus. However, our data set of numerous specimens of the latter taxon indicate that *S. permulticostatum* is within the wide range of morphological variation of *S. koeneni*; the taxon is here considered to be a synonym.

Substeueroceras lamellicostatum and *S. durangense* described by Burckhardt (1912) from Mexico supposedly differ by the intercalation of single ribs and type of ribbing, but these differences are minor and also within the wide morphological range of *S. koeneni*.

Substeueroceras steueri was described by Gerth (1925). The author indicated that the taxon closely resembles *S. lamellicostatum*, which we consider to be a synonym of *S. koeneni*. Our revision of the Gerth (1925) collection at STIPB indicates that *S. steueri* is morphologically inseparable from juveniles of *S. koeneni* and *S. lamellicostatum* is also considered to be a synonym.

Gerth (1925) emphasized the similarity between *Substeueroceras rotundatum* and *S. steueri*. According to this author, minor differences exist in a wider and low whorl section in *S. rotundatum* (figure 4.57 – 4.58), slightly stronger ribs and their interruption on the venter, but the latter is a preservational bias. *S. rotundatum* was based on a single specimen which corresponds to *S. steueri* and is therefore synonymous with *S. koeneni*.

Substeueroceras kellumi was defined by Imlay (1939) based on finer and more flexuous ribs and a slightly more involute shell. These subtle differences are part of the variation of *S. koeneni*.

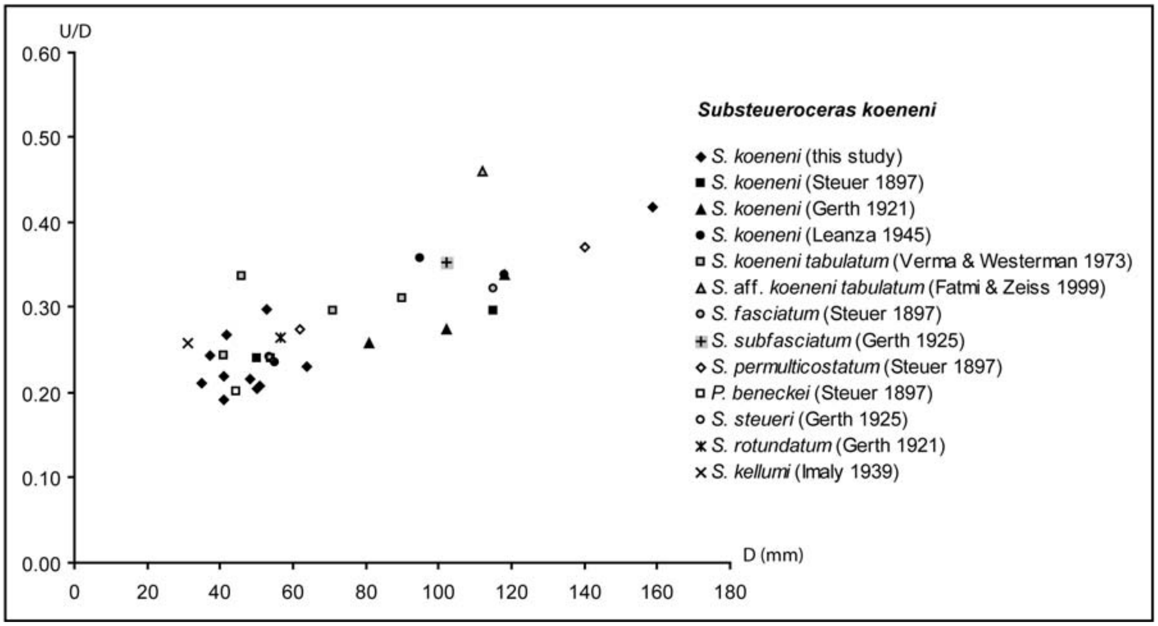


Figure 4.57. Relationship between U/D and D in *Substeueroceras koeneni* (Steuer 1897), and the junior synonymies included in this study. The umbilicus is gradually wider toward adult stages (D > 70 mm).

Occurrence: In the Lo Valdés Formation *Substeueroceras koeneni* is present in the Siltstone member at Cajón del Morado, Lo Valdés and Cruz de Piedra (figures 5.6, 5.7 and 5.8). It was previously recorded for the Siltstone member at Lo Valdés by Biro (1964, 1980). This author assigned an Uppermost Tithonian age to the specimens which he considered to differ from isolated specimens from the Upper Berriasian sequence. The latter were assigned to *S. permulticostatum*. *S. koeneni* was also recorded from the Rio Leñas Formation (= Baños del Flaco Formation) in Central Chile and assigned to the Upper Tithonian (Corvalán 1959). In Central-Argentina *S. koeneni* and its synonyms were initially recorded for the Portlandian, Lower

Valangianian, Infravalanginian and Upper Tithonian (Steuer 1897- 1921, Gerth 1925, Burckhardt 1930, Windhausen 1931 and Weaver 1931. Leanza (1945) proposed *S. koeneni* as an index fossil of the Uppermost Tithonian and subsequent Argentinian authors followed this interpretation (e.g. Leanza 1981b, Riccardi 1988, Parent 2001).

In Perú *S. koeneni* was registered for the Upper Tithonian (Rivera 1951), in Colombia for the Upper Berriasian (Haas 1960), in Mexico for the Portlandian (Burckhardt 1906), Lower Berriasian (Burckhardt 1912) and Upper Tithonian (Imlay 1939, Verma & Westermann 1973). *S. koeneni* was recorded in the Upper Tithonian of Pakistan (Fatmi & Zeiss 1999), the Upper Tithonian *Durangites* and Berriasian *Occitanica* Zones of Yemen (Howarth 1998) and the Berriasian of far East Russia (Sey & Kalacheva 1999, 2001).

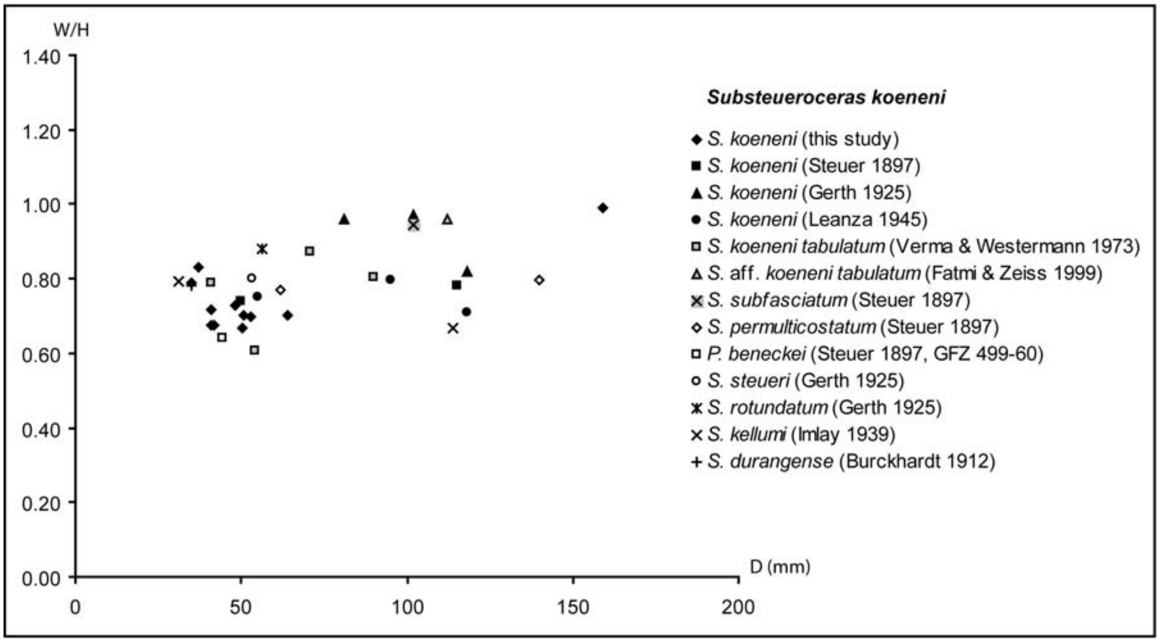


Figure 4.58. Relationship between W/H and D in *Substeueroceras koeneni* (Steuer 1897), and the junior synonymies included in this study. The whorl section change gradually from higher that wide wider that high.

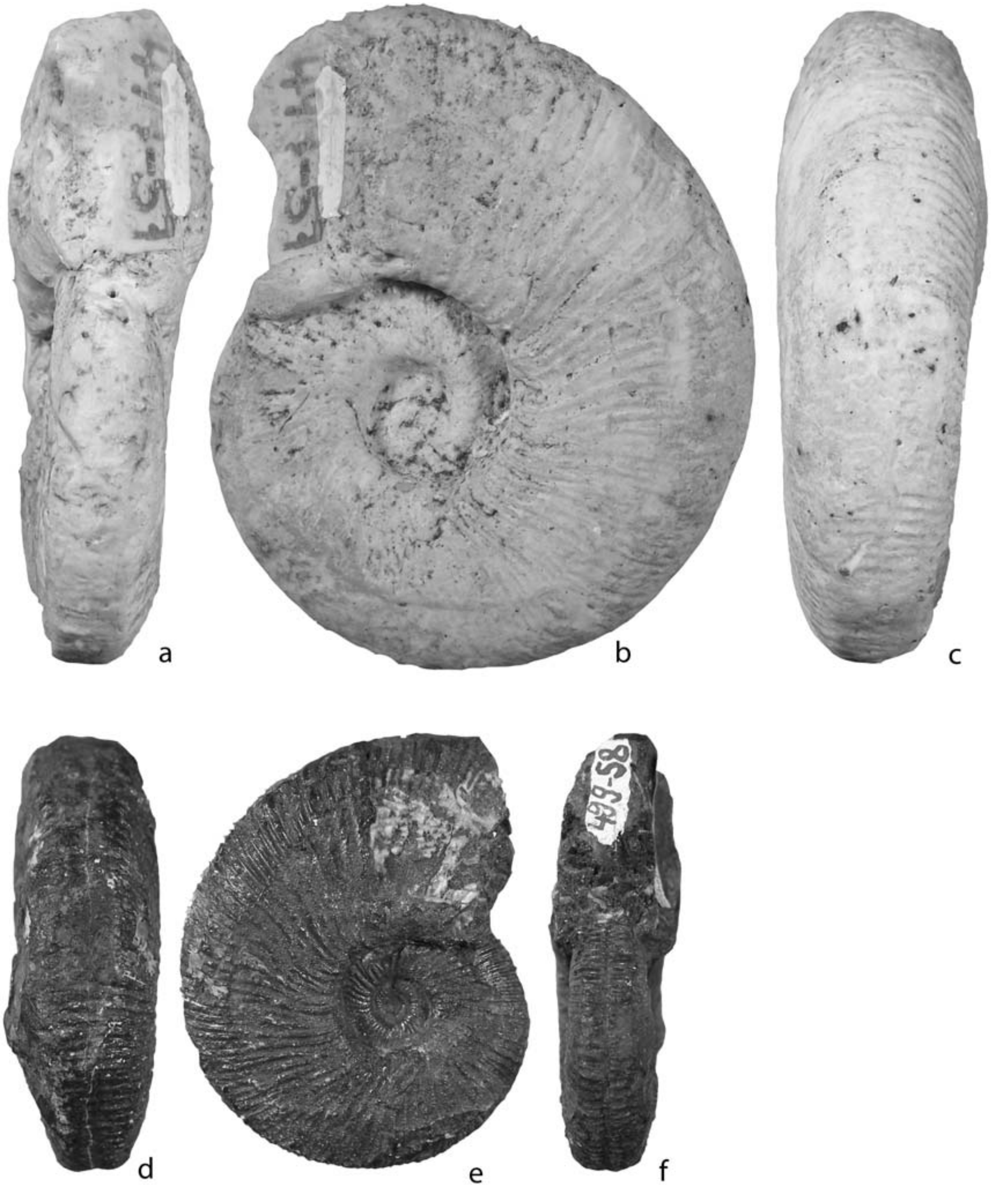


Figure 4.59. a-f: *Substeueroceras koeneni* (Steuer 1897). **a-c:** GZG 499-57, x0.75; gypsum copy of lectotype of "*Odontoceras*" *koeneni* illustrated by Steuer (1897, p. 45, pl. 17, figs. 1-3); the original lectotype is lost. **d-f:** GZG 499-58, x1; neotype, correspond to the specimens, illustrated as *Odontoceras koeneni* Steuer (1897, p. 45, pl. 17, figs. 4-5).

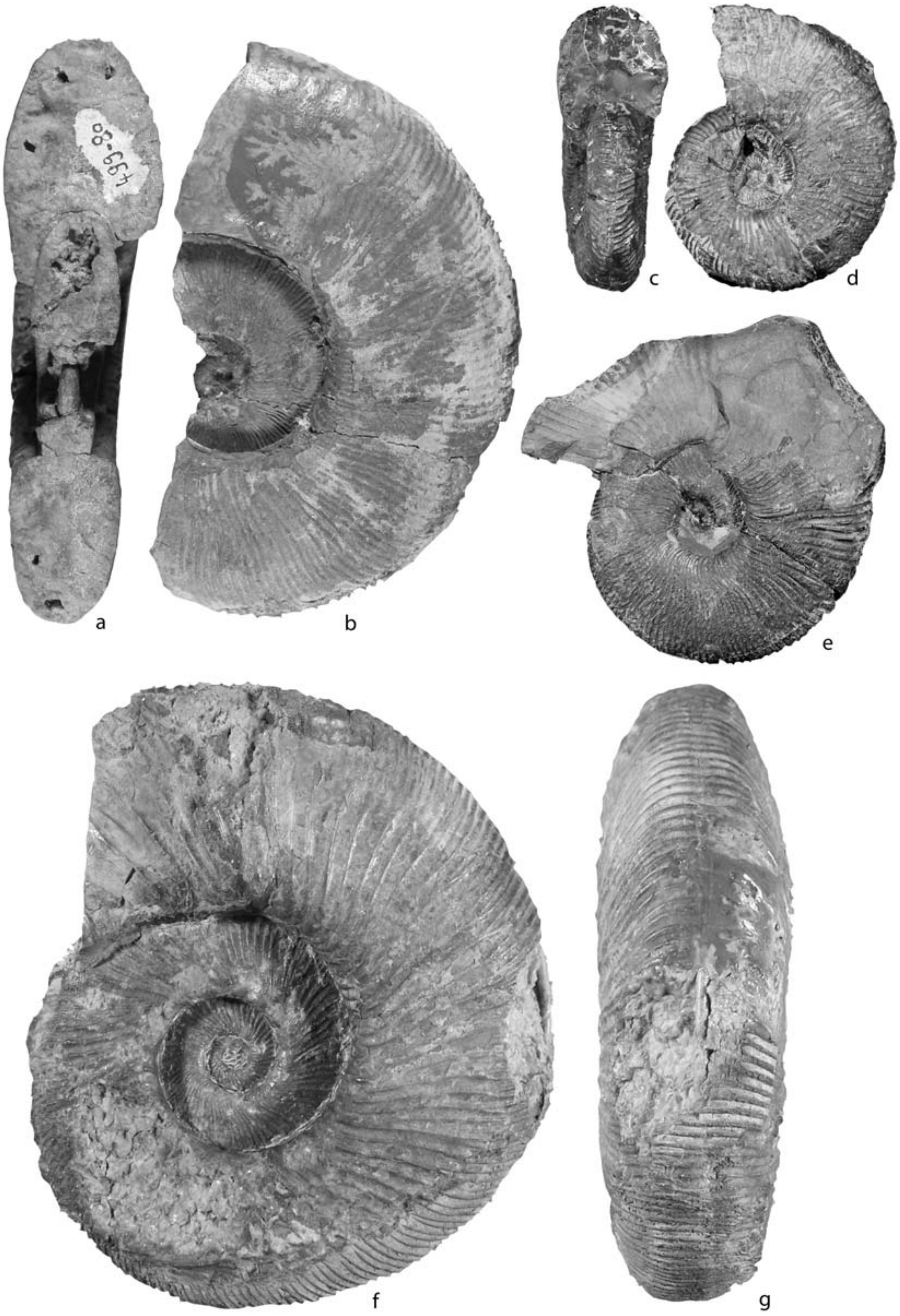


Figure 4.60. a-g: Refigured species included here as junior synonyms of *Substeueroceras koeneni* (Steuer 1897). **a-b:** GZG 499-80, x0.75; "*Odontoceras*" *permulticostatum* Steuer (1897, p. 56, pl. 37, figs. 1-2), **c-d:** STIPB 986, x1; "*Steueroceras*" *rotundatum* Gerth (1925, p. 87, pl. 5, fig. 6). **e:** STIPB 958, x1; "*Steueroceras Steueri*" Gerth (1925, p. 86, pl. 5, fig. 4). f-g: GZG 499-65, x0.75; "*Odontoceras*" *fasciatum* Steuer (1897, p. 46, pl. 32, fig. 1-3).

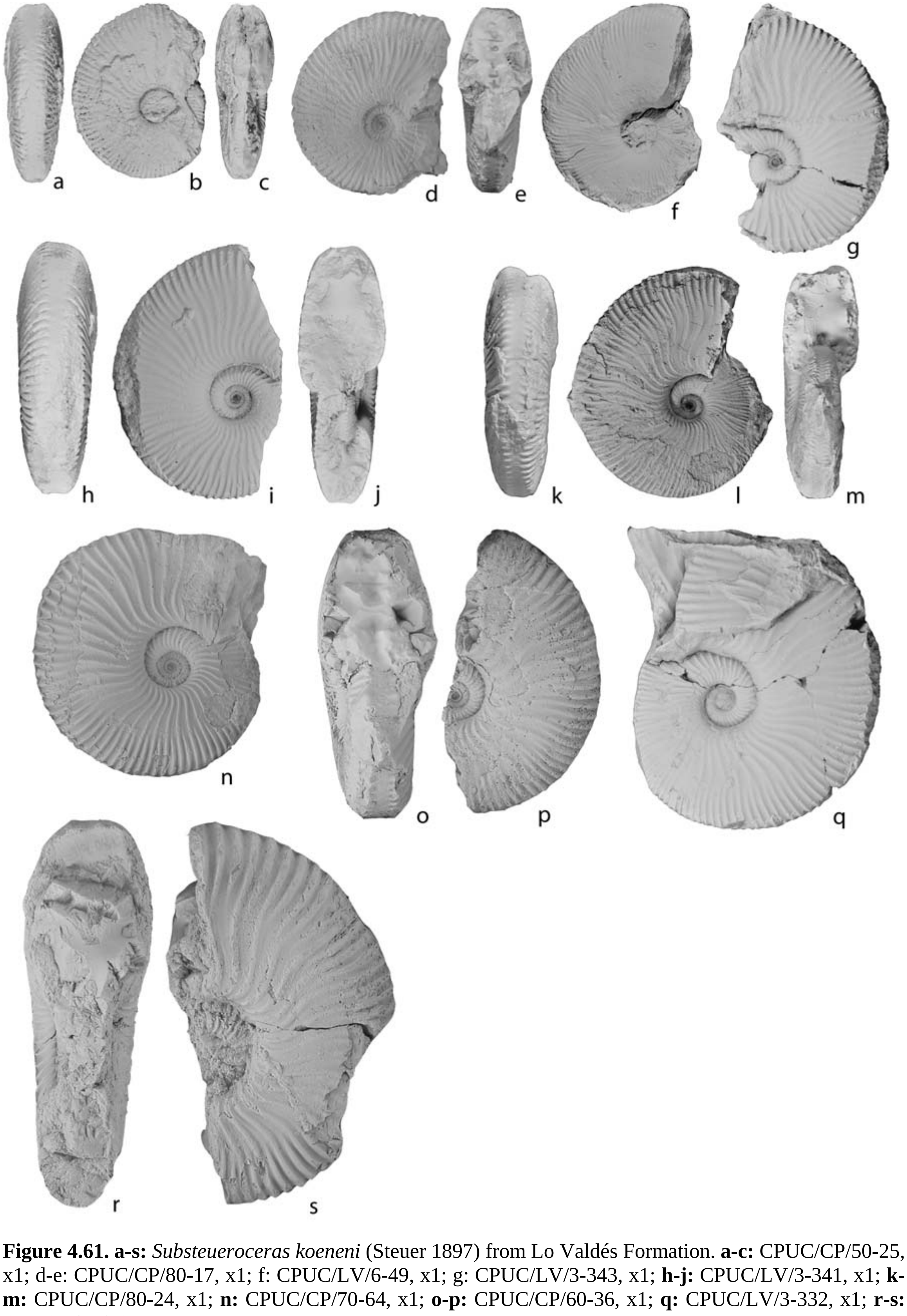


Figure 4.61. a-s: *Substeueroceras koeneni* (Steuer 1897) from Lo Valdés Formation. **a-c:** CPUC/CP/50-25, x1; d-e: CPUC/CP/80-17, x1; f: CPUC/LV/6-49, x1; g: CPUC/LV/3-343, x1; **h-j:** CPUC/LV/3-341, x1; **k-m:** CPUC/CP/80-24, x1; **n:** CPUC/CP/70-64, x1; **o-p:** CPUC/CP/60-36, x1; **q:** CPUC/LV/3-332, x1; **r-s:** CPUC/40-70-37, x1.

Substeueroceras striolatissimum (Steuer 1897)

Figure 4.63, 4.64

non1897 *Reineckeia transitoria* Oppel. Steuer, p. 32, pl. 15, figs. 6-7 (=*Berriasella fraudans*?).

non1897 *Reineckeia mangaensis* n. sp. Steuer, p. 33, pl. 13, figs. 7-9 (= *Aulacosphinctes proximus*).

1897 *Reineckeia striolatissima* n. sp. Steuer, p. 36, pl. 14, figs. 5-7.

1897 *Reineckeia striolata* n. sp.Steuer, p. 36, pl. 14, figs. 8-10.

? 1897 *Perisphinctes densistriatus* n. sp. Steuer, p. 62, pl. 15, figs. 8-10.

1907 *Perisphinctes* cf. *striolatus* (Steuer). Haupt, p. 194.

1921 *Steueroceras striolatissimum* (Steuer). Gerth, p. 147. (= Steuer 1897)

non1921 *Reineckeia transitoria* Oppel. Steuer, p. 59, pl. 15, figs. 6-7 (=*Berriasella fraudans*?) (= Steuer 1897).

non1921 *Reineckeia mangaensis* n. sp. Steuer, p. 60, pl. 13, figs. 7-8 (= *Aulacosphinctes proximus*) (= Steuer 1897).

? 1921 *Perisphinctes densistriatus* n. sp. Steuer, p.91, pl. 15, figs. 8-10 (= Steuer 1897).

1921 *Reineckeia striolatissima* n. sp. Steuer, p. 63, pl. 14, figs. 5-7 (= Steuer 1897).

1921 *Reineckeia striolata* n. sp. Steuer, p. 63, pl. 14, figs. 8-10 (= Steuer 1897).

1925 *Steueroceras striolatissimum* (Steuer). Gerth, p. 85, text-fig. 6.

1928 *Paraulacosphinctes striolatus* (Steuer). Krantz, p. 44.

1931 *Steueroceras striolatissimum* (Steuer). Windhausen, pl. 30, fig. 1 (= Steuer 1897).

non1945 *Aulacosphinctes mangaensis* (Steuer). A. Leanza, p. 21, pl. 3, figs. 1-2 (= *Aulacosphinctes proximus*).

1945 *Pectinatites* (?) *striolatus* (Steuer). A. Leanza, p. 24, pl. 2, figs. 5-8.

1945 *Substeueroceras striolatissimum* (Steuer). A. Leanza, p. 30, pl. 2, figs. 2, 7, 9, 12-13.

1999 *Paraulacosphinctes*? *striolatissimum* (Steuer). Parent & Capello, p. 349.

? 2003 *Perisphinctes densestriatus* (Steuer). Parent , p. 146, fig. 3.

2003 *Paraulacosphinctes striolatus* (Steuer). Parent, p. 156, figs. 1, 5C-E, 9A-H, 10A-B, 11A-B.

2005 *Substeueroceras*? *striolatissimum* (Steuer). Klein, p. 192.

Type: The lectotype is designated here and corresponds to specimen GFZ 499-45, described as *Reineckeia striolatissima* by Steuer (1897, p. 36, pl. 14, figs. 5-7). Parent (2003, p. 156, fig. 9A-B) also designated a lectotype but specimen GFZ 499-45 corresponds to *Reineckeia striolata* Steuer (1897, p. 36, pl. 14, fig. 8-10) and should not be used here

Material: Thirty-four specimens. CPUC/CP/40-70-22, CPUC/CP/50-11, CPUC/CP/50-21, CPUC/CP/70-45, CPUC/CP/70-80, CPUC/CP/70-60, CPUC/CP/80-3, CPUC/CP/80-6 and CPUC/CP/90-14 are well preserved complete phragmocones.

Description: The coiling is involute with a wide umbilicus. The whorl section is rounded, slightly higher than wide (figure 4.63), with a rounded umbilical border and flanks, and a widely rounded venter. Ribs are fine and dense, slightly flexuous. Dorsolaterally they are rursiradiate and concave, then gently bend to proriradiate and convex on the middle part of the flank and back to concave ventrolaterally. Ribs remain simple up to the ventrolateral part of the flank, where most of them bifurcate and others remain simple. Ribs cross the venter without interruption.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CP/40-70-22	46.3	17.3	19.4	0.89	13.8	0.30
CPUC/CP/50-11	40.7	(17.6)	16.4	1.07	12.5	0.31
CPUC/CP/50-21	37.6	14.5	15.2	0.95	11.8	0.31
CPUC/CP/70-60	56.7	(21.2)	24.1	0.88	17.5	0.31
CPUC/CP/80-6	(80.5)	(32.9)	35.2	(0.93)	22.2	(0.28)
CPUC/CP/90-14	91.8	(32.8)	40.7	0.81	25.1	0.27

Remarks: *Substeueroceras striolatissimum* is characterized by fine and dense ribs that are divided ventrolaterally and cross the venter without interruption. These morphological characteristics correspond to the genus *Substeueroceras*. Alternatively Parent (2003) assigned the taxon to *Paraulacosphinctes*, based on the fine ribs and characteristics of the body chamber.

Steuer (1897-1921) pointed out that *R. striolata* and *R. striolatissima* are closely related species, with *R. striolata* differentiated only by slightly stronger ribs; we revised the Steuer collection at GZG and consider the two taxa to be conspecific. The differences in rib strength result from a better preservation of the type material of *R. striolata.*

Perisphinctes densestriatus Steuer (1897-1921) is based on a single adult specimen (figure 4.63). Although ornamentation is similar to *S. striolatissimum*, this taxon differs by a whorl section which is slightly wider than high.

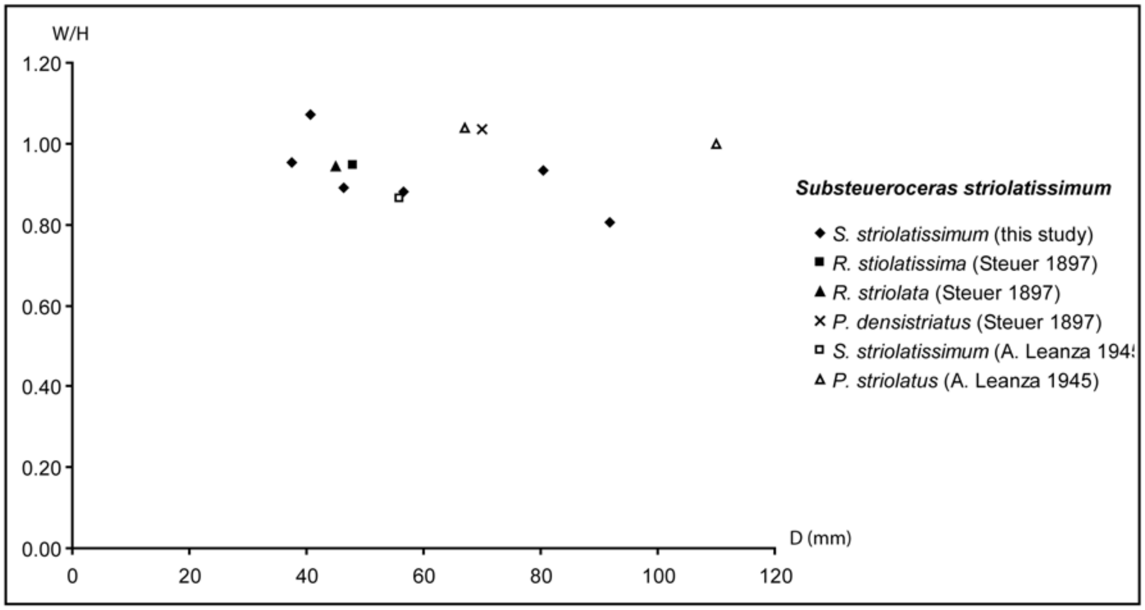


Figure 4.63. Relationship between W/H and D in *Substeueroceras striolatissimum* (Steuer 1897), and the junior synonymies included in this study.

Occurrence: *S. striolatissimum* is here recorded for the first time in Chile, from the Cajón del Morado and Cruz de Piedra sections (figure 5.7 and 5.8). In Argentina *S. striolatissimum* was registered for the Tithonian (Steuer 1897-1921, Gerth 1925, Krantz 1926) and the Upper Tithonian (A. Leanza 1945, Parent 2003).

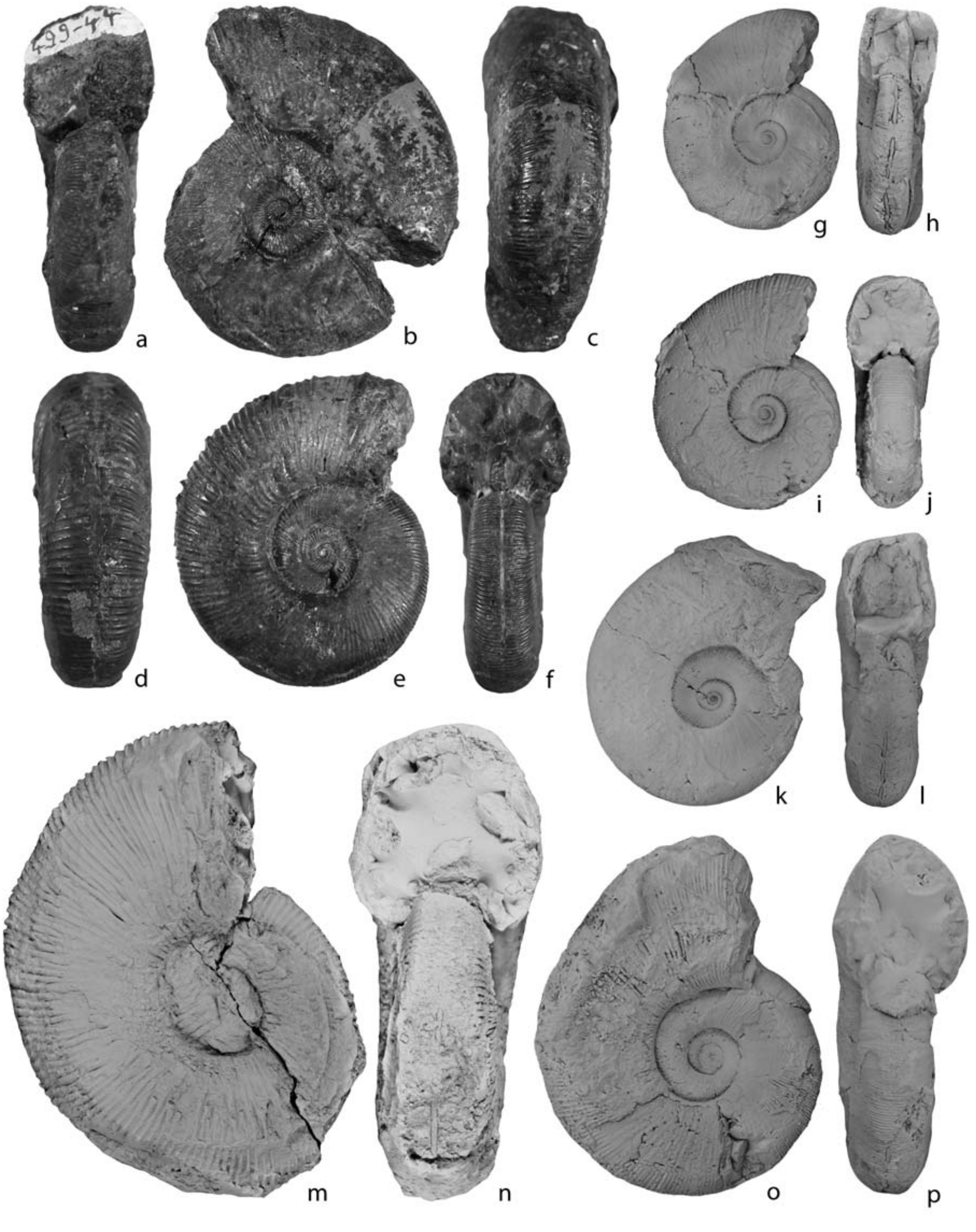


Figure 4.64. a-p: *Substeueroceras striolatissimum* (Steuer 1897). **a-c:** GZG 499-44, x1; "*Reineckeia*" *striolatissima* Steuer (1897, p. 36, pl. 14, figs. 5-6). **d-f:** GZG 499-45, x1; "*Reineckeia*" *striolata* Steuer (1897, p. 36, pl. 14, figs. 8-9). **g-p:** *Substeueroceras striolatissimum* (Steuer 1897) from Lo Valdés Formation. **g-h:** CPUC/CP/50-11, x1; **i-j**: CPUC/CP/50-21, x1; **k-l:** CPUC/CP/40-70-22, x1; **m-n:** CPUC/CP/80-6, x1; **o-p:** CPUC/CP/70-60, x1.

Genus *Malbosiceras* Grigorieva, 1938

Type specie: *Ammonites malbosi* Pictet (1867, p. 77, pl. 14, figs. 1a-1d) by original designation.

Malbosiceras malbosi (Pictet 1867)

Figure 4.65

1867 *Ammonites Malbosi* Pictet, p. 77, figs. 1a-1d, non figs. 2a-2b.
? 1897 *Hoplites malbosiformis* Steuer, p. 59, pl. 4, figs. 1-4.
1900a *Hoplites Malbosi* (Pictet). Burckhardt, p. 48, pl. 28, fig. 1.
1910 *Acanthodiscus malbosiformis* (Steuer). Uhlig, p. 166.
? 1921 *Hoplites malbosiformis* Steuer, p. 88, pl. 4, figs. 1-4 (= Steuer 1897).
1925 *Octagoniceras malbosiforme* (Steuer). Spath, p. 144.
1939 *Berriasella Malbosi* (Pictet). Mazenot, p. 98, pl. 13, figs. 8a.8c. (= Pictet 1867), pl. 14, fig. 1.
1939 *Octagoniceras malbosiforme* (Steuer). Mazenot, p. 198, 199.
1953 *Berriasella Malbosi* (Pictet). Arnould-Saget, p. 52, pl. 5, fig. 7.
1960 *Protacanthodiscus malbosi* (Pictet). Nikolov, p. 174, pl. 14, fig. 4, pl. 15, fig. 1.
1982 *Berriasella* (*Malbosiceras*) *malbosi* (Pictet). Hoedemaeker, p. 32, pl. 2, fig. 4.
1985 *Malbosiceras malbosi* (Pictet). Tavera, p. 265, pl. 38, figs. 2-3, text-fig. 20A.
1992 *Berriasella* (*Malbosiceras*) *malbosi* (Pictet). Howarth, p. 632, pl. 7, figs. 1-4, 7-8.
2005 *Malbosiceras malbosi* (Pictet). Klein, p. 210 (with additional synonymy).
2005 *Neocosmoceras*? *malbosiforme* (Steuer). Klein, p. 220.

Type: The Lectotype was designated and refigured by Mazenot (1939, p. 98, pl. 13, fig. 8). It corresponds to *Ammonites Malbosi* Pictet (1867, pl. 14, fig. 1).

Material: Two specimens. CPUC/LV/5-48 is an incomplete deformed phragmocone with well preserved sculpture. CPUC/LV/5-71 is a fragment of a phragmocone.

Description: Moderately evolute and compressed. The whorl section is higher than wide. Both coarse and fine ribs are present. Each coarse rib is paralleled by intercalated 3 to 5 finer ribs. All ribs are slightly prorsiradiate and concave. Two elongated lines of tubercles are present on the coarse ribs, on the umbilical shoulder and at mid-flank. Approximately every second of the coarse ribs is bifurcated at the mid-flank tubercles. In specimen CPUC/LV/5-71 isolated tubercles are also present on ribs on the venter.

Figure 4.65. a-b: *Malbosiceras malbosi* (Pictet 1867) from Lo Valdés Formation. **a-b:** CPUC/LV/5-48, x1.

Remarks: The two specimens described here show a regular preservation. Differences exist with the lectotype of *Malbosiceras malbosi*, such as a higher whorl section and a narrower umbilicus. However, Mazenot (1939) described and illustrated the considerable variability of *M. malbosi*, regarding shell parameters and the density of ribs and tubercles. For South America, the taxon closest to *M. malbosi* is "*Hoplites*" *malbosiforme*, described by Steuer (1897-1921). According to this author, the Argentinian species differs by coarser, ribs, but this is here considered within the variability of *M. malbosi*.

Occurrence: *Malbosiceras malbosi* is described for first time in central Chile. In the Lo Valdés Formation the taxon is present in the upper part of the Siltstone member at Lo Valdés (figure 5.6). Previously Biro (1964) recorded “*Hoplites*” *malbosiformis* form this unit and locality. Burckhardt (1900a) documented *M. malbosi* for South Chile. In central Argentina, Steuer (1897-1921) described “*Hoplites*” *malbosiformis* for the Upper Tithonian. Elsewhere, *Malbosiceras malbosi* is known from the Upper Berriasian of South-east France (Mazenot 1939), Spain (Hoedemaeker 1982 and Tavera 1985), Tunisia (Arnould-Saget 1953), Bulgaria (Nikilov 1982), Iraq (Howarth 1992) Crimea (Kvantaliani 1999) and the Causasus (Khimchiashvili 1989, 1990).

Genus *Chigaroceras* Howarth, 1992

Type specie: Specimen BMNH C.86930, *Chigaroceras banikense* Howarth (1992, p. 643, pl. 10, figs. 1-2) by original designation.

Chigaroceras bardensis (Krantz 1928)

Figue 4.66, 4.67

1926	*Berriasella bardensis* Krantz, p. 438, pl. 15, figs. 1-2.
1926	*Berriasella Gerthi* Krantz, p. 439.
1928	*Berriasella bardensis* n. sp. Krantz, p. 21, pl. 1, figs. 7a-7b (= Krantz 1926).
1928	*Berriasella Gerthi* n. sp. Krantz, p. 22, pl. 1, figs. 8a-8b.
1945	*Berriasella bardensis* Krantz. A. Leanza, p. 38, pl. 2, figs. 3-4, text-fig. 4.
1981b	*Berriasella bardensis* Krantz. H. Leanza, pl. 3, figs. 7-8 (= A. Leanza 1945).
1992	*Chigaroceras wetzeli* n. sp. Howarth, p. 643, pl. 10, figs. 4-5, pl. 11, figs. 1, 3-5.
1996a	*Chigaroceras gerthi* (Krantz). H. Leanza, p. 215.
1996b	*Chigaroceras gerthi* (Krantz). H. Leanza, p. 451, figs. 1a-1b (= Krantz, 1928).
1996b	*Berriasella bardensis* Krantz. H. Leanza, p. 453.
2000	*Chigaroceras* cf. *wetzeli* Howarth. Kalacheva & Sey, p. 93, pl. 8, figs. 3-4.
2005	*Delphinella*? *bardensis* (Krantz). Klein, p. 184.
2005	*Chigaroceras*? *gerthi* (Krantz). Klein, p. 216.

2005 *Chigaroceras wetzeli* Howarth. Klein, p. 216.
2011b *Blanfordiceras bardense* (Krantz). Parent et al., p. 58, fig. 25B.
2011b *Chigaroceras gerthi* (Krantz). Parent et al., p. 62, figs. 25C, 26A.

Type: The lectotype is designated by Parent et al. (2011b p. 58, fig. 25B) and corresponds to specimen STIPB 615 described as *Berriasella bardensis* by Krantz (1926 p. 438, pl. 15, figs. 1-2).

Material: Six specimens. CPUC/CM/16-111, CPUC/CM/17-20, CPUC/CM/17-31, CPUC/CM/17-48, CPUC/CM/17-49 and CPUC/CM/17-79 are fragmentary phragmocones.

Description: Involute, compressed, with a narrow umbilicus. The whorl section is discoidal, higher than wide. The umbilical border is rounded; the flanks are almost flat and converge towards the narrowly rounded to flat venter. The whorl section is widest on the umbilical shoulder. The sculpture consists of moderately strong ribs, which are gently prorsiradiate and slightly sinuous with elongated tubercles on the umbilical border; they increase in strength towards the middle part of the flank where they are divided in two or three secondary ribs, with an elongated tubercle at the point of division. Simple primary ribs are intercalated between secondaries. All ribs cross the venter without interruption.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/17-20		34.9	38.0	0.92		
CPUC/CM/17-48		52.5	59.3	0.89		
CPUC/CM/17-49		45.9	52.7	0.87		

Remarks: "*Berriasella*" *bardensis* described by Krantz (1926-1928) is here assigned to *Chigaroceras* (Howarth 1992, p. 641; Wright et al. 1996, p. 52), as assumed earlier by Leanza (1996b). The originals of *Berriasella bardensis* Krantz (1926-1928) and the single specimen described as *Berriasella gerthi* by Krantz (1926-1928) were revised for this review. Krantz (1928) indicated that the only difference between the two taxa is a subrounded to flat venter in *Berriasella bardensis* and a rounded to subrounded venter in *B. gerthi*. The two are here considered conspecific.

Chigaroceras bardensis is thus characterized by involute coiling, a narrow umbilicus, parallel flanks, a flat to subrounded venter, moderately strong ribs divided into two or three secondaries,

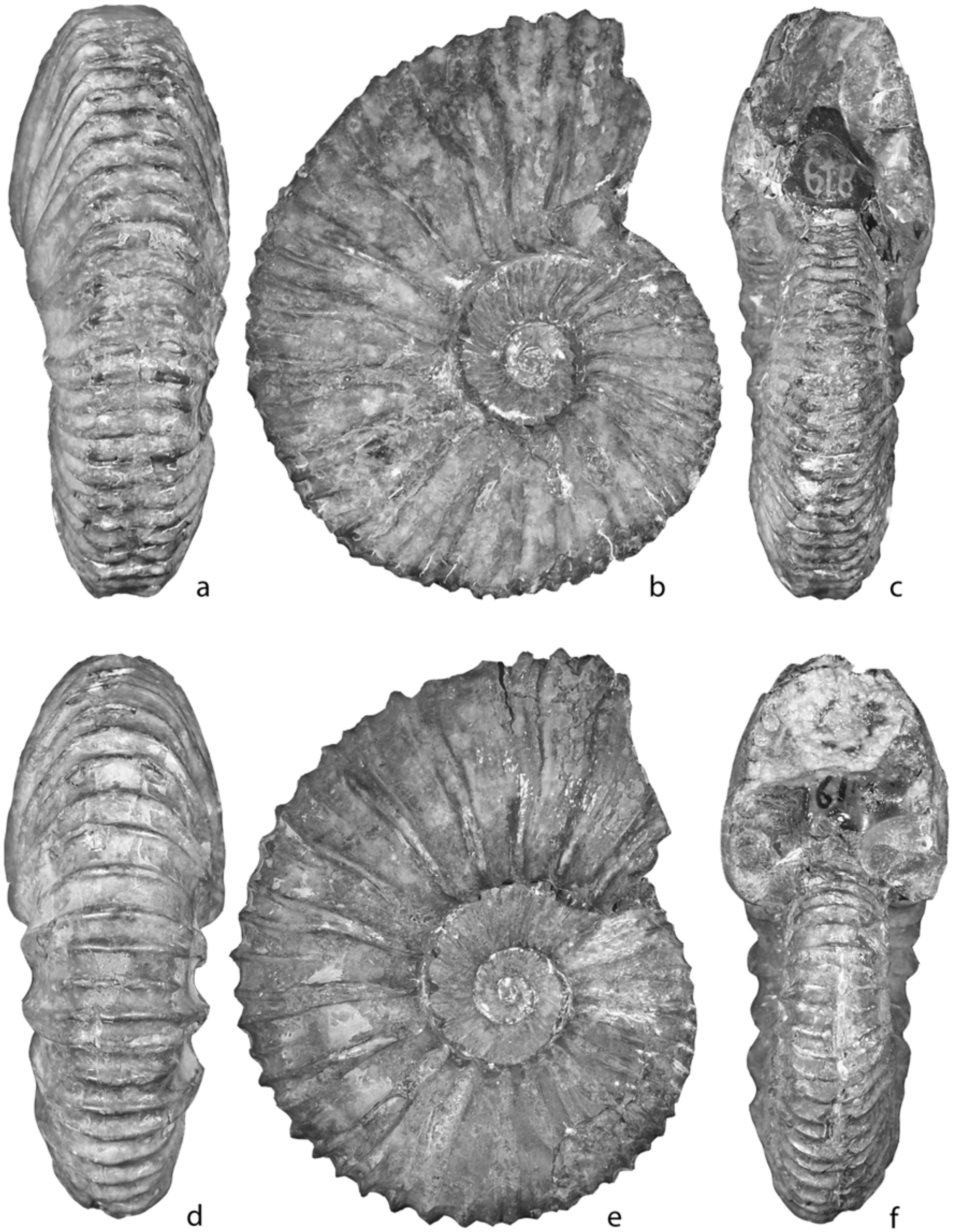


Figure 4.66. a-f: *Chigaroceras bardensis* (Krantz 1928). **a-c:** STIPB 618, x1; Lectotype of *Chigaroceras bardensis* Krantz (1928, p. 21, pl. 1, figs. 7a-7b). **d-f:** STIPB 617, x1; *Chigaroceras* "*gerthi*" Krantz (1928, p. 22, pl. 1, figs. 8a-8b).

Figure 4.67. a-f: *Chigaroceras bardensis* (Krantz 1928). **a-c:** CPUC/CM/17-49, x0.75. **d:** CPUC/CM/17-48, x0.75. **e:** CPUC/CM/17-79, x0.75.

with elongated tubercles at the umbilical shoulder and at the point of division, and by ribs which cross the venter without interruption.

Chigaroceras wetzeli Howarth (1992) from Iraq is a close relative of *Chigaroceras bardensis* and was established only based on a slightly wider umbilicus. We consider this difference as undiagnostic and suggest the two are conspecific.

Occurrence: *Chigaroceras bardensis* is recorded for the first time in Chile. The taxon is present at Cajón del Morado, in the uppermost part of the Sandstone and lower part of the Siltstone members (figure 5.7). In Argentina the taxon is registered for the middle part of the Upper Tithonian (A. Leanza 1945, H. Leanza 1981b, 1996b, Parent 2011b). In Iraq, it is recorded for the Uppermost Tithonian Durangites Zone (Howarth 1992) and in the Caucasus for the Berriasian (Kalacheva & Sey 2000).

Genus *Neocosmoceras* Blanchet, 1922

Type species: *Hoplites sayni* Simionescu (1899, p. 480, pl. 1, fig. 7) by subsequente designation of Roman (1938, p. 332).

Necosmoceras sayni (Simionescu 1899)

Figure 4.68, 4.69

1899 *Hoplites Sayni* Simionescu, p. 480, pl. 1, fig. 7-8.
1921 *Acanthodiscus Wichmanni* Gerth, p. 140 (*nomen nudum*).
1925 *Acanthodiscus Wichmanni* Gerth. Gerth, p. 101, pl. 3, fig. 6.
1938 *Neocosmoceras sayni* (Simionescu). Roman, p. 332, text-fig. 42 (=Simionescu 1899).
1939 *Neocosmoceras sayni* (Simionescu). Mazenot, p. 182, pl. 28, figs. 6, 7 (= Simionescu), fig. 9, pl. 29, fig. 1a (= Simionescu), fig. 1b.
1953 *Neocosmoceras sayni* (Simionescu). Arnould-Saget, p. 63, pl. 6, figs. 3-4, 6-7.
1960 *Neocosmoceras sayni* (Simionescu). Nikolov, p. 175, pl. 17, fig. 2.
1971 *Neocosmoceras* sp. Thomson, p. 158, fig. 3c.
1974 *Neocosmoceras* aff. *sayni* (Simionescu). Thomson, p. 29, fig. 4n (= Thomson, 1971).

1985 *Neocosmoceras sayni* (Simionescu). Tavera, p. 280, pl. 41, fig. 3, text-fig. 21C.
? 1988 *Acanthodiscus wichmanni* Gerth. Riccardi, pl. 6, figs. 4-5.
1990 *Neocosmoceras* sp. cf. *sayni* (Simionescu). Aguirre-Urreta & Charrier, p. 269, pl. 1-2.
1993 *Neocosmoceras* sp. cf. *sayni* (Simionescu). Aguirre-Urreta, p. 67, pl. 2, fig. 1 (= Aguirre-Urreta & Charrier 1990).
2005 *Neocosmoceras sayni* (Simionescu). Klein, p. 222 (with additional synonymy).
2005 *Neocosmoceras wichmanni* (Gerth). Klein, p. 223 (with additional synonymy).

Type: As genus.

Material: Six specimens. CPUC/CM/18-70 is a complete phragmocone; CPUC/CM/18-35, CPUC/CM/18-111, CPUC/CM/18-112, CPUC/CM/18-119 and CPUC/CM/18-120 are fragmentary phragmocones.

Description: Evolute, with a wide umbilicus. The whorl section is subrounded, slightly higher than wide. The umbilical border is rounded, flanks are slightly convex and the venter is flat to sub-rounded. Sculpture consists of coarse primary and fine secondary ribs, which are gently prorsiradiate. They initiate in elongated tubercles on the umbilical border. At mid-flank a second row of elongated tubercles is present. Here ribs are bifurcated. Adjacent to the venter, a third row of tubercles is present, at which ribs coarsen. The primary ribs are weak on the venter. The secondary ribs are parallel to the secondaries and are finer than the primary ribs; one to three secondary ribs are intercalated between the primaries and cross the venter without interruption, even though weakening is observed.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/18-70	(51.7)	(13.7)	(14.3)	(0.96)	(21.8)	(0.42)
CPUC/CM/18-112	(153.0)	(45.1)	(48.2)	(0.94)	(67.5)	(0.44)
CPUC/CM/18-119	(237.0)	(59.0)	(78.0)	(0.76)	(92.2)	(0.39)
CPUC/CM/18-120	(255.0)	(64.0)	(85.0)	(0.75)	(120.0)	(0.47)

Remarks: The specimens described here are large adults. Mazenot (1939) described *Neocosmoceras sayni* as morphologically variable. *Neocosmoceras wichmanni* was established by Gerth (1921-1925) based on slightly less evolute coiling, but these differences form part of the wide morphological range of *N. sayni* and the two are here considered to be conspecific.

"*Acanthodiscus*" *wichmanni* was established by Riccardi (1988) but is based only on an illustration, without description. Apparently the coarse ribs are closer and the venter and whorl section wider than in *N. sayni*.

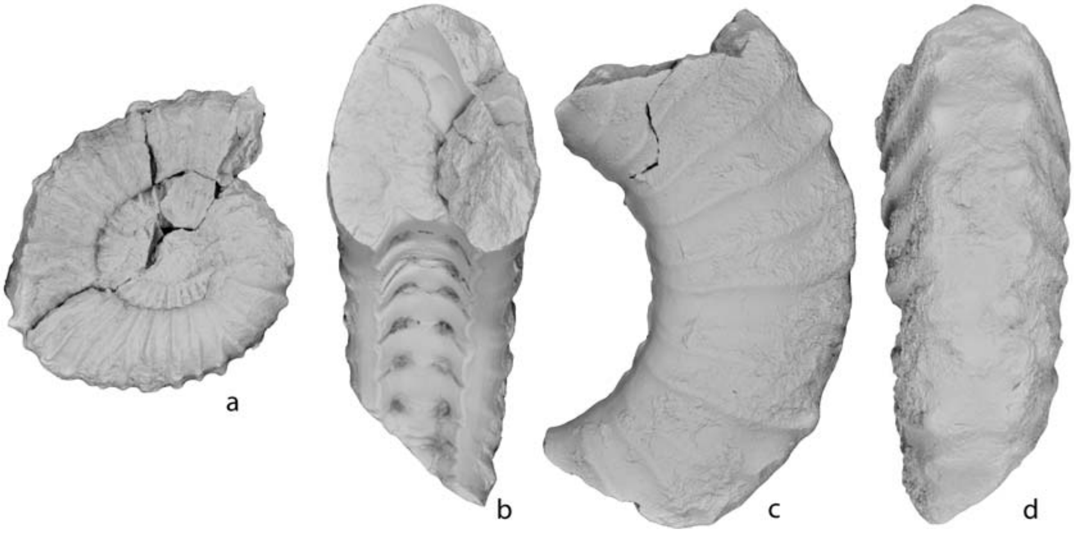


Figure 4.68. a-d: *Necosmoceras sayni* (Simionescu 1899). **a:** CPUC/CM/18-70, x1. **b-d:** CPUC/CM/18-35, x1.

Occurrence: *Neocosmoceras sayni* was previously documented in Chile by Aguirre-Urreta & Charrier (1990) as *Neocosmoceras* sp. cf. *sayni* in the Berriasian of Cruz de Piedra. The taxon is present in the upper part of the Siltstone member at Cajón del Morado (figure 5.7). In Argentina. "*N. wichmanni*" was registered for the lower Valanginian (Leanza 1945) and lower ?Hauterivian (Riccardi 1988). *Neocosmoceras sayni* is recorded for the Berriasian of South-east France (Mazenot 1939, Thomel 1966, Hégarat, 1973), Spain (1985), Hungary (Fülop 1964), Bulgary (Nikolov 1960, 1969), Tunisia (Arnould-Saget 1953), Algeria (Benest et al. 1977), Caucaus (Khimashvili 1976), India (Spath 1939), and Antarctica (Thomson 1971, 1974).

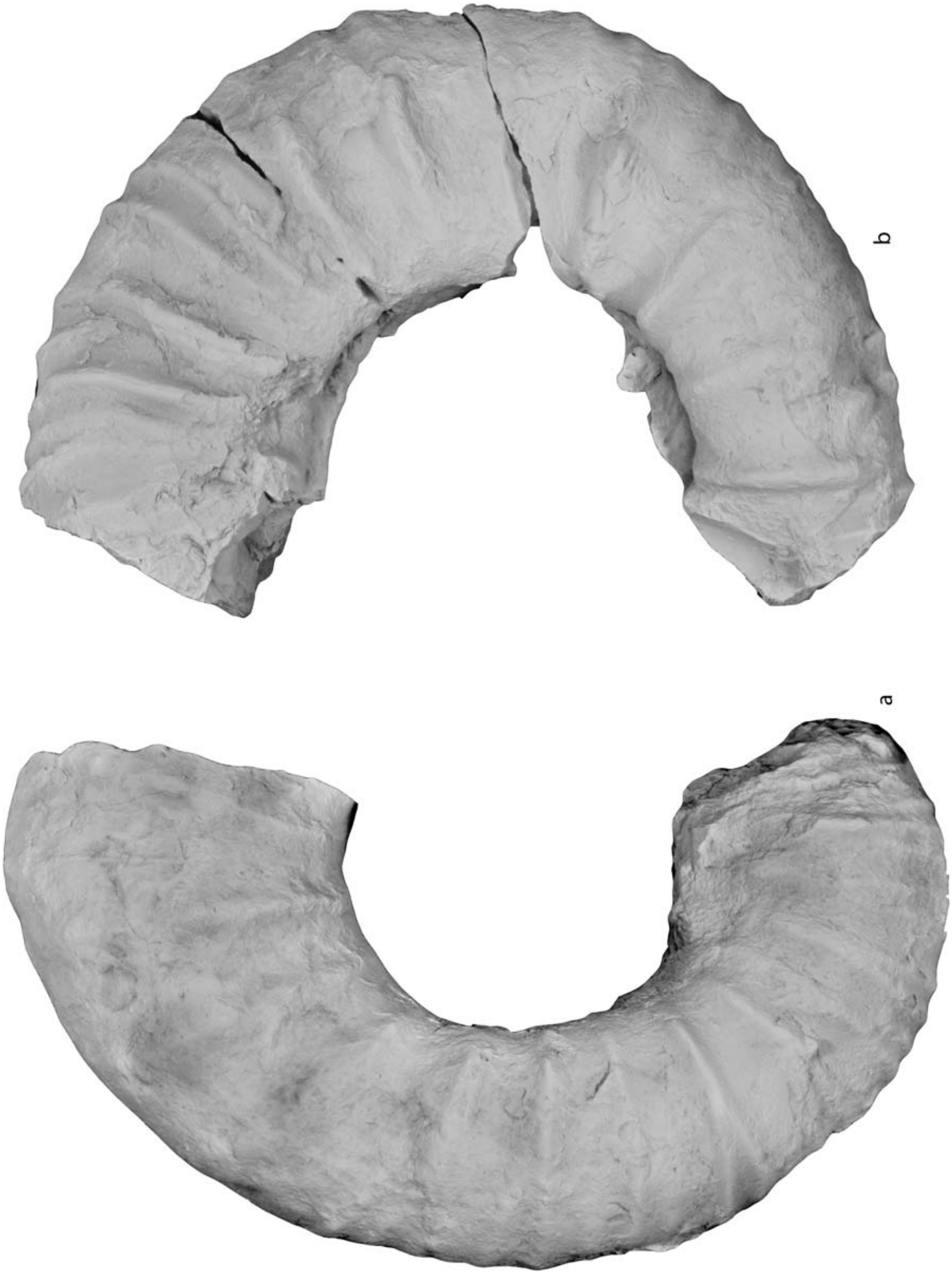


Figure 4.69. a-b: *Necosmoceras sayni* (Simionescu 1899). **a:** CPUC/CM/18-119, x0.70. **b:** CPUC/CM/18-112, x1.

Genus *Lytohoplites* Spath, 1925

Type specie: *Hoplites burckhardti* Mayer-Eymar in Burckhardt (1900b, p. 17, pl. 26, figs. 1-2) by original designation.

Lytohoplites paredesi n. sp.

Figue 4.70, 4.71

Types: Holotype is CPUC/LV/3-137, a complete phragmocone. Paratypes are CPUC/LV/3-42, CPUC/LV/3-136, CPUC/LV/3-135, CPUC/LV/3-61, CPUC/LV/3-62, CPUC/LV/3-77, CPUC/LV/3-78, CPUC/LV/3-247, CPUC/LV/3-371, CPUC/LV/3-372, CPUC/LV/3-373, CPUC/LV/3-374, CPUC/CM/16-122 and CPUC/CM/16-123 which correspond to fragmentary phragmocones.

Etymology: Species dedicated to Luz Lily Paredes in recognition of her assistance and importance to the authors.

Diagnosis: Evolute, with a narrow umbilicus in juvenile stages and a wide umbilicus in adults. The whorl section is discoidal, higher than wide. Ribs are fine, dense and prorsiradiate. Two rows of tubercles are present on the ventral border in juveniles and fine spines in adult specimens.

Description: In juvenile stages (D< 40 mm) coiling is evolute and the umbilicus narrow. The whorl section is discoidal, higher than wide, with a steep umbilical shoulder, slightly convex flanks and a flat venter (figure 4.70). Fine and dense unbranched ribs are slightly convex and prorsiradiate. They terminate on the ventral border; the venter is smooth and shows a furrow. Every second to third rib terminates in two rows of tubercles on the ventral border. Adult stages (D> 40 mm) are evolute with a wide umbilicus. The whorl section is discoidal, higher than wide; the umbilical border is rounded, flanks are convex and the venter flat (figure 4.70). Ribs are fine and dense, but slightly more spaced than in juvenile stages. They are prorsiradiate and gently sinuous, with a slight convexity on the venter. On the ventral border, each rib presents a fine spine. All ribs cross the venter without interruption.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/3-137	37.2		14.2		13.0	0.35
CPUC/LV/3-42		(19.2)	24.5	0.78		

Remarks: *Lytohoplites* n. sp. 2 differs from *Lytohoplites* n. sp. 1 by a subquadrate whorl section the presence of finer secondary ribs and stronger primary ribs. *Lytohoplites besairei* Collignon (1960) differs by a more inflated whorl section and stronger, wider-spaced ribs which are grouped in two. *Lytohoplites hourcqi* (Besairie 1936) presents a rounded whorl section and stronger and wider spaced ribs.

Occurrence: *Lytohoplites paredesi* n. sp. is present in the Sandstone member at Cajón del Morado and Lo Valdés (figure 5.6 and 5.7).

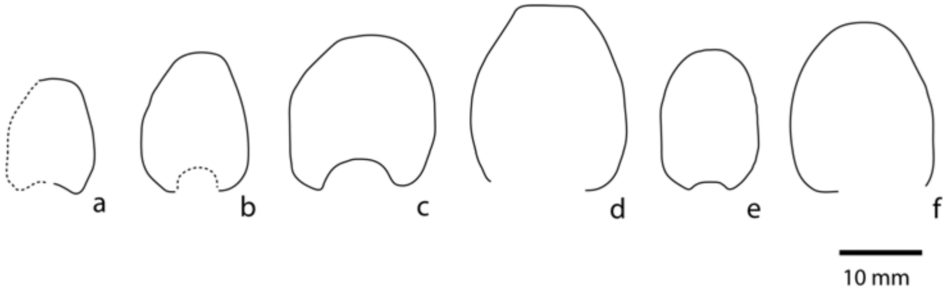


Figure 4.70. Whorl section of *Lytohoplites* from Lo Valdés Formation. **a:** *Lytohoplites paredesi* n. sp., CPUC/LV/3-137 (Holotype). **b:** *Lytohoplites paredesi* n. sp., CPUC/LV/3-62. **c:** *Lytohoplites zambranoi* n. sp., CPUC/LV/III/48 (Holotype). **d:** *Lytohoplites zambranoi* n. sp., CPUC/LV/3-131. **e:** *Lytohoplites varelae* n. sp., CPUC/CM/16-125 (Holotype). **f:** *Lytohoplites rauloi* n. sp., CPUC/CM/16-93 (Holotype).

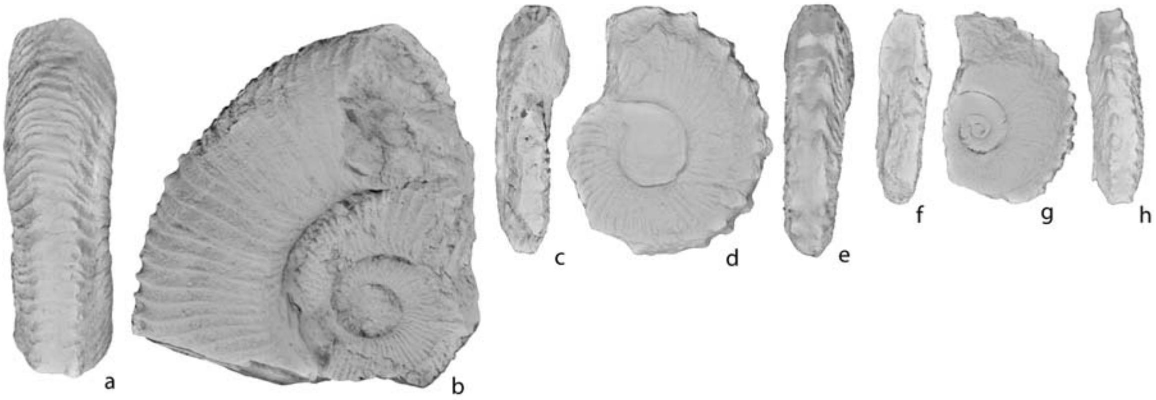


Figure 4.71. a-h: *Lytohoplites paredesi* n. sp. from Lo Valdés Formation. **a-b:** CPUC/LV/3-42, x1; **c-e:** CPUC/LV/3-136, x1; **f-h:** CPUC/LV/3-137 (Holotype), x1.

Lytohoplites zambranoi n. sp.

Figue 4.70, 4.72

1964 *Lytohoplites burckhardti* (Mayer-Eymar). Biro, p. 102, pl. 23, figs. 3a-3b.

Types: Holotype is CPUC/LV/III-48, a fragmentary phragmocone. Paratypes are CPUC/LV/3-145, a fragmentary phragmocone and body chamber, as well as CPUC/LV/3-131, CPUC/LV/3-150, CPUC/LV/3-272, CPUC/LV/3-99, CPUC/LV/3-100, CPUC/LV/3-146, CPUC/LV/3-147, CPUC/LV/3-148, CPUC/LV/3-149 and CPUC/LV/3-201 which correspond to fragmentary phragmocones.

Etymology: This species is dedicated to Patricio Zambrano, in acknowledgement for his assitance in the field works for this research.

Diagnosis: Ribs are sinuous, spaced on the phragmocone and finer and denser on the body chamber (CPUC/LV/3-145). Occasionally the ribs are divided from the umbilical border to the ventrolateral part. Some ribs show fine protuberances on the ventrolateral part of the flank. In addition, two rows of fine tubercles on each rib are present on both sides of the venter.

Description: Coiling is evolute and the umbilicus wide. The whorl section is discoidal to subrounded (figure 4.70). The umbilical border is rounded, flanks are convex and the venter is subrounded to flat. Sculpture consists in spaced sinuous ribs on the phragmocone, and denser and finer ribs on the body chamber (e.g. CPUC/LV/3-145). Most ribs are simple, but some are bifurcated from the umbilical border to ventrolaterally. On the ventral border, two rows of fine tubercles are present on each rib. On the venter ribs are weakened.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/III-48		16.7	17.2	0.97	18.3	
CPUC/LV/3-145		25.3	29.8	0.85		
CPUC/LV/3-131		18.6	22.5	0.83		

Remarks: Biro (1964) described specimen CPUC/LV/III-48 as *Lytohoplites burckhardti*, but this taxon is characterized by wider-spaced, strong and protuberant primary ribs and intercalated fine lirae. *Lytohoplites rauloi* n. sp. differs from *Lytohoplites zambranoi* n. sp. by finer ribbing, pairs of two ribs grouped on the ventral border, stronger tubercles and a less inflated whorl section. *Lytohoplites hourcqi* (Besairie 1936) differs from our material by a rounded whorl section and stronger and wider spaced ribs. *Lytohoplites besairei* Collignon (1960) differs by a more inflated whorl section and ribs which are stronger, wider spaced and grouped in two.

Occurrence: *Lytohoplites zambranoi* n. sp. is recorded from the Sandstone member at Lo Valdés (figure 5.6).

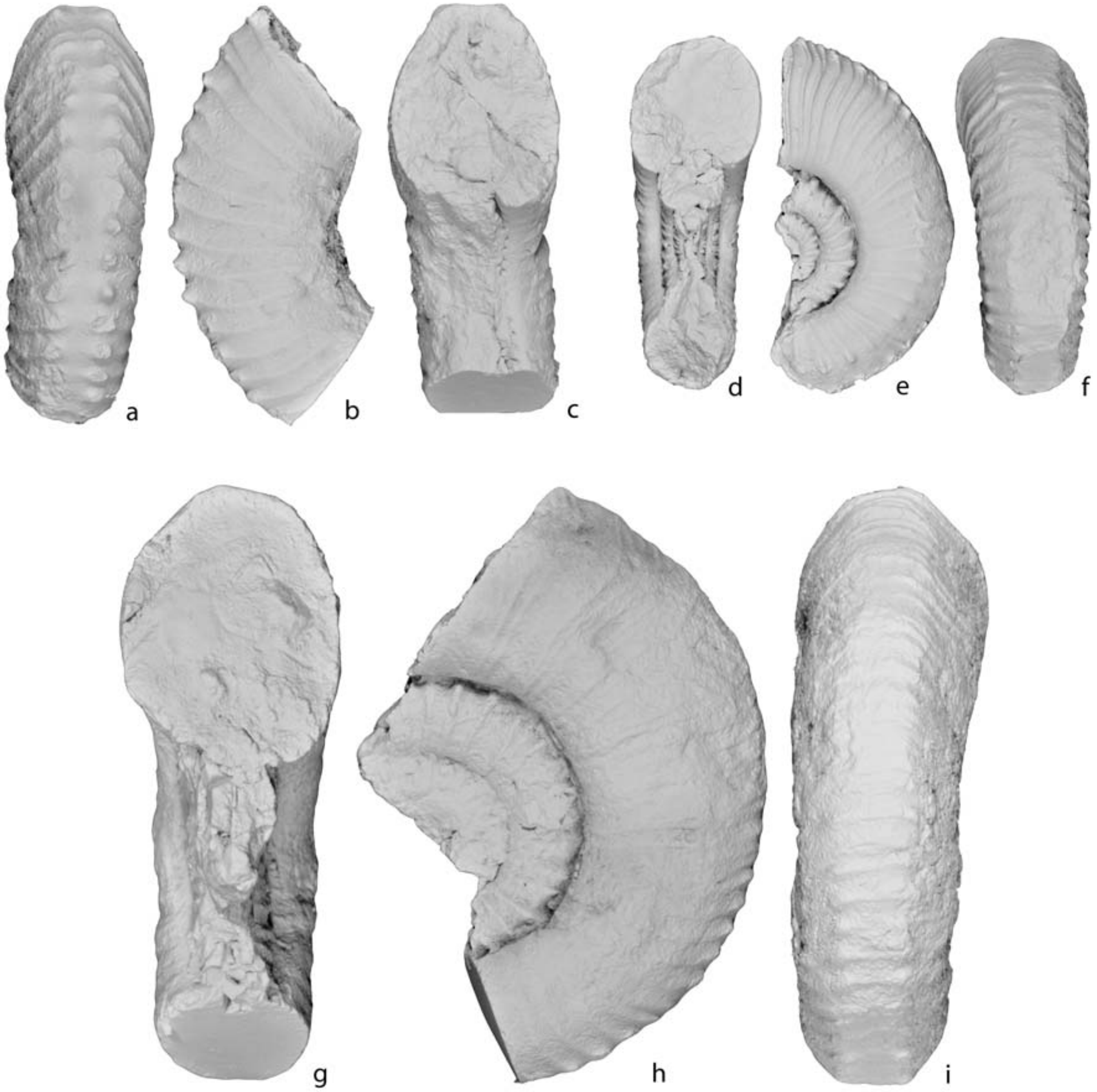


Figure 4.72. a-i: *Lytohoplites zambranoi* n. sp. from Lo Valdés Formation. **a-c:** CPUC/LV/3-131, x1. **d-f:** CPUC/LV/III-48 (Holotype), x1; **g-i:** CPUC/LV/3-145, x1.

Lytohoplites varelae n. sp.

Figue 4.70, 4.73

Types: Holotype is CPUC/CM/16-125, a fragmentary phragmocone. Paratypes are CPUC/CM/16-120, CPUC/CM/16-104, CPUC/CM/16-116, CPUC/CM/16-48, CPUC/CM/14-1, CPUC/CM/14-2, CPUC/CM/14-22, CPUC/CM/15-1, CPUC/LV/3-24, CPUC/LV/3-27 and CPUC/LV/3-264 which correspond to complete and fragmentary phragmocones.

Etymology: This taxon is dedicated to Natalia Varela in acknowledgement of her assistance in the field work.

Diagnosis: Evolute, discoidal, with a whorl section which is higher than wide. Primary ribs are dense and fine. Some are bifurcated ventrolaterally at fine protuberances. An additional row of fine tubercles is present on both sides of the venter. Ribs are denser on the body chamber.

Description: Evolute, with a wide umbilicus. The whorl section is discoidal, higher than wide (figure 4.70). The umbilical border is rounded, flanks are subparallel to slightly convex and the venter is rounded. Ribs are fine and dense, prorsiradiate and gently sinuous. On the body chamber ribs are denser (e.g. CPUC/CM/14-2). Most ribs are simple, but a few are divided ventrolaterally, with a fine protuberance at the point of bifurcation. Ribs cross the venter without interruption. On both sides of the venter rows of fine fine tubercles are present on all ribs.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/16-125	48.6	12.3	15.1		21.1	
CPUC/CM/16-120	(65.5)		(24.6)		24.1	
CPUC/CM/16-104	26.3	11.0	9.5		11.6	

Remarks: *Lytohoplites paredesi* n. sp. differs by stronger ribs, stronger tubercles on the ventral border and a lower whorl section. In *Lytohoplites burckhardti* primary ribs are spaced and strong, but fine secondaries occur between them. *Lytohoplites hourcqi* (Besairie 1936) differs by a rounded whorl section and stronger and spaced ribs. *Lytohoplites besairei* Collignon (1960) differs by a more inflated whorl section. In addition, ribs are stronger, spaced and grouped in two.

Occurrence: *Lytohoplites varelae* n. sp. is present in the Sandstone member at Lo Valdés and Cajón del Morado (figure 5.6 and 5.7).

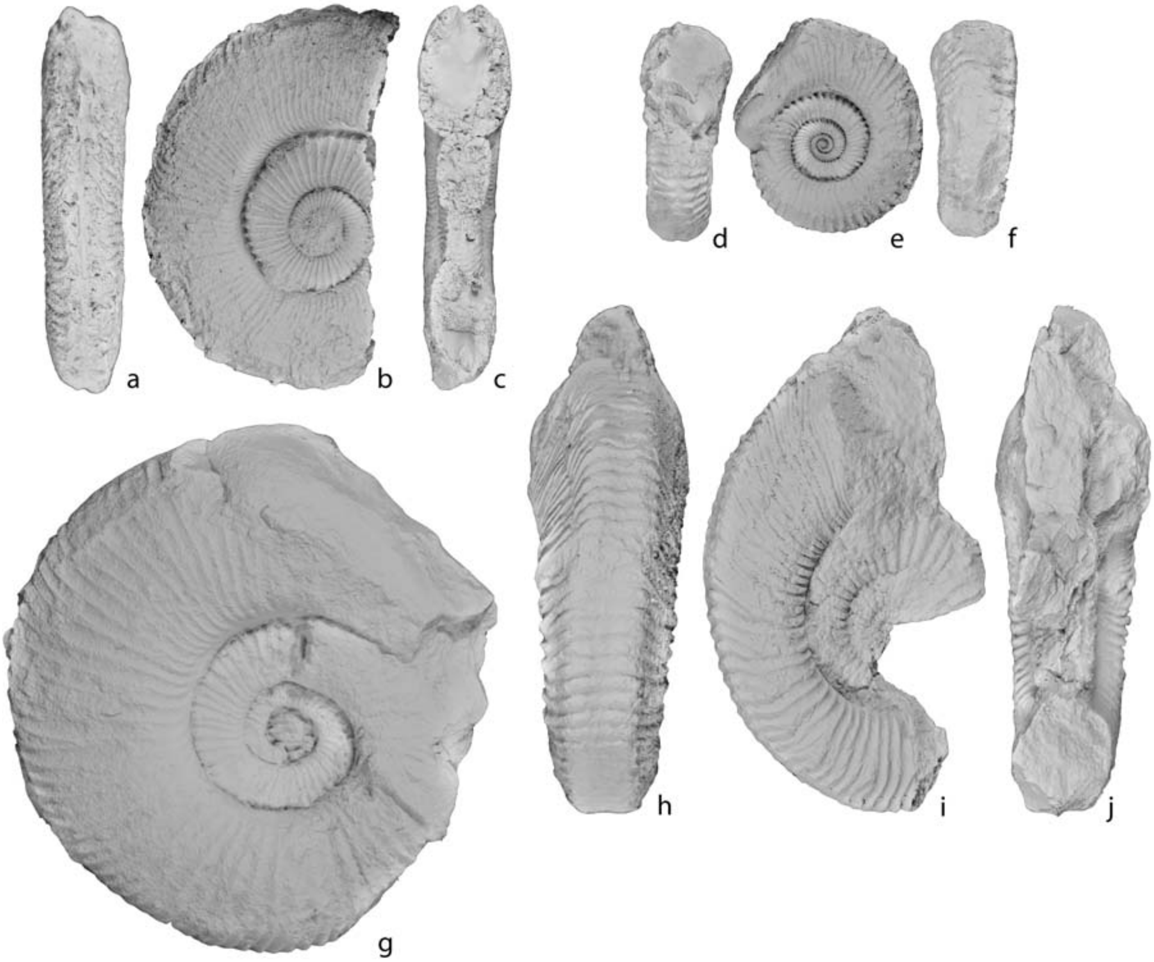


Figure 4.73. a-g: *Lytohoplites varelae* n. sp. from Lo Valdés Formation. **a-c:** CPUC/CM/16-125 (Holotype), x1; **d-f:** CPUC/CM/16-104, x1; **g:** CPUC/CM/16-120, x1; **h-j:** CPUC/CM/14-2, x1.

Lytohoplites rauloi n. sp.

Figue 4.70, 4.74

Types: Holotype is CPUC/CM/16-93, a complete phragmocone. Paratypes are CPUC/CM/16-58, CPUC/CM/16-42, CPUC/CM/16-82, CPUC/CM/16-83, CPUC/CM/16-87 and CPUC/CM/16-89, also corresponding to complete phragmocones; CPUC/CM/16-16-13 is a fragmentary phragmocone. An additional 63 specimens correspond to complete and fragmentary phragmocones.

Etymology: This species is dedicated to Raul Nuñez, in acknowledgement for his long and dedicated work as a technician in geology at the Departamento de Ciencias de la Tierra, Universidad de Concepción, Chile.

Diagnosis: Whorl section higher than wide, flanks slightly convex and venter rounded. Prorsiradiate and convex ribs are grouped in two or three; two rows of ventrolateral tubercles.

Description: Evolute and compressed. The umbilicus is narrow. The whorl section is higher than wide, with a rounded umbilical border, slightly convex flanks and a rounded venter (figure 4.70). The sculpture is composed by fine ribs, grouped in two or three. They initiate on the umbilical border. Rounded tubercles are present on each rib ventrolaterally and close to the venter. Ribs are weakened on the venter.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/16-93	54.7	17.5	21.0	0.83	19.4	0.35
CPUC/CM/16-58	43.8	14.6	16.7	0.87	15.7	0.36
CPUC/CM/16-83	54.5		22.6		18.3	0.34
CPUC/CM/16-42	38.9	10.9	13.3	0.82	16.1	0.41
CPUC/CM/16-89	29.0	11.8	12.8	0.92	10.7	0.37
CPUC/CM/16-87	23.5	8.6	9.8	0.88	8.3	0.35

Remarks: *Lytohoplites rauloi* n. sp. is closely related with *Lytohoplites paredesi* n. sp. , but characterized by wider spaced ribs and rounded ventrolateral tubercles.

Lytohoplites varelae n. sp. differs from *Lytohoplites rauloi* n. sp. by denser and finer ribs, few ribs bifurcated ventrolaterally, and by fine protuberances at the point of rib bifurcation.

Occurrence: *Lytohoplites rauloi* n. sp. is present in the Sandstone member at Cajón del Morado and Lo Valdés (figure 5.6 and 5.7).

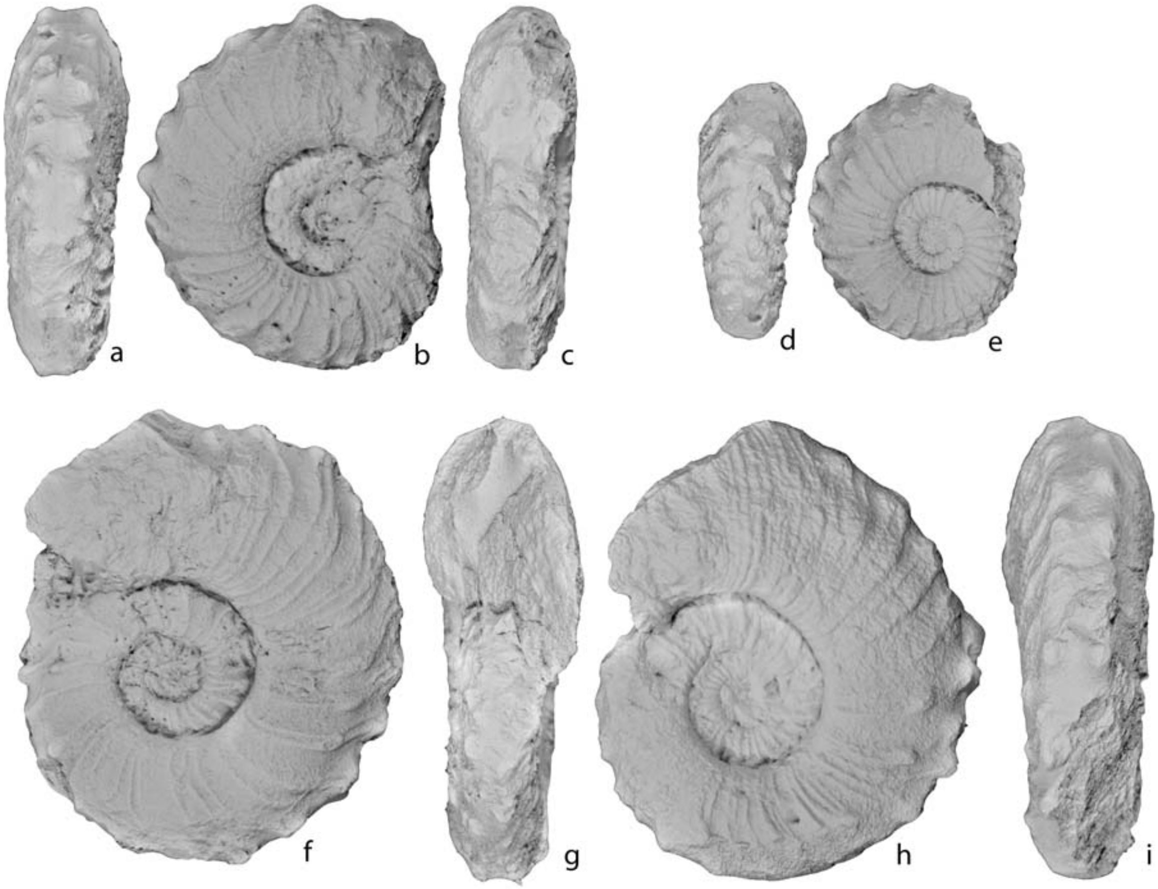


Figure 4.74. a- i: *Lytohoplites rauloi* n. sp. from Lo Valdés Formation. **a-c:** CPUC/CM/16-58, x1; **d-e:** CPUC/CM/16-89, x1; **f:** CPUC/CM/16-83, x1; **g-i:** CPUC/CM/16-93 (Holotype), x1.

Subfamily NEOCOMITINAE Salfeld, 1921

Genus *Argentiniceras* Spath, 1924

Type species: *Reineckeia argentina* described by Steuer (1897) is based on a complete adult specimen, GZG 499-34, which is revised here. This specimen presents important morphological changes from juvenile and adult stages. *Odontoceras malarguense* described by Steuer (1897, p. 55, pl. 20, figs. 1-3) and revised here is considered to present the neotype of *Argentiniceras* (see Spath 1924a, p. 89). However, this taxon is based on specimen GZG 499-72, a juvenile which is here considered to be a junior synonym of *Argentiniceras argentinum*. See below for detailed description and remarks on *Argentiniceras argentinum*. Here we suggest to replace the generotype of *Argentiniceras* and propose *Reineckeia argentina* Steuer (1897, p. 26, pl. 10, figs. 1-2) as a neotype.

Argentiniceras argentinum (Steuer 1897)

Figure 4.75, 4.76

1897 *Reineckeia argentina* n. sp. Steuer, p. 26, pl. 10. figs. 1-2, pl. 12, fig. 8.
1897 *Odontoceras malarguense* n. sp. Steuer, p. 55, pl. 20, figs. 1-3.
1921 *Steueroceras malarguense* (Steuer). Gerth, p. 140.
1921 *Reineckeia argentina* n. sp. Steuer, p. 52, pl. 10. figs. 1-2, pl. 12, fig. 8 (= Steuer 1897).
1921 *Odontoceras malarguense* n. sp. Steuer, p. 83, pl. 20, figs. 1-3 (= Steuer 1897).
1922b *Reineckeia Argentina* Steuer. Djanélidzé, p. 198.
1925 *Andesites argentinus* (Steuer). Gerth, p. 78.
1925 *Andesites curvatus* n. sp. Gerth, p. 79, pl. 5, fig. 5.
1938 *Argentiniceras malarguense* (Steuer). Roman, p. 328, pl. 32, fig. 308, text-fig. 308 (= Steuer 1897).
1957 *Argentiniceras malarguense* (Steuer). Arkell et al., p. L354, figs. 462: 6a, 6b, 6c (= Steuer 1897).
1964 *Andesites* cf. *curvatus* Gerth. Biro, p. 53.
1979 *Argentiniceras malarguense* (Steuer). Nikolov, p. 197, pl. 1, fig. 1 (= Steuer 1897).
1996 *Argentiniceras malarguense* (Steuer). Wright et al., p. 55, figs 39: 3a, 3b, 3c (= Steuer 1897).
1998 *Argentiniceras mintaqi* n. sp. Howarth, p. 97, pl. 22, figs. 1-4.
2005 *Argentiniceras argentinum* (Steuer). Klein, p. 248.
2005 *Argentiniceras curvatum* (Gerth). Klein, p. 249.
2005 *Argentiniceras malarguense* (Steuer). Klein, p. 249.
2005 *Argentiniceras mintaqi* Howarth. Klein, p. 249.

Type: The lectotype is designated here and corresponds to specimen GFZ 499-34 described as *Reineckeia argentina* by Steuer (1897, p. 26, pl. 10. figs. 1-2, pl. 12, fig. 8).

Material: Four specimens which include the originals of Steuer (1897) and Gerth (1925). Lectotype GZG 499-34 (*R. argentina*), Paralectotype GZG 499-38 (*R. argentina*); GZG 499-72 (*O. malarguense*) and STIPB 1021 (*A. curvatus*). NO TENEMOS NINGUN ESPECIMEN DE CHILE? ENTONCES POR QUÉ SE DESCRIBE AQUI? Esta descripcion y discusion la hice en base a la revision de los ejemülares de Steuer, puede ser un articulo solitario, que hacemos?

Description: Evolute and compressed in juvenile stages (D< 100 mm), with a narrow umbilicus. The whorl section is subquadrate to subrounded, slightly wider than high, the umbilical border rounded, flanks are flat and subparallel, and the venter is rounded. Bifurcated ribs arise from gentle protuberances on the umbilical border or dorsolaterally; simple ribs are rare. All ribs are slightly prorsiradiate and sinuous. Occacional shallow constrictions are present. Adult specimens (D> 100 mm) are evolute, with a notably wider umbilicus. The whorl section is subrounded and increases in width, but clearly remains wider than high; the umbilical shoulder is rounded, the flanks are highly convex, and the venter is wide and rounded. Bifurcated ribs initiate between the dorsolateral and central part of the flank, the point of bifurcation migrates to mid-flank during ontogeny. In the adult specimens, strong tubercles are present at the point of rib division . 2-3 prorsiradiate to rectiradiate constrictions are present on the last whorl.

Dimensions	D	W	H	W/H	U	U/D
GZG 499-34	180	74	47	1.57	83	0.46
GZG 499-38	142	53	33	1.61	57	0.40
GZG 499-72	106	35	30	1.16	40	0.38
STIPB 1021	67	26	22	1.18	21	0.31

Figure 4.75. a-b: *Argentiniceras argentinum* (Steuer 1897), GZG-499-34 (lectotype) , x0.75.

Figure 4.76. a-e: *Argentiniceras argentinum* (Steuer 1897). **a-c:** STIPB 1021 "*Andesites curvatus*" from Gerth`s collection, x1. **d-e:** GZG 499-72 "*Odontoceras malarguense*" from Steuer`s collection, x1.

Remarks: “*Reineckeia*” *argentina* described by Steuer (1897) is based on an adult specimen, whereas “*Odontoceras*” *malarguense* Steuer (1897) and “*Andesites*” *curvatus* described by Gerth (1925) correspond to juvenile specimens of *Argentiniceras argentinum*. These specimens were revised at GZG and STIPB. An unpublished specimen in the Gerth (1925) collection (STIPB 1207) clearly indicates the morphological variation from juveniles to adults. “*Andesites*” *curvatus* also corresponds to a juvenile “*R*”. *argentina*. *Argentiniceras mintaqi* (Howarth 1998) is similar to *A. malarguense* and differs only by a wider spacement of ribs. Again, this is a typical feature for adults of *A. argentinum* and *A. mintaqi* is here considered a synonym of this species.

Occurrence: *A. argentinum* is recorded from the Upper Tithonian of central Argentina (Steuer 1897-1921, Gerth 1925), while *A. mintaqi* was decribed for the Berriasian of Yemen (Howarth 1998).

Argentiniceras fasciculatum (Steuer 1897)

Figure 4.77, 4.78

1897 *Perisphinctes noduliferus* n. sp. Steuer, p. 64, pl. 1, figs. 1-4.
1897 *Perisphinctes fasciculatus* n. sp. Steuer, p. 64, pl. 3, figs. 1-3.
1921 *Perisphinctes fascicula*tus n. sp. Steuer, p. 92, pl. 3, figs. 1-3 (= Steuer 1897).
1921 *Perisphinctes noduliferus* n. sp. Steuer, p. 64, pl. 1, figs. 1-4 (= Steuer 1897).
1925 *Andesites fasciculatus* (Steuer). Gerth, p. 76, pl. 4, fig. 6, text-fig. 5.
1925 *Andesites noduliferus* (Steuer). Gerth, p. 77.
1928 *Argentiniceras fasciculatum* (Steuer). Gerth, p. 470, pl. 18, fig. 7 (= Gerth 1925).
1936 *Argentiniceras fasciculatum* (Steuer). Feruglio, p. 73.
1945 *Argentiniceras noduliferum* (Steuer). A. Leanza, p. 48, pl. 23, fig. 1.
1945a *Argentiniceras fasciculatus* (Steuer). Royo y Gómez, p. 226.
1964 *Andesites fasciculatus* (Steuer). Biro, p. 54.
1970 *Argentiniceras fasciculatus* (Steuer). Tavera, p. 179, pl. 1, fig. 1, pl. 2, fig. 2.
1984 *Argentiniceras* cf. *noduliferum* (Steuer). Jeletzky, pl. 2, figs. 3, 6.
? 1993 *Argentiniceras noduliferum* (Steuer). Aguirre-Urreta, pl. 1, fig. 1 (= ?*Spiticeras tripartitum*).
2005 *Argentiniceras fasciculatum* (Steuer). Klein, p. 249.
2005 *Argentiniceras noduliferum* (Steuer). Klein, p. 250.

Type: The lectotype is designated here and corresponds to specimen GFZ 499-8 described as *Perisphinctes fasciculatus* Steuer (1897, p. 64, pl. 3, figs. 1-3).

Material: Thirty-one specimens. CPUC/LV/8-32, CPUC/LV/8-89, CPUC/CM/18-60, CPUC/CM/18-61, CPUC/CM/18-202, CPUC/CM/18-283, CPUC/CM/19-19 and CPUC/CM/19-66 are well preserved fragmentary phragmocones. In addition to the Chilean material we here include the lectotype GZG 499-8 and GZG499-2, GZG 499-1 as well as STIPB 1101 from Argentina.

Description: Evolute, with a wide umbilicus. Most specimens considered here are tectonically deformed but the whorl section was apparently higher than wide. The umbilical border is rounded, flanks are slightly convex and the venter is rounded. Strong primary ribs are rectiradiate to prorsiradiate and gently sinuous. In well preserved specimens they resemble elongated tubercles. Ribs are bi- or trifurcated at mid flank but these secondaries are weaker than the primary ribs. A few single primary ribs are intercalated between the secondary ribs. On the venter all ribs are slightly inclined towards the aperture. The single specimen of *A. fasciculatum* and the two specimens of *A. noduliferum* described by Steuer (1897) are large (D> 140 mm) and show protuberances or sharp-elongated tubercles on their last whorl.

Dimensions	D	W	H	W/H	U	U/D
GZG 499-8	200	62	46		96	
GZG 499-1	150	53	39		63	
STIPB 1101	114	37	30		42	
	78	29	24		25	

Remarks: Steuer (1897-1921) indicated that *Argentiniceras fasciculatum* and *Argentiniceras noduliferum* are closely related taxa. *A. noduliferus* was established based on sharp-elongated tubercles, but these are also present in large specimens of *Argentiniceras argentinum*. Gerth (1925) suggested that tubercles present in *A. noduliferus* should be “treated only as a variety with tubercles (or sexual dimorphism) of *Argentiniceras fasciculatum*”. From the revision of *A. noduliferus* and *A. fasciculatum*, the types of Steuer (1897-1921) in the GZG and the Gerth (1925) specimens in the STIPB, it is also evident that the two taxa are closely related. The sharp-elongated tubercles on the last whorl of large specimens of *A. noduliferus* are here considered

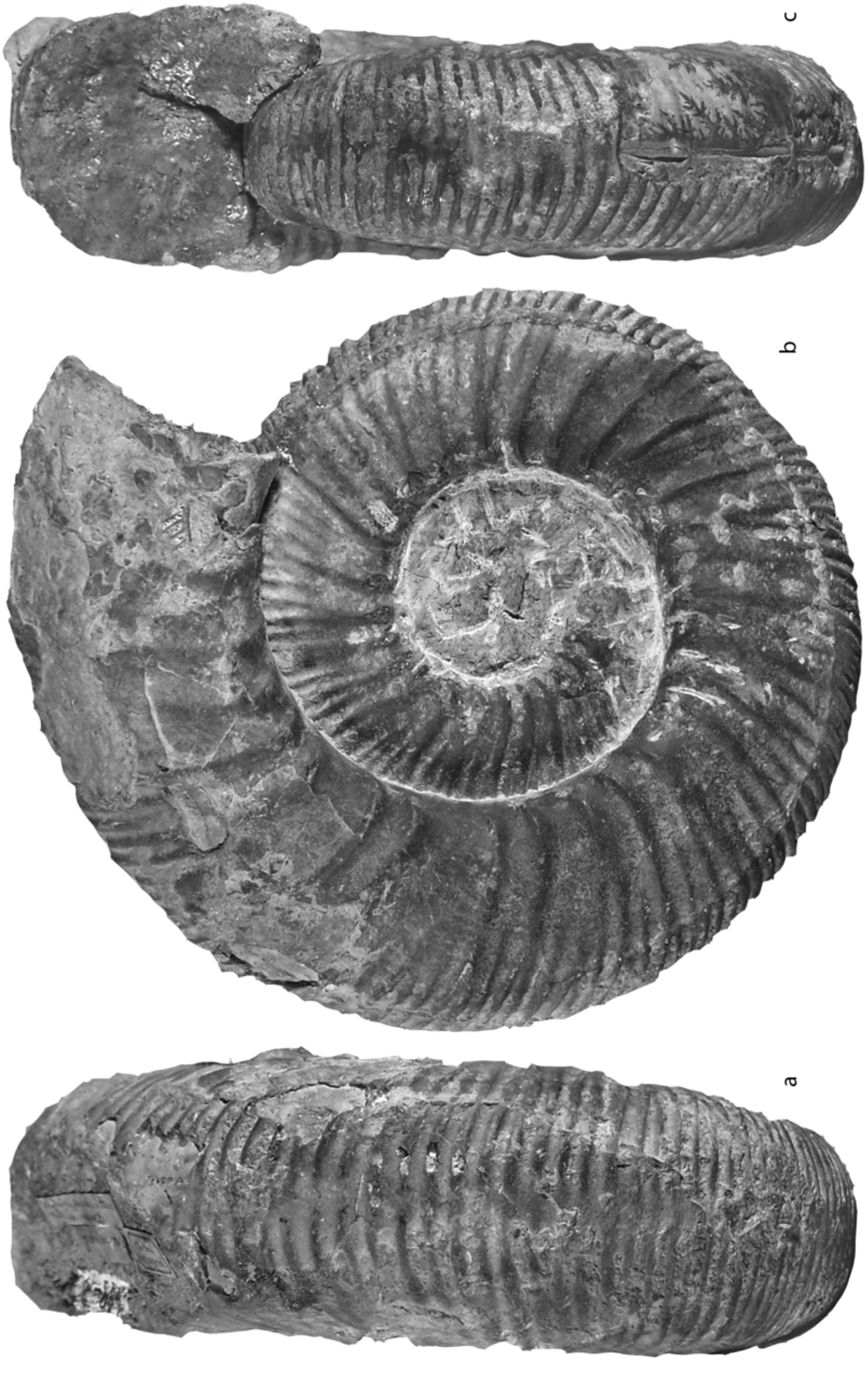


Figure 4.77. a-c: *Argentiniceras fasciculatum* (Steuer 1897), GZG 499-8 (lectotype), x0.75.

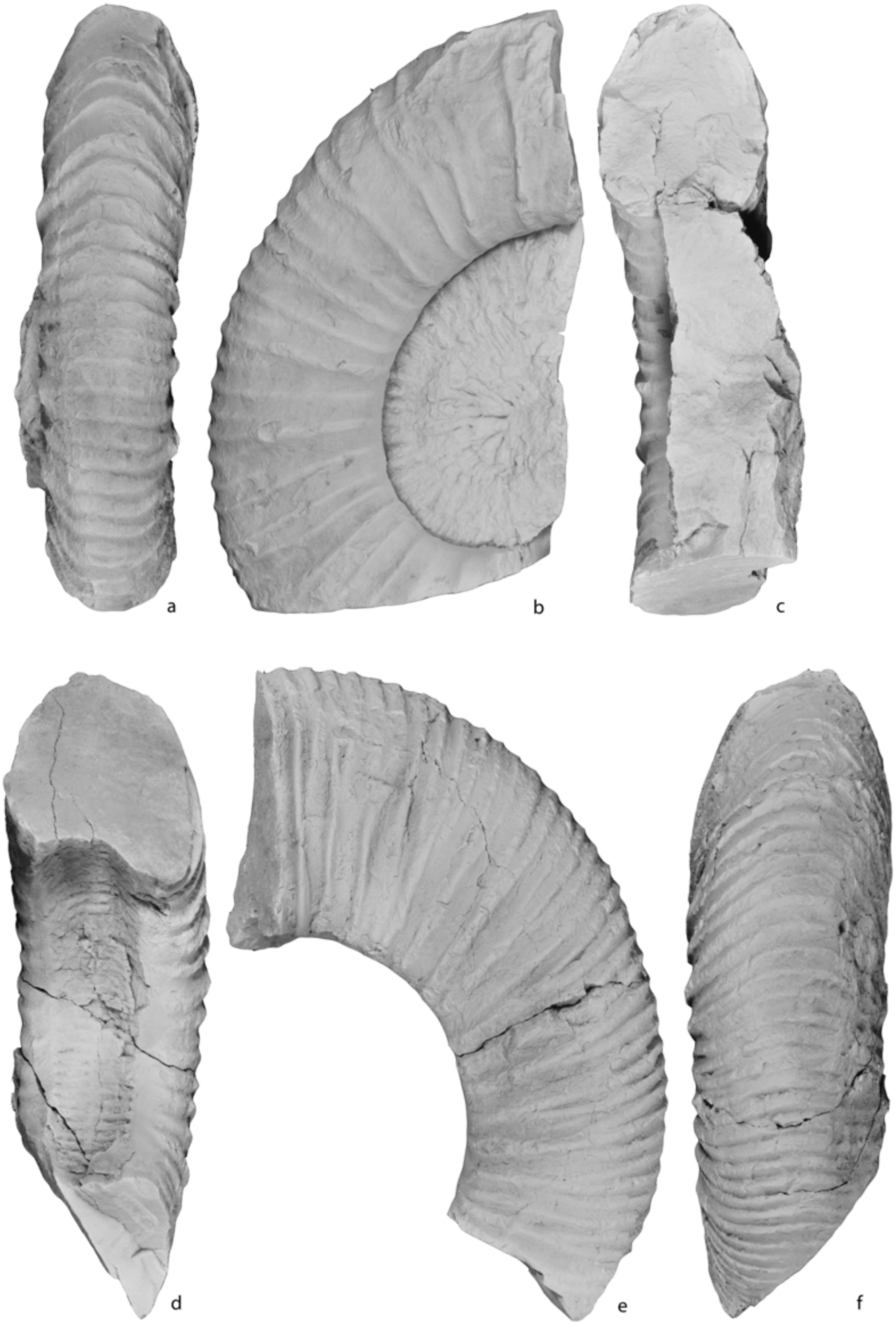


Figure 4.78. a-f: *Argentiniceras fasciculatum* (Steuer 1897) from Lo Valdés Formation. **a-c:** CPUC/CM/19-19, x0.75. **d-f:** CPUC/CM/18-202, x0.75.

within the morphological range of *A. fasciculatum*. Hence, *A. noduliferus* is suggested to be a junior synonym of *A. fasciculatum*.

A. noduliferus figured by Aguirre-Urreta (1993) presents wide tubercles which are wider on the mid-flank, and primary ribs which appear to be divided into more than two or three secondaries. These are morphological characteristics of *Spiticeras tripartitum*. It is presently unclear whether the figured specimen corresponds to this taxon, because no description was included.

Occurrence: *A. fasciculatum* occurs in the uppermost part of the Siltstone member and lower part of the Limestone member at Lo Valdés (figure 5.6) and in the upper part of the Siltstone member at Cajón del Morado (figure 5.7). Previously Biro (1964) registered this taxon for the uppermost part of the Siltstone member at Lo Valdés. *A. fasciculatum* has been recorded from Central Argentina for the Upper Tithonian (Steuer 1897-1921), Valanginian (Gerth 1925, Weaver 1931), and for the lower Berriasian (Leanza 1945). Elsewhere the taxon was recorded from the Berriasian of Antarctica (Tavera 1970), Colombia (Royo & Gómez 1945) and Canada (Jeletzky 1984).

Genus *Frenguelliceras* A. Leanza, 1945

Type species: *Frenguelliceras magister* A. Leanza (1945, p. 65, pl. 11, figs. 7-8), by original designation.

Frenguelliceras magister A. Leanza 1945

Figue 4.79

1945 *Frenguelliceras magister* n. sp. A. Leanza, p. 68, pl. 11, figs. 7-9.
1945 *Frenguelliceras simplex* A. Leanza, p. 69, pl. 11, figs. 5-6.
1957 *Frenguelliceras magister* A. Leanza. Arkell et al. p. L358, fig. 470: 6a, b (= A. Leanza 1945).
1966 *Frenguelliceras* cf. *magister* A. Leanza. Fuenzalida, p. 139.
1981b *Frenguelliceras magister* A. Leanza. H. Leanza, pl. 4, figs. 7-8 (= A. Leanza 1945).

1996 *Frenguelliceras magister* A. Leanza. Wright et al. p. 55, fig. 39: 5a, 5b (= A. Leanza 1945).

Type: The holotype was described and illustrated by A. Leanza (1945, p. 68, pl. 11, figs. 7-8).

Material: Sixty regular to well preserved complete and fragmentary phragmocones. CPUC/CM/18-7 is a complete well preserved phragmocone, CPUC/CM/18-15, CPUC/CM/18-171 and CPUC/CM/18-232 are well preserved fragmentary phragmocones.

Description: Evolute, with a wide umbilicus and a higher than wide whorl section. The umbilical shoulder is rounded, flanks are sligthly convex and the venter is rounded. Gently sinuous rectiradiate to slightly prorsiradiate ribs initiate at protuberances on the umbilical border. Ribs are spaced and either remain single or are divided into two or three from the umbilical border to midflank. Ocasionally two or three constrictions are present on the last whorl and are parallel to the ribs. Ventrolaterally, all ribs show a fine protuberance; they are weakened on the venter.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/18-7	66.1	(16.9)	20.0	(1.18)	32.3	0.49
CPUC/CM/18-71	(61.7)	(16.5)	(18.4)	(0.90)	(29.6)	0.48
CPUC/CM/18-232		13.1	15.9	(0.82)		

Remarks: A. Leanza (1945) gives a full description and discussion of *Frenguelliceras magister* and indicates that this taxon shows a wide morphological range. Even though, the author considered *F. simplex* to be a different though closely related taxon, separated from *F. magister* by coarse and wider-standing ribs. Based on our abundant material we here suggest that *F. simplex* forms part of the morphological variability of *F. magister* and thus consider *F. simplex* as a junior synonym.

Occurrence: *Frenguelliceras magister* is here recorded for the first time in Central Chile. The taxon occurs in the uppermost part of the Siltstone and lower part of the Limestone member at Lo Valdés (figure 5.6), and in the upper part of the Siltstone and lowermost part of the Limestone member at Cajón del Morado (figure 5.7). In southern Chile the taxon was recorded from the Lower Berriasian (Fuenzalida 1966). In central Argentina *F. magister* is registered for the lower Berriasian (A. Leanza 1945).

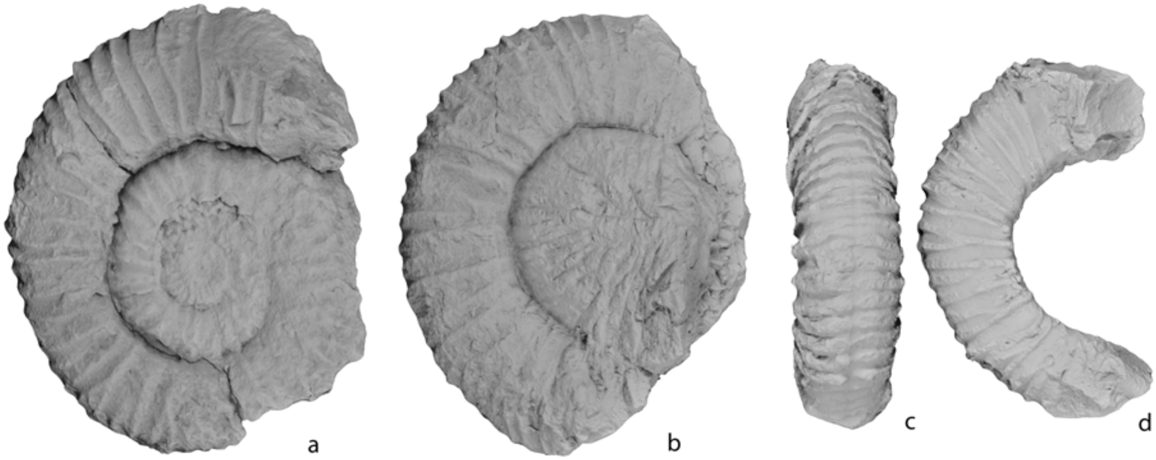


Figure 4.79. a-d: *Frenguelliceras magister* A. Leanza (1945) from Lo Valdés Formation. **a:** CPUC/CM/18-7, x1. **b:** CPUC/CM/18-171, x1. **c-d:** CPUC/CM/18-232, x1.

Genus *Tirnovella* Nikolov, 1966

Type species: *Berriasella alpillensis* Mazenot (1939, p. 73, pl. 6, fig. 22), by subsequent designation of Nikolov (1966, p. 639).

Tirnovella kayseri (Steuer 1897)

Figue 4.80, 4.81, 4.82

1897	*Odontoceras Kayseri* n. sp. Steuer, p. 48, pl. 22, figs. 6-8.
1897	*Odontoceras tenerum* n. sp. Steuer, p. 49, pl. 22, figs. 9-11.
1912	*Neocomites Kayseri* (Steuer). Burckhardt, p. 163.
1912	*Neocomites densestriatus* n. sp. Burckhardt, p. 190, pl. 45, figs. 1-15, 19.
1912	*Necomites* sp. ind. Burckhardt, p. 195, pl. 46, figs. 1, 3.
1921	*Odontoceras Kayseri* n. sp. Steuer, p. 76, pl. 22, figs. 6-8 (= Steuer 1897).
1922	*Odontoceras tenerum* n. sp.Steuer, p. 77, pl. 22, figs. 9-11 (= Steuer 1897).
1925	*Thurmannia*? *discoidalis* n. sp. Gerth, p. 98, pl. 5, fig. 3.
1926	*Neocomites tenerus* (Steuer). Krantz, p. 447.
1926	*Neocomites Kayseri* (Steuer). Krantz, p. 458.
1928	*Neocomites Kayseri* (Steuer). Krantz, p. 31.
1928	*Neocomites tenerus* (Steuer). Krantz, p. 31.
1928	*Thurmannia discoidalis* Gerth. Gerth, p. 477.

1930 *Neocomites tenerus* (Steuer). Burckhardt, table 11.
1945 *Thurmannites*? *discoidalis* (Gerth). A. Leanza, p. 65.
1945 *Thurmannites discoidalis*? (Gerth). Royo y Gomez, p. 228.
1951 *Neocomites* cf. *densestriatus* Burckhardt. Rivera, p. 41, pl. 3, fig. 6.
1964 *Neocomites densestriatus* Burckhardt. Muñoz, p. 25, pl. 7, figs. 6-7.
1988 *Thurmanniceras discoidalis* (Gerth). Riccardi, pl. 4, figs. 1-2.
2005 *Tirnovella*? *densestriata* (Burckhardt). Klein, p. 255.
2005 *Tirnovella*? *kayseri* (Steuer). Klein, p. 255.
2005 *Tirnovella*? *tenera* (Steuer). Klein, p. 257
2005 *Thurmanniceras discoidale* (Gerth). Klein, 277.

Type: The lectotype is designated here and corresponds to specimen GFZ 499-78, described as *Odontoceras kayseri* by Steuer (1897, p. 48, pl. 22, figs. 6-8).

Material: Two specimens. CPUC/CP/50-17 and CPUC/CP/60-57 are complete and well preserved phragmocones.

Description: Involute and gently depressed. The whorl section is discoidal, higher than wide, with a rounded umbilical border, subparallel flanks on the dorsolateral area and convergence towards the venter beginning at about mid-flank. The venter is narrow and flat. Ribs are rectiradiate to prorsiradiate and flexuous. They are concave on the umbilical shoulder, convex on the middle part of the flank and again concave on the ventrolateral part of the flank. On the venter, ribs are interrumped by a smooth furrow. On the middle part of the flank most ribs are bi- or trifurcated while others, about one third to a fouth part, remain single.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CP/60-53	62.2	18.3	29.4	0.6	13.1	0.21
CPUC/CP/50-17	57.0	16.2	28.0	0.6	11.7	0.21

Remarks: The lectotype of *Tirnovella kayseri* is an adult specimen (D> 50 mm, figure 4.80), which presents elongated umbilical bullae not present in juveniles. *Tirnovella densestriata* described by Burckhardt (1912) was based on fragmentary phragmocones of juveniles. The taxon is here considered a junior synonym of *T. kayseri*. *T. tenera* was differentiated by Steuer (1897) based on finer sculpture, but the single specimen described by Steuer (1897) is a juvenile (D = 47 mm) with the morphometric characteristics of juvenile *T. kayseri* (figure 4.80).

T. kayseri is similar to *T. occitanica* (Pictet 1867), but the latter presents elongated umbilical tubercles and a wider and rounded venter.

S. duraznense (Gerth 1925) is similar in sculpture, but the venter is wider and the W/H relationship higher (figure 4.80).

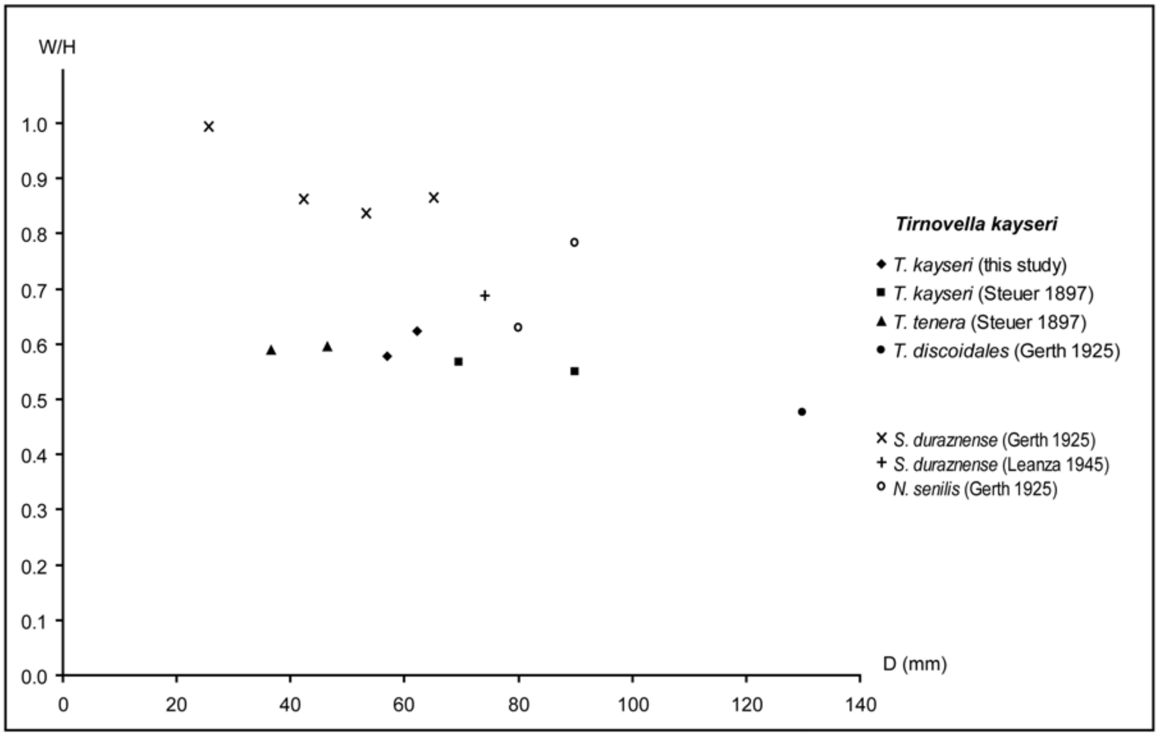


Figure 4.80. Relationship between W/H and D in *Tirnovella kayseri* (Steuer 1897), and the junior synonymies included in this study.

Occurrence: *T. kayseri* is here recorded for the first time in Chile and is present in the Siltstone member of the Cruz de Piedra section (figure 5.8). *T. kayseri* is also registered from the Tithonian of Argentina (Steuer 1897, 1921, Krantz 1926, 1928) and from the Berriasian of Peru (Rivera 1951), Argentina (Gerth 1925), Colombia (Royo y Gomez 1945) and Mexico (Burckhardt 1912).

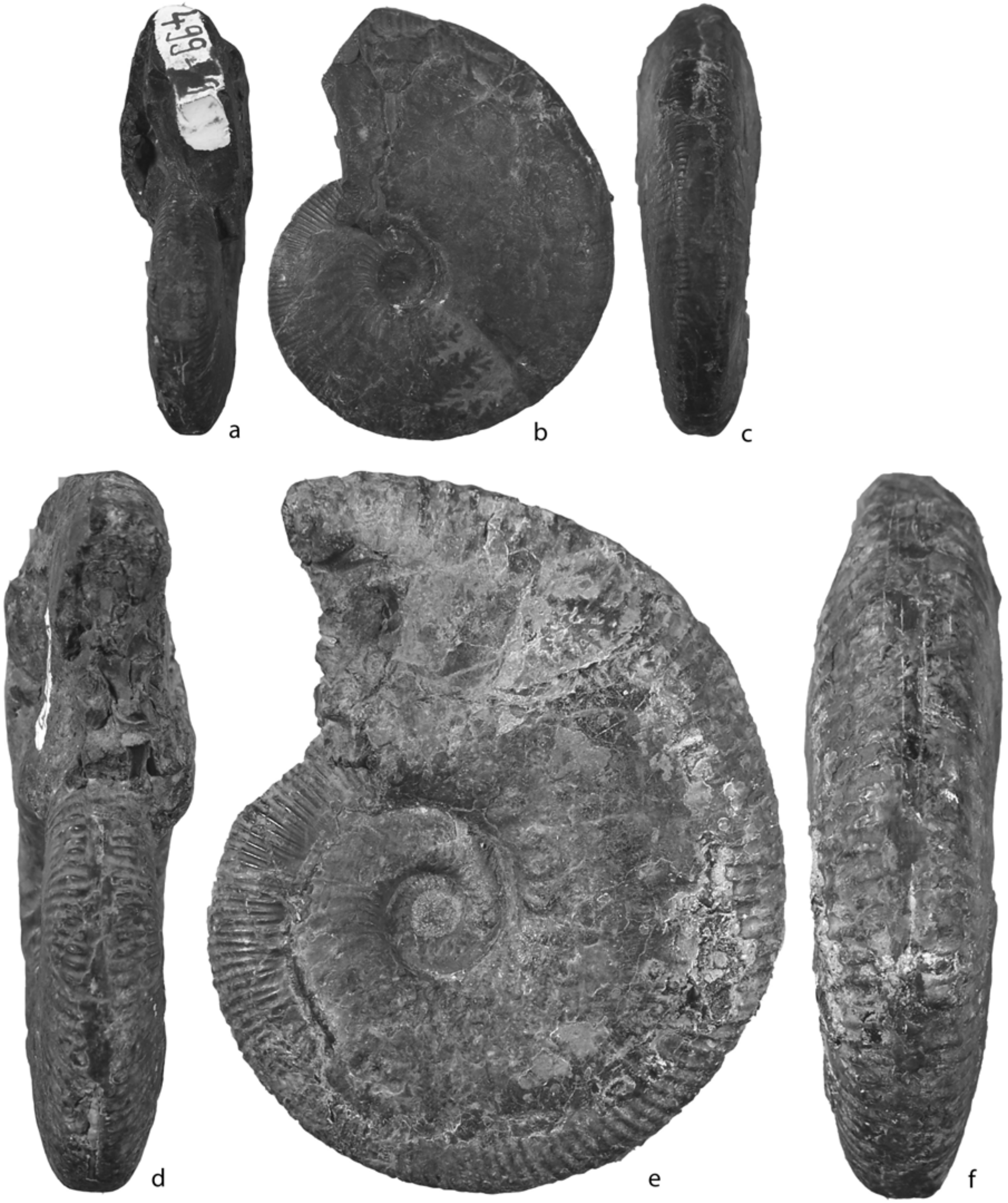


Figure 4.81. a-f: *Tirnovella kayseri* (Steuer 1897). **a-c:** GZG 499-79 "*Odontoceras tenerum*" from Steuer`s collection, x1. **d-f:** GZG 499-78, lectotype of *Tirnovella kayseri* from Steuer`s collection, x1.

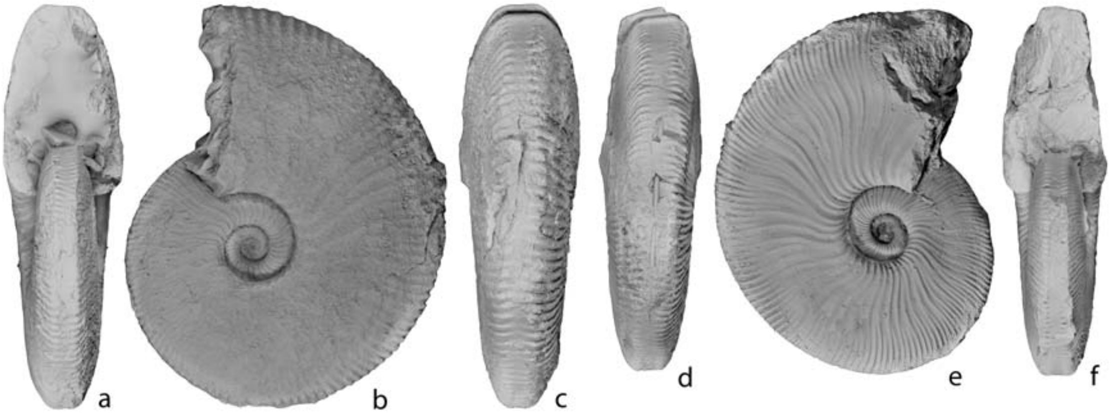


Figure 4.82. a-f: *Tirnovella kayseri* (Steuer 1897) from Lo Valdés Formation. **a-c:** CPUC/CP/60-53, x1; **d-f:** CPUC/CP/50-17, x1.

Genus *Cuyaniceras* A. Leanza, 1945

Type species: The generotype is specimen GFG 499-56, described as *Odontoceras transgrediens* by Steuer (1897, p. 40, pl. 16, figs. 11-14), by subsequent designation of Arkell (1952, p. 860).

Cuyaniceras transgrediens (Steuer 1897)

Figure 4.83, 4.84

1897	*Odontoceras transgrediens* n. sp. Steuer, p. 40, pl. 16, figs. 11-14.
1897	*Odontoceras raripartitum* n. sp. Steuer, p. 54, pl. 19, figs. 7-8.
1921	*Neocomites transgrediens* (Steuer). Gerth, p. 141.
1921	*Neocomites inflatus* Gerth, p. 141 (*nomen nudum*).
1921	*Odontoceras transgrediens* n. sp. Steuer, p. 67, pl. 16, figs. 11-14 (= Steuer 1897).
1921	*Odontoceras raripartitum* n. sp. Steuer, p. 82, pl. 19, figs. 7-8 (= Steuer 1897).
1925	*Neocomites transgrediens* (Steuer). Gerth, p. 105.
1925	*Odontoceras raripartitum* Steuer. Gerth, p. 129.
1925	*Neocomites inflatus* Gerth, p. 106, pl. 4, fig. 5.
1928	*Lyticoceras transgrediens* (Steuer). Gerth, p. 478.
1928	*Lyticoceras inflatum* (Gerth). Gerth, p. 478, pl. 18, fig. 6 (= Gerth 1925).
1931	*Neocomites transgrediens* (Steuer). Windhausen, p. 297, pl. 33, fig. 4 (= Steuer 1897).

non 1937 *Lyticoceras transgrediens* (Steuer). Feruglio, p. 57, pl. 5, figs. 8-10 (*Neocomitidae* indet.).
1945 *Cuyaniceras mendozanum* n. sp. A. Leanza, p. 55, pl. 21, figs. 4-5.
1945 *Cuyaniceras transgrediens* (Steuer). A. Leanza, p. 54, pl. 22, fig. 3-4.
1945 *Cuyaniceras raripartitum* (Steuer). A. Leanza, p. 56, pl. 13, figs. 3-4.
1945 *Cuyaniceras acanthicum* n. sp. A. Leanza, p. 56, pl. 13, figs. 1-2.
1945 *Cuyaniceras inflatum* (Gerth). A. Leanza, p. 57. pl. 21, fig. 2, 3.
1945 *Cuyaniceras argentinum* n. sp. A. Leanza, p. 59, pl. 12, fig. 4.
1957 *Cuyaniceras transgrediens* (Steuer). Arkell et al., p. L358, figs. 472: 5a, 5b, 5c (= Steuer 1897).
1957 *Cuyaniceras* cf. *transgrediens* (Steuer). Bürgl, pl. 2, fig. 5.
1957 *Cuyaniceras* sp. (Gerth). Bürgl, pl. 2, fig. 10.
1958 *Cuyaniceras transgrediens* (Steuer). Corvalán & Pérez, p. 46, pl. 14, fig. 34, pl. 15, fig. 36 (= Steuer 1897).
1960 *Cuyaniceras transgrediens* (Steuer). Bürgl, p. 201, pl. 2, figs. 5-6 (=Bürgl, 1957).
1960 *Cuyaniceras inflatum* (Gerth). Bürgl, p. 202, pl. 3, figs. 13 (=Bürgl, 1957).
1981b *Cuyaniceras mendozanum* A. Leanza. H. Leanza, pl. 5, figs. 5-6 (= A. Leanza 1945).
1981b *Cuyaniceras transgrediens* (Steuer). H. Leanza, pl. 5, figs. 8-9 (= A- Leanza 1945).
1988 *Cuyaniceras transgrediens* (Steuer). Riccardi, pl. 3, figs. 7-8.
1990 *Cuyaniceras raripartitum* (Steuer). Aguirre-Urreta & Charrier, p. 268, pl. 1, fig. 4.
1996 *Cuyaniceras transgrediens* (Steuer). Wright et al. p. 58, figs. 40: 2a, 2b, 2c. (= Steuer 1897).
2005 *Cuyaniceras acanthicum*. A. Leanza. Klein, p. 268.
2005 *Cuyaniceras argentinum* A. Leanza. Klein, p. 268.
2005 *Cuyaniceras inflatum* (Gerth). Klein, 269.
2005 *Cuyaniceras mendozanum* A. Leanza. Klein, p. 269.
2005 *Cuyaniceras raripartitum* (Steuer). Klein, p. 269.
2005 *Cuyaniceras transgrediens* (Steuer). Klein, p. 269.

Type: As for the genus.

Material: Twenty-three regular to well preserved complete and fragmentary phragmocones. Only the best-preserved specimens were measured and are listed here. These are CPUC/LV/7-17, CPUC/CP/40-70-43, CPUC/CP/100-3, CPUC/CP/100-5, CPUC/CP/100-8 and CPUC/CP/100-21. For the description the material presented by Steuer (1897) and Gerth (1925) was also considered.

Description: Evolute with a narrow umbilicus in juveniles and gradually increasing towards adult stages (U/D: 0.26-0.42). The whorl section is subrounded, higher than wide, with a relationship of W/H increasing with diameter (figure 4.83). The maximum width is reached dorsolaterally. The umbilical border is rounded, flanks are slightly convex and the venter is rounded. In juveniles, ribs are rectiradiate to prorsiradiate and gently flexuous; they are slightly concave on the umbilical border and gently prorsiradiate and convex on the flank. In occasions, ribs initiate in weak protuberances on the umbilical border. Most ribs are bifurcated on the dorsolateral half of the flank or near mid-flank. In adults, ribs are rarely bifurcated and they are less flexuous and prorsiradiate. Tubercles are present on both sides of the venter. In internal moulds, including the lectotype, ribs are interrupted at these tubercles.

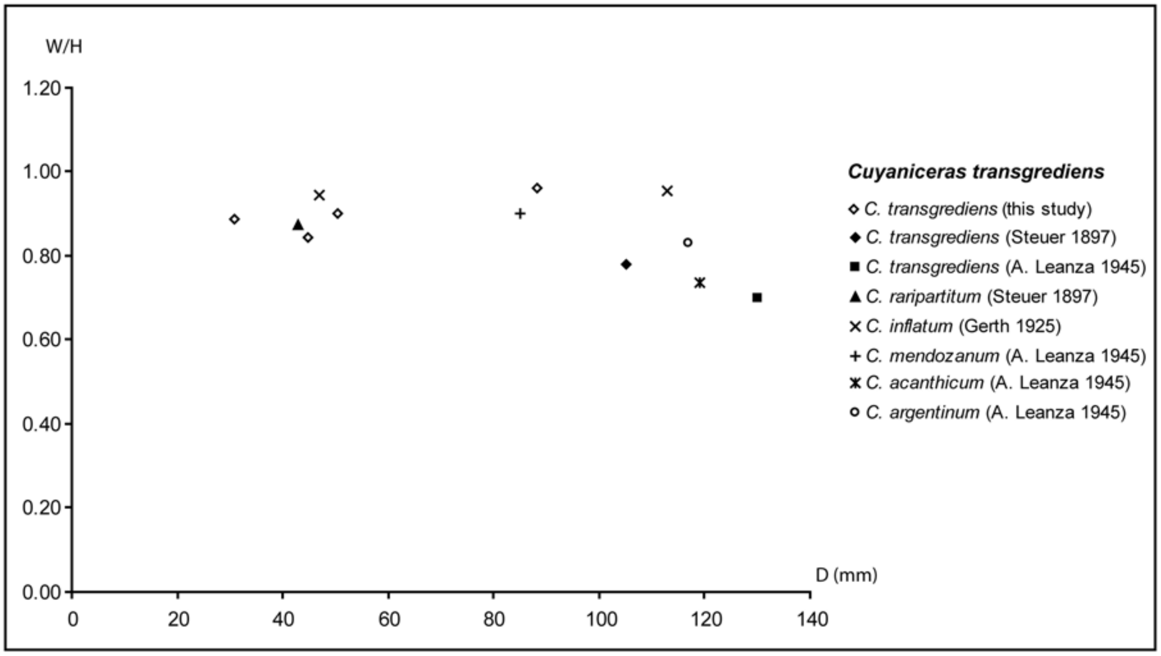


Figure 4.83. Relationship between W/H and D in *Cuyaniceras transgrediens* (Steuer 1897) and the junior synonymies included in this study.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/7-17	88.3	31.9	33.2	0.96	32.0	0.36
CPUC/CP/100-5	44.8	14.1	16.7	0.84	16.1	0.36
CPUC/CP/100-8	50.5	18.3	20.3	0.90	18.4	0.36
CPUC/CP/100-21	30.9	11.1	12.5	0.89	10.2	0.33

Remarks: *Cuyaniceras acanthicum* was established by A. Leanza (1945) based on a single specimen. Even though the author differentiated the taxon from C. *transgrediens* based on a wider than high whorl section, dimensions (W: 28 mm, H: 38 mm; A. Leanza 1945, p. 56) of the specimen figured as *C. acanthicum* (op.cit., pl. 13, fig. 1) indicate that the whorl section is higher than wide.

Cuyaniceras argentinum A. Leanza (1945) was differentiated from *C. transgrediens* based on a stronger and more regular sculpture on the outermost half whorl, which, however, corresponds to the body chamber and is indistinguishable from *C. transgrediens*. Morphological characteristics of the phragmocone of *Cuyaniceras argentinum* fully agree with those known to exist in *C. transgrediens* and the two are considered to be conspecific.

In addition to the material collected in the Lo Valdés Formation, our description of *Cuyaniceras transgrediens* is based on the revision of type specimens published by Steuer (1897) as *Cuyaniceras transgrediens* and *Cuyaniceras raripartitum*, as well as on the type of *Cuyaniceras inflatum* in the collection of Gerth (1925); our description also includes characteristics seen in *Cuyaniceras mendozanum*, *C. acanthicum* and *C argentinum* established by A. Leanza (1945). These species were based on single specimens; subsequent descriptions by other authors added another seven individuals, bringing the total number to 13.

For the present review were collected a total of 23 specimens of different size stages (D: 88.3-30.9 mm) which give evidence for a morphologically variable taxon in terms of sculpture, coiling and whorl section. *C. raripartitum*, *C. inflatum*, *C. acanthicum*, *C. argentinum* and *C. mendozanum* form part of this variability and are considered here to be junior synonyms of *Cuyaniceras transgrediens.*

C. crassituberculatum and *C. inflatuberculatum*, both described by Gerth (1925), are strongly ribbed, present rows of tubercles on the umbilical border, at mid-flank, and two rows of tubercles on the vental border. According to the author, the main difference between the two taxa is the whorl section, which is wider than high in *C. crassituberculatum*, and higher than wide in *C.*

inflatuberculatum. The originals were revised in the collection of STIPB (Gerth 1925) and contain three specimens of *C. crassituberculatum* and a single individual of *C. inflatuberculatum.* They show stages of transition between juveniles and adults and are here considered conspecific.

Figure 4.84. a-k: *Cuyaniceras transgrediens* (Steuer 1897) from Lo Valdés Formation. **a-b:** GZG 499-56 (lectotype), x1; **c-e:** CPUC/CP/100-5, x1; **f-h:** CPUC/CP/100-8, x1; **i-k:** CPUC/LV/7-17, x1.

Occurrence: In the Lo Valdés Formation, *Cuyaniceras transgrediens* is registered in the upper part of the Siltstone member at Lo Valdés (figure 5.6) and at Cruz de Piedra (figure 5.8). Previously, Biro (1964) also recorded *C. transgrediens* from the upper part of the Siltstone member at Lo Valdés and considered the taxon to be Upper Berriasian in age. At Cruz de Piedra, Aguirre-Urreta & Charrier (1990) described *Cuyaniceras transgrediens* for the Berriasian. In Colombia *C. transgrediens* is present in the Upper Berriasian (Bürgl 1960). In Argentina Steuer (1897) assigned *C. transgrediens* to the Upper Tithonian, but the taxon was subsequently considered to be an index fossil for the Upper Berriasian (A. Leanza 1945, H. Leanza 1981b, Riccardi 1988).

Genus *Thurmanniceras* Cossmann, 1901

Type species: *Ammonites thurmanni* Pictet & Campiche (1860, p. 250, pl. 34, fig. 1a, 1b) by original designation of Cossmann (1901, p. 58).

Thurmaniceras thurmanni (Pictet & Campiche, 1860)

Figure 4.85, 4.86

1860 *Ammonites Thurmanni* Pictet & Campiche, p. 250, pl. 34, figs. 1a, 1b, 2a, 2b, 3a, 3b, 3c. pl. 34 bis, figs. 1a, 1b, 2a, 2b.

1906 *Hoplites* cf. *Thurmanni* (Pictet & Campiche). Burckhardt, p. 189, pl. 42, figs. 1-2.

1906 *Hoplites Thurmanni* (Pictet & Campiche). Baumberger, p. 57, pl. 6, fig. 5, pl. 10.

1907 *Thurmannia Thurmanni* (Pictet & Campiche). Sayn, p. 40, pl. 9 (5), figs. 1a, 1b, 5a, 5b, 14.

1907 *Hoplites* cf. *Thurmanni* (Pictet & Campiche). Lisson, p. 48, pl. 7, fig. 2.

1921 *Thurmannia Duraznensis* Gerth, p. 147 (*nomen nudum*)

1925 *Thurmannia duraznensis* n. sp. Gerth, p. 97, pl. 4, fig. 1, 1a.

1926 *Thurmannia constricta* n. sp. Krantz, p. 448, text-fig. 6.

1928 *Thurmannia duraznensis* Gerth. Gerth, p. 477, pl. 18, figs. 5, 5a (= Gerth 1925).

1928 *Thurmannia constricta* n. sp. Krantz, p. 33, pl. 2, figs. 7a-7b, text-fig. 6, text-fig. 7.

1931 *Thurmanniceras chicoensis* n. sp. Weaver, p. 452, pl. 56, figs. 354-355.

1938 *Thurmannites Thurmanni* (Pictet & Campiche). Roman, p. 329, pl. 33, figs. 315, 315a, text-fig. 315.

1945 *Thurmannia duraznensis* var. *lateumbilicatum* A. Leanza, p. 66, pl. 2, fig. 4.

1945 *Thurmannites neogaeus* n. sp. A. Leanza, p. 67, pl. 15, fig. 2b.

1958 *Thurmannia duraznensis* Gerth. Corvalán & Pérez, p. 45, pl. 13, figs. 28a-28b (= Gerth 1925).

1960 *Thurmanniceras thurmanni* (Pictet & Campiche). Nikolov, p. 177, pl. 18, figs. 4-5.

1970 *Thurmanniceras duraznensis*? Gerth. Tavera, p. 179, pl. 2, fig. 4.

1976 *Thurmanniceras grandium* n. sp. Chao, pl. 14, fig. 9.

1987 *Thurmanniceras thurmanni* (Pictet & Campiche). Company, p. 114, pl. 7, figs. 1-2, 3a, 3b, 4-6, pl. 18, fig. 19.

1990 *Thurmanniceras duraznense* Gerth. Aguirre-Urreta & Charrier, p. 268, pl. 1, figs. 5-6.

1993 *Thurmanniceras duraznense* Gerth. Aguirre-Urreta, pl. 2, fig. 3 (=Aguirre-Urreta & Charrier 1990).

1995 *Thurmanniceras thurmanni* (Pictet & Campiche). González-Arreola et al., p. 195, pl. 1 fig. 12.

2001 *Thurmanniceras thurmanni* (Pictet & Campiche). Wippich, p. 86, pl. 19, figs. 1-4, pl. 20, fig. 1.

2003 *Thurmanniceras thurmanni* (Pictet & Campiche). Wippich, fig. 8E (= Wippich, 2001, pl. 19, fig. 1).

2005 *Substeueroceras*? *duraznense* (Gerth). Klein, p. 188 (with aditional synonymy).

2005 *Substeueroceras*? *duraznense lateumbilicatum* A. Leanza. Klein, p. 189 (with additional synonymy).

2005 *Thurmanniceras chicoensis* (Weaver). Klein, p. 277.

2005 *Thurmanniceras constrictum* (Krantz). Klein, p. 277.

2005 *Thurmanniceras grandium* Chao. Klein, p. 277.

2005 *Thurmanniceras neogaeum* (A. Leanza). Klein, p. 277.

2005 *Thurmanniceras thurmanni* (Pictet & Campiche).Klein, p. 281 (with additional synonymy).

Type: The lectotype corresponds to *Ammonites Thurmanni* Pictet & Campiche (1860, p. 250, pl. 34, figs. 1a, 1b), designated by Baumberger (1906, p. 53).

Material: Sixty-six specimens which correspond to regular to well preserved complete and fragmentary phragmocones. CPUC/CM/18-126, CPUC/CM/18-281, CPUC/CM/19-64, CPUC/LV/8-48 and CPUC/LV/8-86 are preserved best.

Description: Juveniles (D< 100 mm) are evolute and the umbilicus is narrow. The whorl section is subcircular, higher than wide. The umbilical border is rounded, flanks are convex and the venter is rounded. Prorsiradiate and slightly sinuous ribs are present and initiate in gentle elongated umbilical protuberances. They are concave on the dorsolateral side of the flank, then bend back to slightly convex near mid-flank and pass the ventrolateral side of the flank slightly concave. Here they end in a gently elongated protuberance on the ventral border. At mid-flank most ribs are bifurcated. Two to three constrictions are present per half whorl.

In adult specimens (D>100 mm) coiling is evolute and gently narrower. The whorl section is subrectangular, much higher than wide; the flanks are slightly convex to flat. The sculpture is similar to juveniles but ribs are more sinuous and are bifurcated between mid-flank and the ventrolateral area. On the venter ribs are slightly inclined toward the aperture; they cross the venter without interruption. Two to three constrictions are present per half whorl. CPUC/CM/19-64 is a large specimen with a diameter of 186.2 mm. Half of its last whorl corresponds to the body chamber; sculpture remains as on the phragmocone, but two or three constrictions are present.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/19-64	(186.2)		65.8		(73.5)	(0.39)
CPUC/CM/18-281	(217.1)	(47.4)	(76.4)	(0.62)	75.6	(0.34)
CPUC/CM/18-371	106.3	(29.6)	41.7	(0.71)	35.6	(0.33)
CPUC/LV/8-86		39.2	48.5	0.81		

Remarks: Company (1987) presented a full description and discussion of *Thurmanniceras thurmanni*, indicating the wide variability of this taxon. Here we follow this view.

Specimen STIPB-972 is designated here as the lectotype of “*Thurmannia*? *duraznensis*” Gerth (1925), but without discussion of the taxon. The specimen is relatively small (D: 65 mm). According to Gerth (1925) the taxon is involute, ribs are divided at different heights of the flank and are weakened on the venter. In a revision of the lectotype at STIPB, however, the evolute coiling and narrow umbilicus are characteristic features for juvenile specimens of

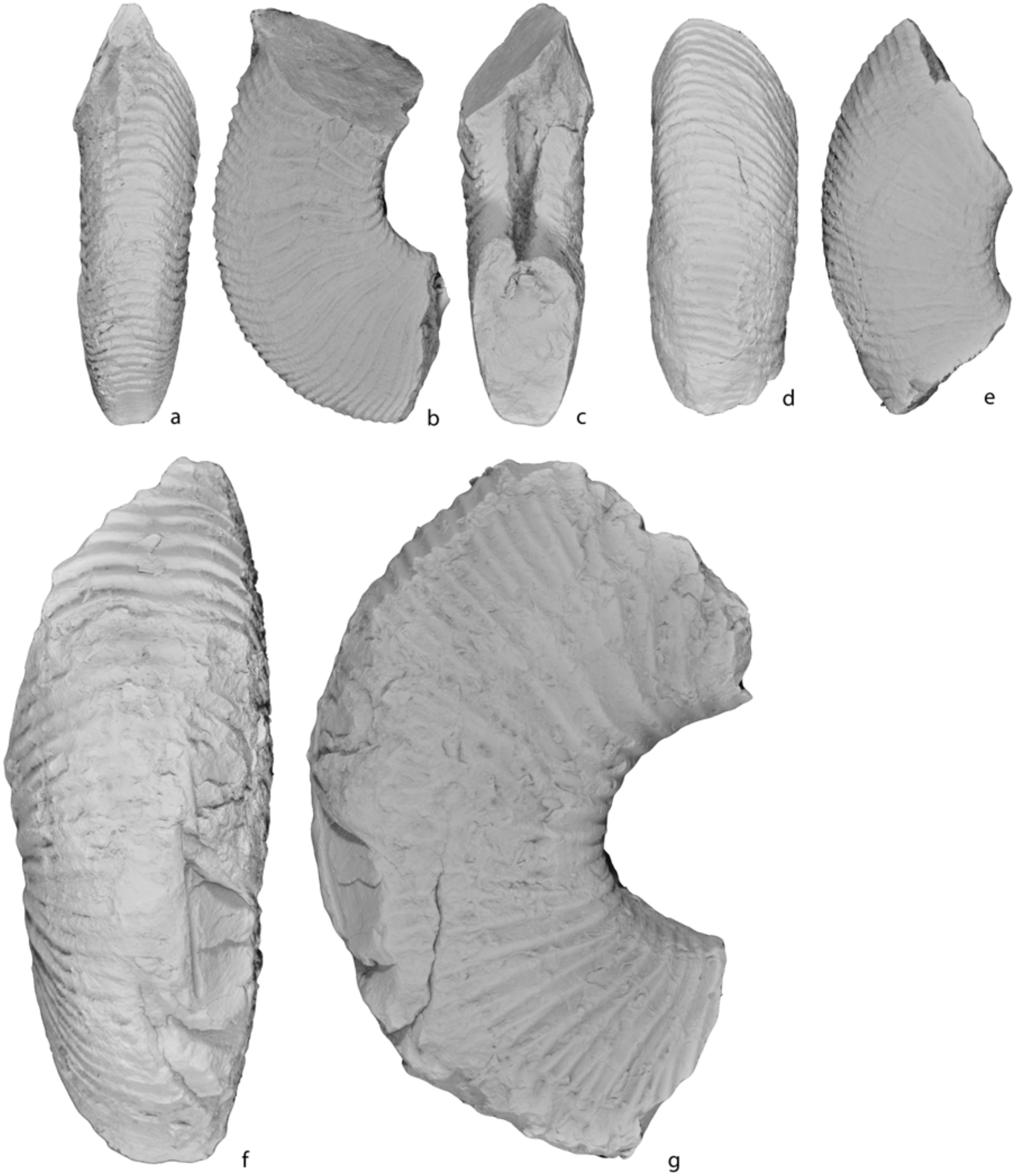


Figure 4.85. a-g: *Thurmaniceras thurmanni* (Pictet & Campiche, 1860) from Lo Valdés Formation. **a-c:** CPUC/CM/18-126, x1; **d-e:** CPUC/LV/8-48, x1; **f-g:** CPUC/LV/8-86, x1.

Thurmanniceras thurmanni; in individuals of this latter species ribs are usually weakened or even interrupted on the venter, depending on the preservation, and most ribs are divided at mid-flank. The single specimen of *T. duraznense* described by Aguirre-Urreta & Charrier (1990) is also a juvenile and its morphological elements are close to those described for "*Thurmannia*? *duraznensis*" of Gerth (1925). We propose that "*Thurmannicera duraznensis*" is within the morphological variability of *Thurmanniceras thurmanni*. The latter shows important ontogenetic changes of the morphology which were discussed by various authors (e.g., Company 1987).

Figure 4.86. a: *Thurmaniceras thurmanni* (Pictet & Campiche, 1860) from Lo Valdés Formation. **a:** CPUC/CM/19-64, x1.

"*Thurmannicera duraznesis*" var. *lateumbilicata* described by A. Leanza (1945) is also a junior synonym of *Thurmanniceras thurmanni*. *Thurmannia chicoensis* described by Weaver (1931) was distinguished based on a wider umbilicus, but is also included in *T. thurmanni* here.
"*Thurmannicera constricta*" described by Krantz (1926-1928) is based on four juvenile specimens, "*Thurmannites neogaeus*" A. Leanza (1945) on a single specimen, and "*Thurmannicera grandium*" Chao (1976) also on a single specimen. Differences described between these taxa and "*Thurmannicera duraznensis*" Gerth (1925) are minor. They are also considered here as junior synonyms of *Thurmanniceras thurmanni*.

Occurrence: In the Lo Valdés Formation *Thurmanniceras thurmanni* is present in the upper part of the Siltstone member at Cajón del Morado and in the upper part of the Siltstone member and lower part of the Limestone member at Lo Valdés (Figure 5.6 and 5.7). *T. thurmanni* is officially registered for the first time in Chile. Previously, however, Aguirre-Urreta & Charrier (1990) recorded "*Thurmannicera duraznesis*" from the Berriasian of the Paso Los Bayos section (Lo Valdés Formation). In Argentina the junior synonyms of *T. thurmanni* were registered from the Upper Berriasian (Krantz 1926-1928, Weaver 1931, Leanza 1945). *Thurmanniceras thurmanni* is known from the lower Valanginian of Perú (Lisson 1907), México (Burckhardt 1906, Gonzalez-Arreola et al. 1995), south France (Pictet & Campiche 1860, Roman 1938), south Germany (Baumberger 1906a), south Spain (Hoedemaeker (1982) and Bulgary (Nikolov 1960). In south Spain (Company 1987) and south-west Morrocco (Wippich 2001, 2003) *Thurmanniceras thurmanni* is recorded from the *T. pertransiens* Zone of the lower Early Valanginian.

Subfamily ENDEMOCERATINAE Schindewolf, 1966

Genus *Pseudofavrella* A. Leanza & H. Leanza, 1973

Type species: *Hoplites angulatiformis* Behrendsen (1892, p. 16, pl. 4, figs. 2b-2c), by original designation.

Pseudofavrella angulatiformis (Behrendsen, 1892)

Figure 4.87 d-m

1892 *Hoplites angulatiformis* Behrendsen, p. 16, pl. 4, figs. 2a-2c.
1910a *Favrella angulatiformis* (Behrendsen). Douvillé, p. 166.

1921 *Hoplites angulatiformis* Behrendsen, p. 210, pl. 4, figs. 10a-10c (= Behrendsen 1892).

1925 *Favrella* cf. *angulatiformis* (Behrendsen). Gerth, p. 111.

1931 *Favrella angulatiformis* (Behrendsen). Weaver, p. 460, pl. 57, fig. 366.

1939 *Favrella angulatiformis* (Behrendsen). Spath, p. 147.

1964 *Favrella* cf. *angulatiformis* (Behrendsen). Biro, p. 47.

1967 "*Hoplites*" *angulatiformis* Behrendsen. A. Leanza, p. 164.

1970 *Neocomites angulatiformis* (Behrendsen). Riccardi, p. 123.

1971 *Favrella angulatiformis* (Behrendsen). Riccardi et al. p. 115, pl. 14, figs. 1-2, fig. 3 (= *Pseudofavrella garatei*), figs. 4-5.

1973 *Pseudofavrella angulatiformis* (Behrendsen). A. Leanza & H. Leanza, p. 131, fig. 2.

1980 *Pseudofavrella angulatiformis* (Behrendsen). H. Leanza & Wiedmann, p. 954, pl. 4, fig. 1.

1981b *Pseudofavrella angulatiformis* (Behrendsen). H. Leanza, pl. 7, figs. 5-6 (= H. Leanza & Wiedmann 1980).

1988 *Pseudofavrella angulatiformis* (Behrendsen). Riccardi, pl. 5, figs. 5-6.

1996 *Pseudofavrella angulatiformis* (Behrendsen). Wright et al. p. 64, pl. 48, fig. 2 (= A. Leanza & H. Leanza 1973).

1997 *Pseudofavrella angulatiformis* (Behrendsen). Aguirre-Urreta & Rawson, p. 454, pl. 7, figs. h-i.

2005 *Pseudofavrella angulatiformis* (Behrendsen). Klein, p. 356.

2005 *Pseudofavrella angulatiformis* (Behrendsen). Aguirre-Urreta et al. fig. 5c,d.

2010 *Pseudofavrella angulatiformis* (Behrendsen). Aguirre-Urreta & Rawson, p. 329, fig. 6 A-K.

Type: Lectotype is specimen GZG 499-24 which corresponds to *Hoplites angulatiformis* Behrendsen (1892, pl. 4, figs. 2b-c); it was designated by Spath (1939, p. 147).

Material: Seven specimens. CPUC/CM/18-76, CPUC/CM/18-292, CPUC/CM/18-33, CPUC/CM/18-106, CPUC/CM/18-149, CPUC/CM/18-151 and CPUC/CM/18-330 are fragmentary phragmocones.

Description: Evolute, with a moderately wide umbilicus. The whorl section is discoidal to trapezoidal. The umbilical wall is steep; flanks are convex and converge towards the arched venter. The maximum whorl width is reached around mid-flank. The ribs are rursiradiate to prorsiradiate. Most are bifurcated at mid-flank. Protuberances or tubercles are present on these ribs on the umbilical border, at the point of bifurcation at mid-flank, and on the ventral border, with two rows of elongated-rounded tubercles. Occasionally, constrictions are present parallel to the ribs.

Dimensions	D	W	H	W/H	U	U/D
CPUC/CM/18-292	(75.7)	23.3	28.1	0.83	(32.6)	(0.43)
CPUC/CM/18-76		49.7	66.1	0.75		

Remarks: A. Leanza & H. Leanza (1973) and Aguirre-Urreta & Rawson (2010) present a full description and discussion of the genus *Pseudofavrella* and of *P. angulatiformis*.

Occurrence: *Pseudofavrella angulatiformis* is present in the upper part of the Siltstone member at Cajón del Morado (Figure 5.6). Previously "*Favrella*" cf. *angulatiformis* was mentioned for the Valanginian at Lo Valdés by Biro (1964). In Argentina the taxon is considered an index fossil for the Valanginian (Weaver 1931, A. Leanza & H. Leanza 1973, H. Leanza & Wiedmann 1980, and Riccardi 1988). More recently the taxon was restricted to the lower Early Valanginian by Aguirre-Urreta & Rawson (1997, 2010).

Suborder ANCYLOCERATINA Wiedmann, 1966
Superfamily BOCHIANITOIDEA Spath, 1922
Family BOCHIANITIDAE Spath, 1922
Subfamily BOCHIANITINAE Spath, 1922
Genus *Bochianites* Lory, 1898

Type specie: *Baculites neocomiensis* D`Orbigny 1842, p. 560 (Busnardo in Gauthier, 2006, pl. 9, fig. 4, text-fig. 73a, 73b), by original designation.

Bochianites sp.

Figure 4.87a-c

Material: Fifty-six specimens, which are regular to very well preserved fragmentary to complete phragmocones. CPUC/CM/16-128 corresponds to a rock specimen with nineteen individuals. CPUC/CM/16-64 and CPUC/LV/3-132 are well preserved specimens.

Description: Straight shell with an ellipsoidal cross-section. Most specimens are internal moulds that are smooth and barrel-shaped. A few specimens preserve the shell, which is characterized by annular ribs or wavy constrictions.

Dimensions	L	D	d	d/D	R	R/L
CPUC/LV/3-732	46.2	8.1	6.1	0.75	9	0.19
CPUC/LV/3-197a	35.6		5.2		7	0.20
CPUC/LV/3-197b	15.3	2.9			5	0.33
CPUC/LV/3-318a	24.0	7.0	5.6	0.80	4	0.17
CPUC/LV/3-318b	27.1	6.4	5.3	0.83	4	0.15
CPUC/LV/3-318c	20.7	4.8	4.1	0.85	4	0.19
CPUC/CM/16-64	38.0	7.7	3.8	0.49	6	0.16
CPUC/CM/16-66	22.2	7.1	4.7	0.66	4	0.18

Remarks: Species of *Bochianites* are mainly distinguished by their suture line, but the latter is not observed in the specimens presented here.

Occurrence: *Bochianites* sp. is present in the Sandstone member at Lo Valdés and Cajón del Morado (figure 5.6 and 5.7). The genus is here recorded for the first time in Central Chile. In the Atacama Basin of northern Chile it is present in the Valanginian (Mourgues 2007). *Bochianites* is recorded from the lower Tithonian to Barremian of Europe, North and South Africa, Madagascar, the Himalayas, eastern Siberia, Russia, California, East Greenland, Mexico and Antarctica (Wright et al. 1996, Covacevich 1976 and Thomson 1974).

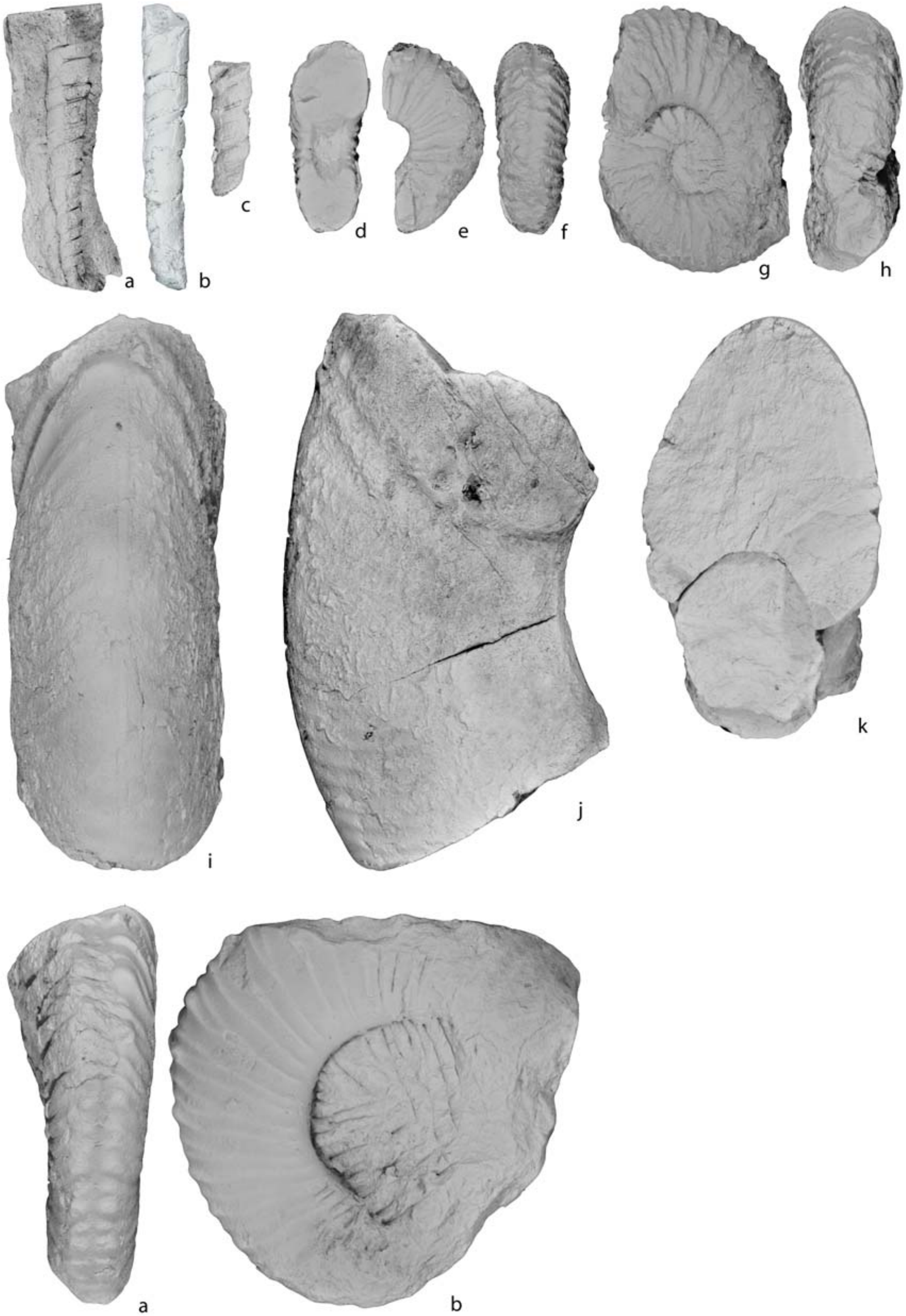


Figure 4.87. a-c: *Bochianites* sp. from Lo Valdés Formation. **a:** CPUC/CM/16-64, x1; **b:** CPUC/LV/3-132, x1; **c:** CPUC/CM/16-66, x1. **d-m:** *Pseudofavrella angulatiformis* (Behrendsen, 1892) from Lo Valdés Formation. **d-f:** CPUC/CM/18-151, x1; **g-h:** CPUC/CM/18-149, x1; **i-k:** CPUC/CM/18-76, x0.75; **l-m:** CPUC/CM/18-292, x1.

Family ANCYLOCERATIDAE Gill, 1871
Subfamily CRIOCERATITINAE Gill, 1871
Genus *Crioceratites* Léveillé, 1837
(= *Crioceras* D`Orbigny 1842, p. 457 unjustifed emendation)

Type species: *Crioceratites Duvalii* Léveillé (1837, p. 313), by subsequent designation by Diener (1925, p. 192).

Remarks on the genus: Systematic nomenclature follows the "Treatise of Invertebrate Paleontology" (Wright et al. 1996). The taxa "*andinum*"and "*diamantense*" were assigned by Vermeulen (2004) to different genera and families. They are here considered to belong to *Crioceratites*. See remarks on "*andinum*"and "*diamantense*".

Crioceratites andinum (Gerth 1925)
Figure 4.88, 4.89, 4.90, 4.91

1921 *Crioceras andinum* Gerth, p. 144 (*nomen nudum*).
1921 *Neohoplites Bederi* Gerth, p. 144 (*nomen nudum*).
1925 *Crioceras andinum* n. sp. Gerth, p. 113, pl. 1, figs. 1-2, pl. 2, figs. 2, 2a, text-fig. 14.
1925 *Crioceras Bederi* n. sp. Gerth, p. 116, pl. 2, figs. 1, 1a.
1928 *Crioceras andinum* Gerth. Gerth, p. 481, pl. 18, figs. 1-2 (= Gerth 1925).
1928 *Crioceras Bederi* Gerth. Gerth, p. 482.
1931 *Crioceras andinum* Gerth. Weaver, p. 463, pl. 57, fig. 362-364.
1931 *Crioceras andinum* Gerth. Windhausen, pl. 34, fig. 2 (= Gerth 1925).
1931 *Crioceras Bederi* Gerth. Windhausen, pl. 34, fig. 3 (= Gerth 1925).
? 1942 *Crioceras cañasense* Neuenschwander & Tavera, p. 1100, photo1.
1950 *Paracrioceras andinum* Gerth. Giovine, p. 56.
1958 *Crioceratites* aff. *andinum* Gerth. Bürgl, pl. 4, fig. 1.
1958 *Crioceras andinum* Gerth. Corvalán & Pérez, p. 38, pl. 11, figs. 24a-24b (= Gerth 1925).
1960 *Crioceratites* cf. *andinum* Gerth. Bürgl, p. 189, pl. 1, fig. 2 (=Bürgl 1958).
1964 *Paracrioceras andinum* (Gerth). Biro, p. 46.

1974 *Crioceras andinum* Gerth. Corvalán, p. 24.
1977 *Paracrioceras andinum* Gerth. Jurgan, p. 414, 426.
1993 *Crioceratites andinum* Gerth. Aguirre-Urreta, pl. 4, fig. 1 (= Gerth 1925).
2001 *Crioceratites* (*Paracrioceras*) cf. *andinum* Gerth. Aguirre, pl. 3, fig. 1.
2004 *Diamanticeras bederi* (Gerth). Vermeulen, p. 77.
2007 *Diamanticeras bederi* (Gerth). Klein et al., p. 65.
2007 *Paracrioceras*? *andinum* (Gerth). Klein et al., p. 82.
? 2007 *Crioceras canasense* Neuenschwander & Tavera. Klein et al., p. 261.

Type: The lectotype is designated here; it is specimen STIPB 1002 described as *Crioceras andinum* by Gerth (1925, p. 113, pl. 1, fig. 1).

Material: Three fragmentary phragmocones, CPUC/CM23-2, CPUC/CM23-5 and CPUC/LV/9-15. Specimen CPUC/LV/VIII-1 was collected and determinated by Biro (1964) and is also included. We also include the lectotype STIPB 1002 as well as paralectotypes STIPB 1065 and STIPB 1001, from the original collection of Gerth (1921-1925).

Description: Evolute, with a wide umbilicus. In juvenile specimens (D< 50 mm) the whorl section is oval to subrounded, higher than wide (figure 4.88). The sculpture is composed of spaced rectiradiate primary ribs. Fine secondaries are intercalated but present mainly on the ventrolateral area. Towards adult stages (D> 50 mm) coiling is even more evolute and the whorl section changes to subrounded and widely rectangular (figure 4.88). Primaries and some secondaries are stronger and equal primaries. Spaces between these ribs are increasingly irregular. The primary ribs are sculptured by tubercles on the umbilical and ventral border and are then frequently accompained by a constriction.

Dimensions	D	W	H	W/H	U	U/D
STIPB 1002	150.0	50.0	50.0	1.00	65.0	0.43
	100.0	35.0	35.5	0.99	41.5	0.42
STIPB 1065	82.0	28.0	29.0	0.97	33.0	0.40
STIPB 1066	38.0	11.0	13.0	0.85	14.0	0.37

Remarks: *Crioceratites andinum* was placed within *Paracrioceras* by Vermeulen (2004) and this genus assigned to the new family Emericiceratidae Vermeulen 2004. However, Klein et al. (2007

p. 67, footnote by Kakabadze) suggested that "creation of the Emericiceratidae is not justified and unnecessary", and that *Paracrioceras* should be included in Crioceratitidae. Ropolo (in Klein et al. 2007, p. 67) agrees with this interpretation which was "based on disputable arguments as tuberculation, for example. Important facts as dimorphism, intrageneric or intraspecific variability, and phylogenetic evolution are ignored". We agree with these arguments and maintain *Crioceratites andinum* as classified in Wright et al. (1996).

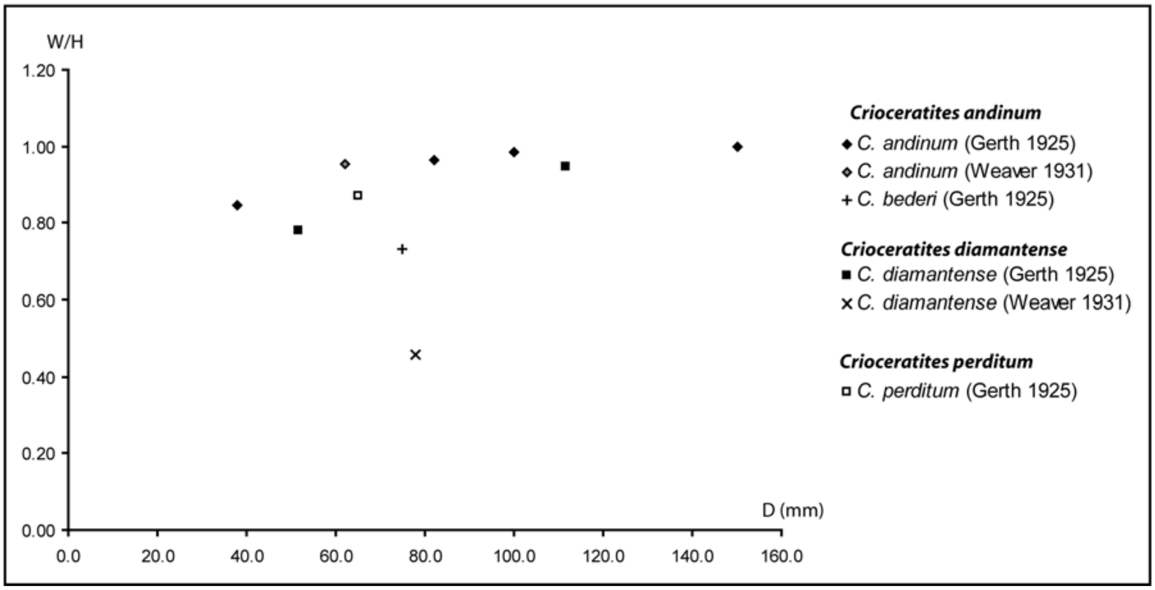


Figure 4.88. Relationship between W/H and D in *Crioceratites andinum, Crioceratites diamantense* and *Crioceratites perditum*.

The lectotype of *Crioceratites andinum* is designated here. It is specimen STIPB 1002, *Crioceras andinum* Gerth (1925, p. 113, pl. 1, fig. 1). According to Klein et al. (2007, p. 81), the lectotype was designated by Aguirre-Urreta (1993, p. 64). This assignement, however, is not valid, because specimen STIPB 1002 was only figured, but not officially designated as the lectotype.

"*Crioceras*" *bederi* Gerth (1925) was grouped with "*Crioceras*" *diamantense*, but no differential diagnosis of the taxon was given by Gerth (op. cit.) and the distinction of "*Crioceras*" *bederi* from other closely related taxa remains unclear. The single original located in Bonn (STIPB) agrees with the inner whorls of *Crioceratites andinum* as shown in the lectotype (STIPB 1002), and even weak eroded tubercles are present on the umbilical and ventral border. Hence, *C. bederi* is here considerd a junior synonym of *Crioceratites andinum*.

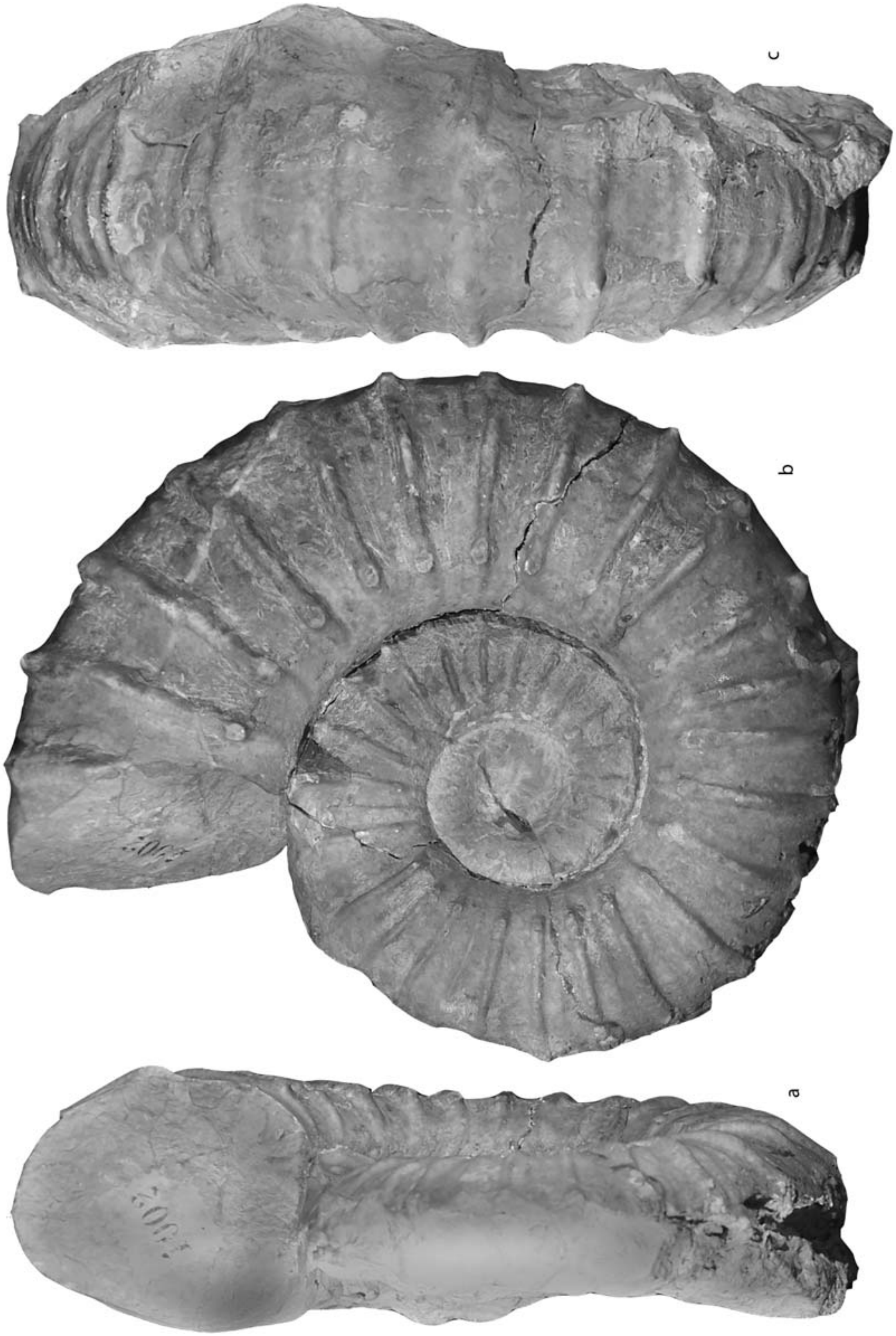


Figure 4.89. a-c: Lectotype of *Crioceratites andinum* (Gerth 1925). **a-c:** STIPB 1002, x1.

"*Crioceras*" *canasense* Neuenschwander & Tavera (1942) resembles *C. andinum* in the sculpture and coiling, but we were unable to locate the holotype.

Crioceratites diamantense differs from *Crioceratites andinum* by the absence of tubercles and stronger secondary ribs (see remarks on *C. diamantense*).

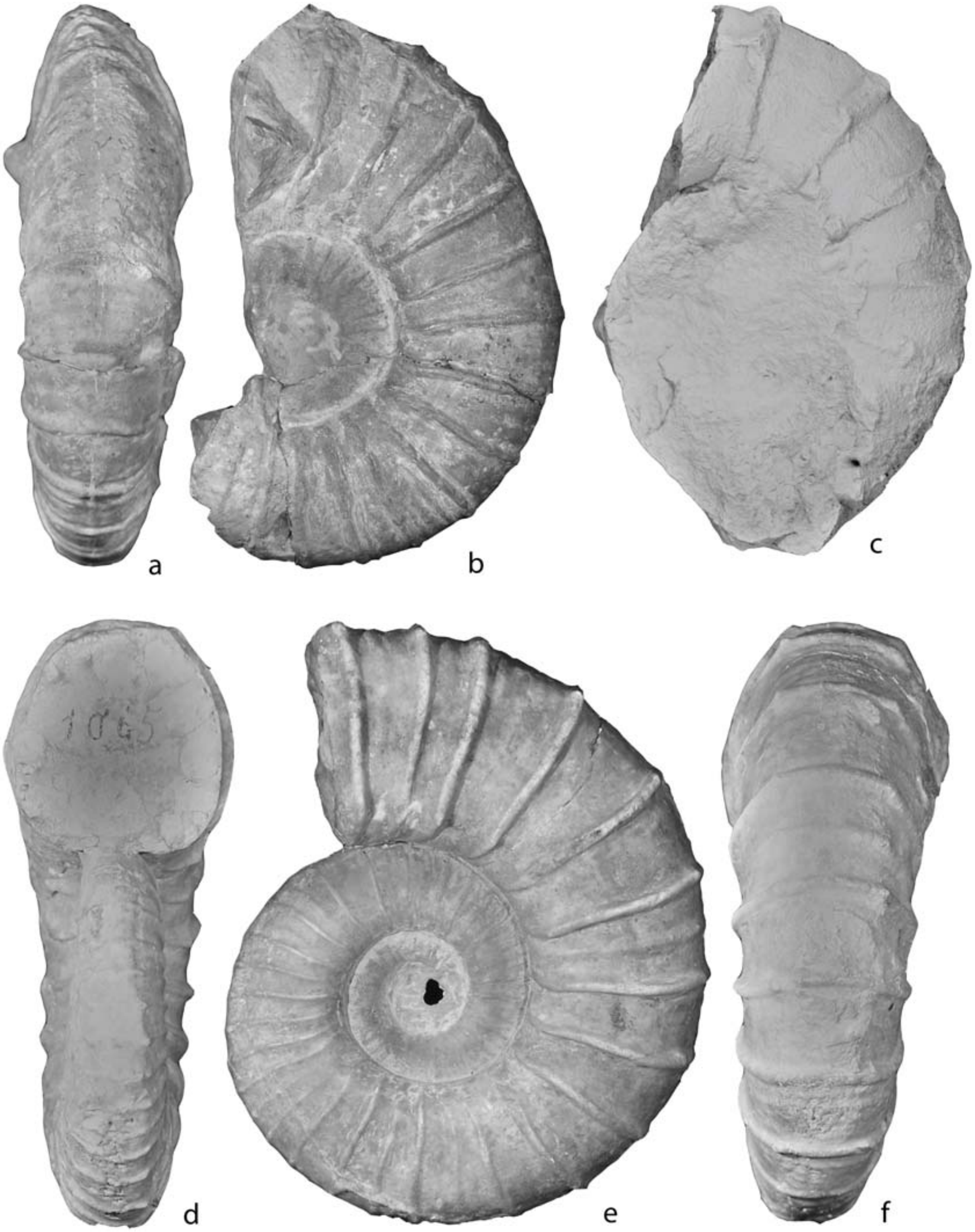


Figure 4.90. a-b, d-f: *Crioceratites andinum* (Gerth 1925) from Gerth`s collection (STIPB). **a-b:** "*Crioceras Bederi*", STIPB 1006, x1; **d-f:** "*Crioceras andinum*", STIPB 1065, x1. **c:** *Crioceratites andinum* (Gerth 1925) from Lo Valdés Formation. **c:** CPUC/LV/9-15, x1.

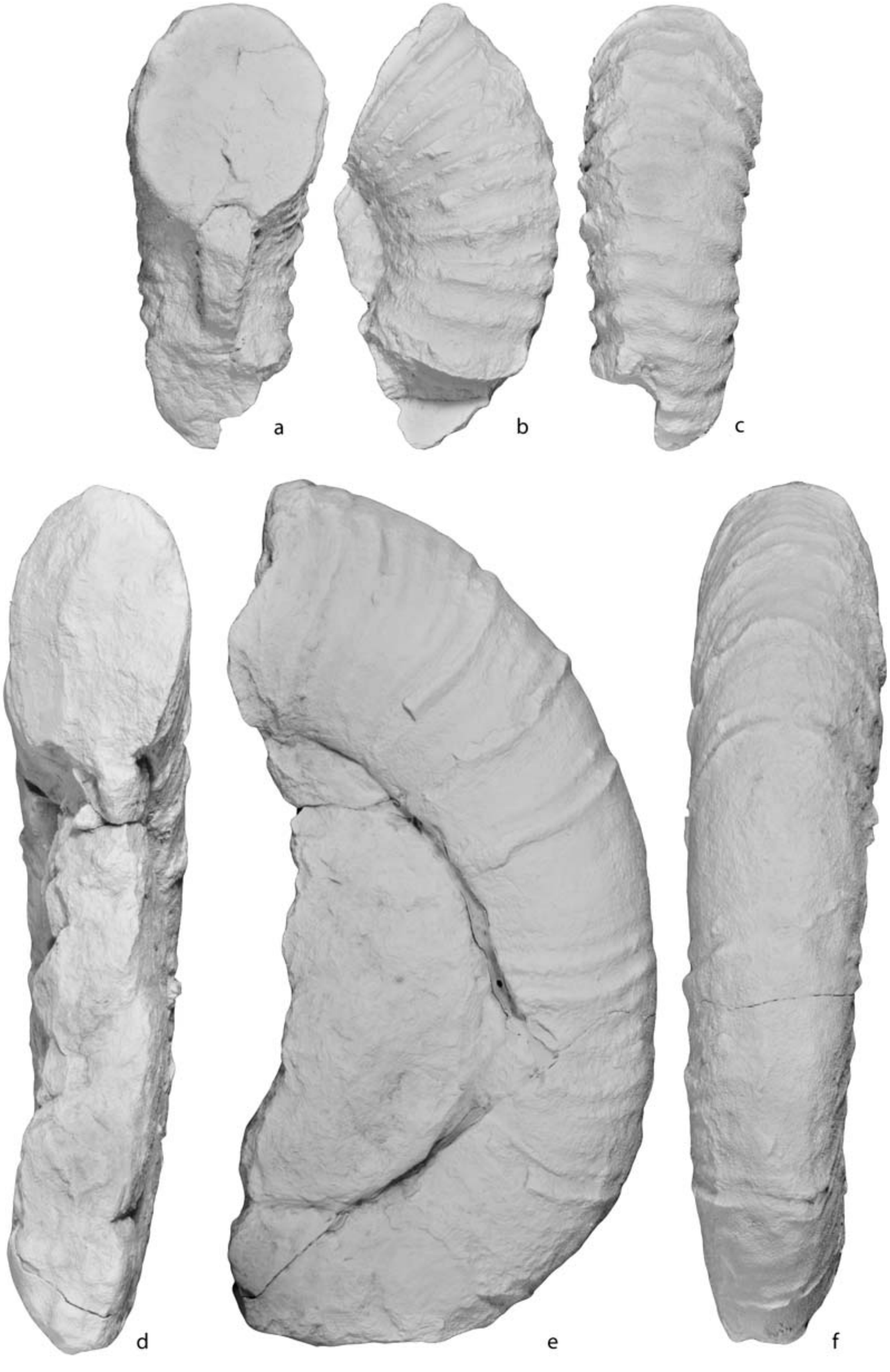


Figure 4.91. a-f: *Crioceratites andinum* (Gerth 1925) of Biro`s collection (1964) from Lo Valdés Formation. **a-c:** "*Paracrioceras andinum*", CPUC/LV/VIII-1, x1. **d-f:** "*Crioceras bederi*", CPUV/LV/VIII-30, x1.

Occurrence: *Crioceratites andinum* is present in the upper part of the Limestone member at Lo Valdés and Cajón del Morado (Figure 5.6 and 5.7). The taxon was earlier recorded by Biro (1964) from the Hauterivian of the Lo Valdés Formation and the Chañarcillo Group of northern Chile (Corvalán 1974, Jurgan 1977 and Aguirre 2001). In Colombia the taxon was recorded for the Valanginian (Bürgl 1960b). In Argentina *Crioceratites andinum* is known to occur in the Upper Hauterivian (Gerth 1921-1925, Weaver 1931 and Aguirre-Urreta 1993).

Crioceratites diamantense (Gerth 1925)

Figure 4.88, 4.92, 4.93, 4.94, 4.95

1921 *Neohoplites diamantensis* Gerth, p. 144 (*nomen nudum*)
1925 *Crioceras diamantense* n. sp. Gerth, p. 115, pl. 1, fig. 3-4, text-fig. 15-16
1928 *Crioceras diamantense* Gerth. Gerth, p. 482, pl. 19, figs. 4-5 (= Gerth 1925).
1931 *Crioceras diamantense* Gerth. Weaver, p. 462, pl. 57, fig. 360-361.
1950 *Crioceras diamantense* Gerth. Giovine, p. 53, pl. 5, fig. 1, pl. 6, fig. 3-4.
? 1956 *Crioceras diamantense* var. *nodosus* Gerth. Tavera, p. 207.
1958 *Crioceras diamantense* Gerth. Corvalán & Pérez, p. 44, pl. 11, fig. 25 (= Gerth 1925).
1964 *Crioceras diamantense* Gerth. Biro, p. 46.
1974 *Crioceras diamantense* Gerth. Corvalán, p. 26.
1977 *Crioceratites* (?) cf. *diamantense* (Gerth). Jurgan, p. 428.
1988 *Crioceratites diamantense* (Gerth). Riccardi, pl. 7, fig. 1, 2.
1993 *Crioceratites diamantense* (Gerth). Aguirre-Urreta, pl. 3, fig. 8 (= Gerth 1925).
1999 *Crioceratites diamantense* (Gerth). Aguirre-Urreta et al. pl. 1, fig. 11.
2004 *Diamanticeras diamantense* (Gerth). Vermeulen, p. 76, pl. 2, figs. 1-2 (= Riccardi 1988).
2004 *Crioceratites* aff. *schlagintweiti* (Giovine). Mourgues, p. 7, fig. 5e.
2005 *Crioceratites diamantense* (Gerth). Aguirre-Urreta et al., fig. 7h.
2007 *Crioceratites diamantense* (Gerth). Mourgues, p. 50, pl. 3, fig. 7 (= Gerth 1925 pl. 1, fig. 3), pl. 4, fig. 1 (= Gerth 1925 pl. 1, fig. 3) fig. 2, 4 (CPBA), pl. 5, figs. 1-2.

2007 *Crioceratites diamantense* (Gerth). Aguirre-Urreta et al., fig. 7E (= Mourgues 2007, pl. 5, fig. 4), 12H.

2007 *Diamanticeras diamantense* (Gerth). Klein et al. p. 66.

Type: The lectotype, designated here, is specimen STIPB 1066 described as *Crioceras diamantense* by Gerth (1925, p. 115, pl. 1, fig. 3). This specimen was refigured by Aguirre-Urreta (1993, p. 62) but not officially assigned as the lectotype, as indicated by Klein et al. (2007, p. 65).

Material: Fifteen complete and fragmentary phragmocones. CPUC/CM/23-3 is a complete specimen; CPUC/CM/23-6, CPUC/LV/9-9, CPUC/LV/9-19 and CPUC/LV/9-20 are well preserved fragmentary phragmocones. CPUC/LV/VIII-3 was collected and determinated by Biro (1964). The lectotype STIPB 1066 and paralectotypes STIPB 1067 and STIPB 1008 from the original collection of Gerth (1921-1925) are also included.

Description: Evolute, with a wide umbilicus. In juvenile stages (D< 50 mm) the whorl section is subrounded, higher than wide (figure 4.88). The maximum width is reached on the dorsolateral part of the shell. The umbilical border, flanks and venter are rounded. Ribs are strong and slightly sinuous. The transition from juvenile to adult stages (D> 50 mm) is gradual and characterized by an even wider umbilicus. The whorl section is subrounded to wide rectangular (figure 4.88). One in each four to seven ribs is stronger and presents a parallel constriction. Both stronger (primaries) and weaker ribs (secondaries) are slightly sinuous. In large specimens of D >100 mm, such as CPUC/LV/19-20, primaries are closer and stronger on the last whorl and are intercalated by two to four secondaries that are stronger than in previous whorls.

Dimensions	D	W	H	W/H	U	U/D
STIPB 1066	111.5	35.0	37.0	0.95	46.0	0.41
STIPB 1067	51.5	16.0	20.5	0.78	16.0	0.31
CPUC/CM/23-3	68.9		23.7		28.7	0.42
CPUC/CM/23-6		26.0	30.8	0.84	30.4	
CPUC/LV/9-19-	130.0	(37.9)	41.8	(1.10)	58.0	0.45

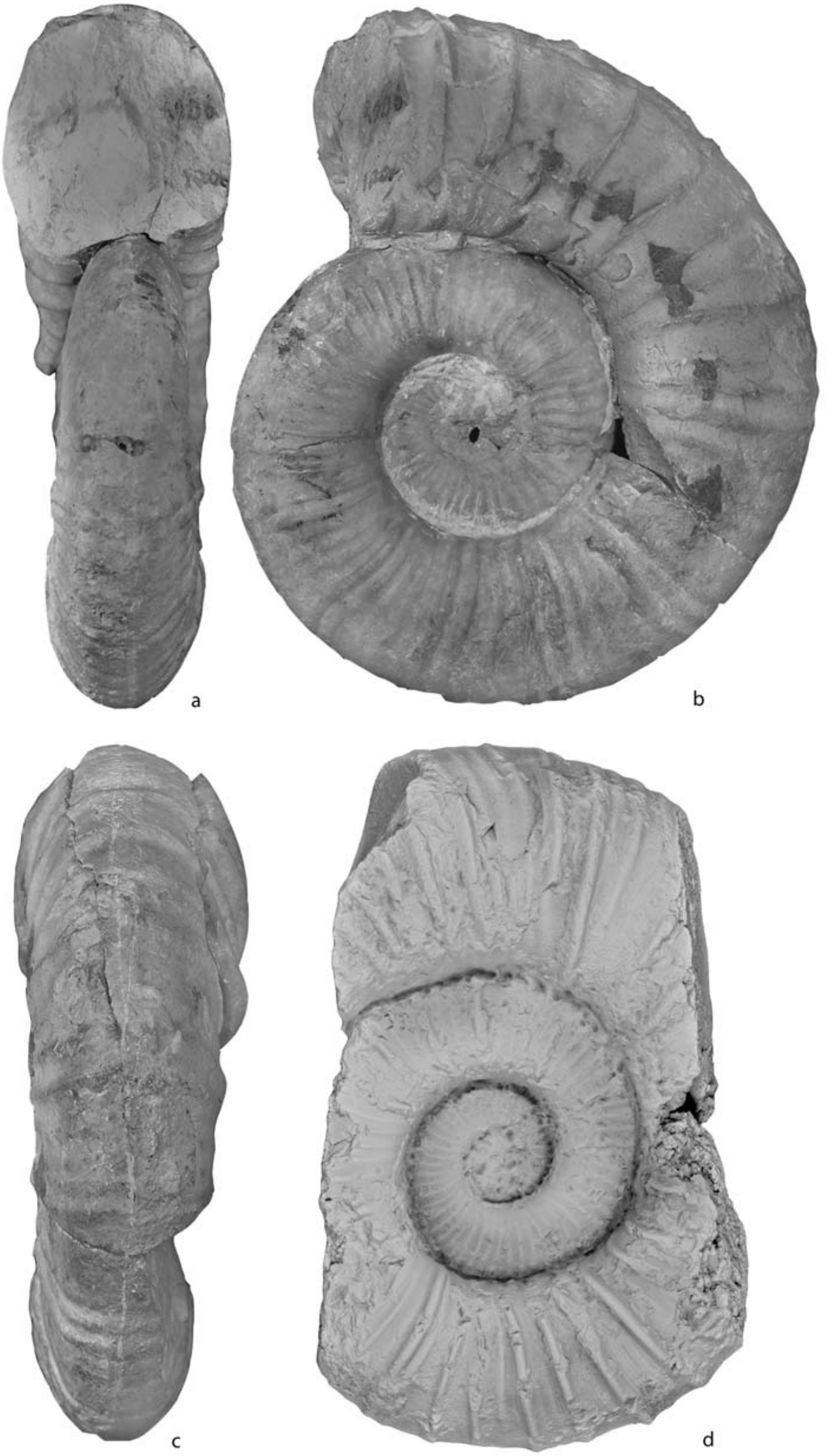


Figure 4.92. a-d: *Crioceratites diamantense* (Gerth 1925). **a-c:** Lectotype of *Crioceratites diamantense*, STIPB 1066, x1. **d:** *Crioceratites diamantense* from Lo Valdés Formation. **d:** CPUC/LV/9-19, x1.

Figure 4.93. a: *Crioceratites diamantense* from Lo Valdés Formation. **a:** CPUC/LV/9-20, x1.

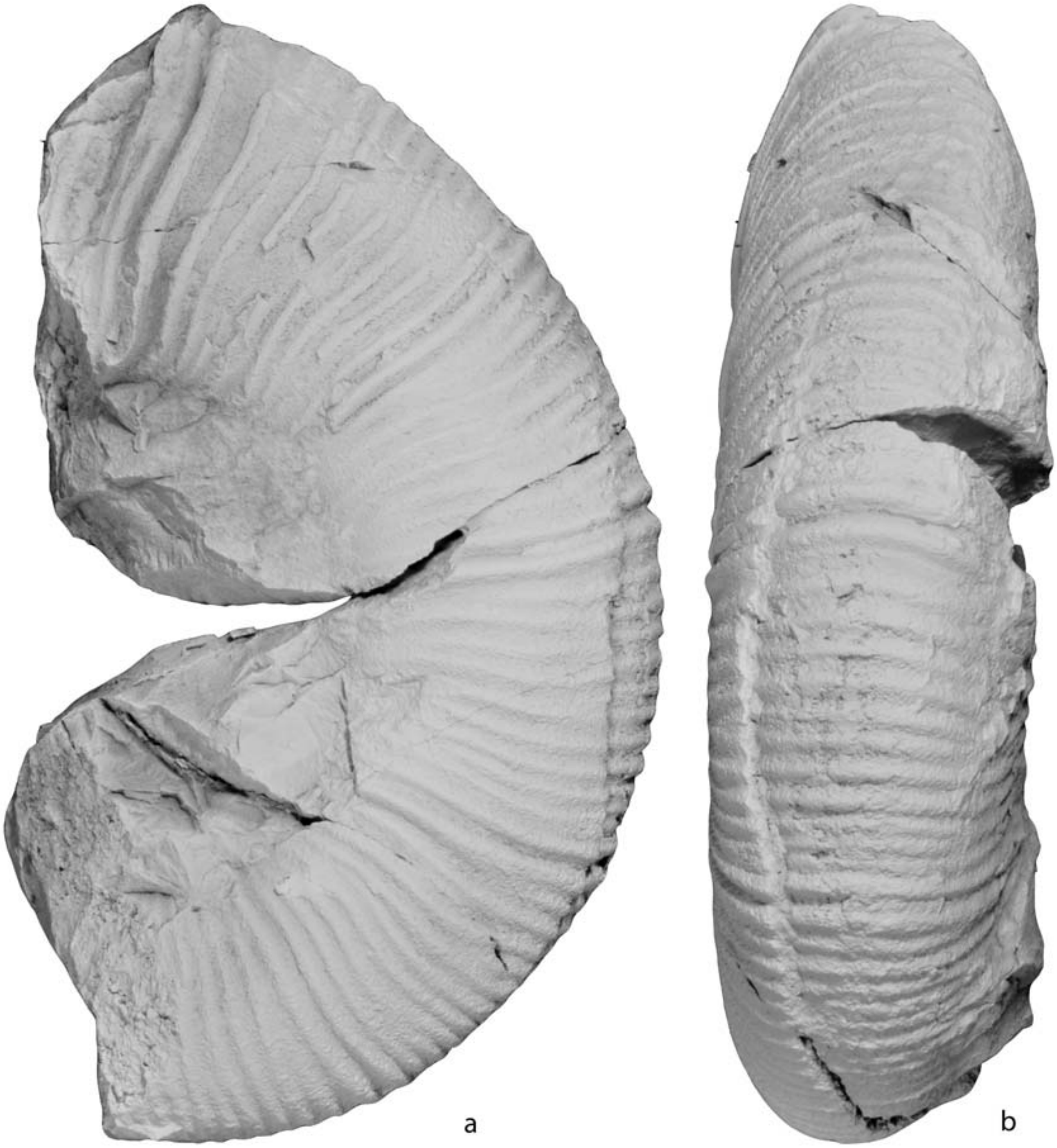


Figure 4.94. a-b: *Crioceratites diamantense* from Lo Valdés Formation. **a-b:** CPUC/LV/VIII-3, x1.

Remarks: *Crioceratites diamantense* was assigned generotype of *Diamanticeras* by Vermeulen (2004). The author also included *Crioceratites bederi* and *C. schlagintweiti* into this new genus (Vermeulen 2004). Here we do not follow this interpretation which does not sufficiently consider the morphological variability of taxa, dimorphism and phylogenetic evolution; we suggest following Wright et al. (1996) and maintaining an assignation within *Crioceratites*.

Crioceratites andinum differs from *Crioceratites diamantense* by the absence of umbilical and ventral tubercles on the primary ribs, and by weaker secondaries. Nevertheless, these differences may also be the result of sexual dimorphism.

Figure 4.95. a-f: *Crioceratites diamantense* from Lo Valdés Formation. **a-c:** CPUC/CM/23-6, x1. **d-f:** CPUC/LV/9-9, x1.

Occurrence: *Crioceratites diamantense* is present in the upper part of the Limestone member at Lo Valdés and Cajón del Morado (Figure 5.6 and 5.7). *C. diamantense* was previously reported for the Hauterivian of the Lo Valdés Formation by Biro (1964) and of the Chañarcillo Group in northern Chile (Corvalán 1974, Aguirre 2001, Mourgues 2004, 2007). In Argentina *C. diamantense* is reported from the Upper Hauterivian (Gerth 1921-1925, Weaver 1931, Aguirre-Urreta 1993 and Aguirre-Urreta et al. 1999, 2005).

Crioceratites perditum (Gerth 1925)

Figure 4.96

1921 *Neocomites perditus* Gerth, p. 144, 146 (*nomen nudum*).
1925 *Crioceras perditum* n. sp. Gerth, p. 114, pl. 1, fig. 5.
1928 *Crioceras perditum* Gerth. Gerth, p. 482.
2007 *Crioceras perditum* Gerth. Klein et al. p. 262.

Type: The lectotype, designated here, is specimen STIPB 1063, described as *Crioceras perditum* by Gerth (1925, p. 114, pl. 1, fig. 5).

Material: Four specimens. CPUC/LV/9-17 and CPUC/CM/23-10 are fragmentary well preserved phragmocones. CPUC/LV/9-16 and CPUC/CM/23-1 are regularly preserved fragmentary phragmocones. Lectotype STIPB 1063 from the original collection of Gerth (1921-1925) was also included in this review.

Description: Evolute with a wide umbilicus. The whorl section is subrounded to rectangular, higher than wide. The umbilical border is rounded, flanks are nearly flat to slightly rounded, and the venter is subrounded. In juveniles, strong slightly prorsiradiate and sinuous ribs occasionally present weak tubercles on the ventral border. In the largest specimen (CPUC/LV/9-17, D: 167.1 mm), these tubercles are absent. Ribs are bifurcated at mid-flank; one to three individual ribs are intercalated between the bifurcated ribs.

Dimensions	D	W	H	W/H	U	U/D
CPUC/LV/9-17	167.1	(49.7)	54.1	(0.92)	(69.9)	(0.42)
CPUC/CM/23-10		40.1	52.9	0.76		
STIPB 1063	65.0	20.0	23.0	0.87	25.0	0.38

Remarks: *Crioceratites perditum* is close to *C. andinum* and *C. diamantense*, but flanks are less rounded, ribs are closer, and no constrictians, or tubercles are present on the umbilical and ventral borders.

Occurrence: *Crioceratites perditum* is registered for first time in Chile in the upper part of the Limestone member at Lo Valdés and Cajón del Morado (Figure 5.6 and 5.7). In Argentina *C. perditum* is recorded for the Hauterivian (Gerth 1925).

Figure 4.96. a-b: *Crioceratites perditum* from Lo Valdés Formation. **a-b:** CPUC/CM/23-3, x1.

4.3 Summary of Systematic Palaeontology

Ammonites from the Baños del Flaco Formation

The Baños del Flaco Formation in central Chile contains abundant and well preserved Tithonian (Late Jurassic) ammonites. At Rio Maitenes in the Curicó province, the unit contains 12 species referred to 10 genera. This faunal assemblage is here described and discussed for the first time. *Windhauseniceras internispinosum*, *Corongoceras alternans* and *Substeueroceras koeneni* were informally recorded previously from the coeval Baños del Flaco Formation. *Aulacosphinctes proximus*, *Micracanthoceras spinulosum* and *Corongoceras evolutum* are new records for the Baños del Flaco Formation. *Pseudolissoceras* cf. *zitteli*, *Euvirgalithacoceras malarguense*, *Choicensisphinctes windhauseni*, *Catutosphinctes* cf. *americanensis*, *Virgatosphinctes scythicus* and *Micracanthoceras microcanthum* are first registers for Chile. *Micracanthoceras spinulosum* shows strong ontogenetic changes not recorded previously. *Virgatosphinctes scythicus* is here considered a morphologically variable species and considered synonymous with classical South and Central American taxa such as *Virgatosphinctes andesensis*, *V. mendozanus*, *V. mexicanus* and *V. leñaensis*. *Windhauseniceras internispinosum* is a rare taxon elsewhere but relatively abundant at Rio Maitenes; its morphology varies considerably during ontogeny. *Virgatosphinctes* aff. *pseudolictor* and *V.* cf. *raja*, both described by Indans 1954, and *V. guadalupensis,* are considered synonymous with *E. malarguense,* while *V. tenuilineatus* is synonymous with *C. windhauseni* and *Aulacosphinctes chilensis* with *A. proximus*. Other synonymies include *Micracanthoceras lamberti* and *M. tapiai,* with *M. microcanthum,* and *Corongoceras rigali* with *C. alternans*. *Windhauseniceras internispinosum* and *Corongoceras alternans* indicate a Tithonian age for most of the Baños del Flaco Formation. Unexpectedly, *Virgatosphinctes scythicus* and *Micracanthoceras microcanthum*, Tithonian index fossils for the Russian platform and Tethys, respectively, are present in central Chile and also confirm a Tithonian age for most of the Baños del Flaco Formation. The presence of *Substeueroceras koeneni* suggests a basal Berriasian age for the uppermost Baños del Flaco Formation, if Zeiss`s (1983) correlation is accepted.

Summary of the most important synonymies presented here from Baños del Flaco Formation

This study	Previously publications
Virgatosphinctes scythicus (Vischniakoff, 1882)	- *Virgatosphinctes mexicanus* (Burckhardt 1906) - *V. andesensis* (Douvillé 1910) - *V. mendozanus* (Douvillé 1910) - *Virgatosphinctes leñaensis* (Corvalán 1959)
E. malarguense	- *Virgatosphinctes* aff. *pseudolictor* described by Indans 1954 - *Virgatosphinctes* cf. *raja* described by Indans 1954, - *V. guadalupensis*
Choicensisphinctes windhauseni (Weaver, 1931)	- "*Virgatosphinctes*" (*L.*) *tenuilineatus* (Indans 1954) - *Perisphinctes involutus* by Burckhardt (1900a) - *Virgatites australis* by Burckhardt (1903) and Indans (1954)
Aulacosphinctes proximus.	- *Aulacosphinctes chilensis* Corvalán (1959)
Micracanthoceras microcanthum	- *Micracanthoceras lamberti* - *Micracanthoceras tapiai*
Corongoceras alternans	- *Corongoceras rigali*

Ammonites from the Lo Valdés Formation

The Lo Valdés Formation in the Andes of central Chile contains abundant and well preserved ammonites, indicating a Tithonian-Hauterivian age (Late Jurassic-Early Cretaceous) for this unit. In the type locality at Lo Valdés as well as at Cajón del Morado and Cruz de Piedra, a total of 39 species were distinguished referred to 22 genera. This faunal assemblage is here described and discussed for the first time. *Aulacosphinctes proximus*, *Micracanthoceras spinulosum*, *Corongoceras* cf. *koellikeri*, *Substeueroceras koeneni*, *Argentiniceras fasciculatum*, *Pseudofavrella angulatiformis*, *Crioceratites andinum* and *Crioceratites diamantense* were informally recorded previously from the Lo Valdés Formation. *Frenguelliceras magister* is a new record for the unit and for central Chile. *Pterolytoceras exoticum*, *Aspidoceras rogoznicense*, *Micracanthoceras microcanthum*, *Micracanthoceras vetustum*, *Corongoceras lotenoense*, *Corongoceras mendozanum*, *Spiticeras acutum*, *Spiticeras pricei*, *Spiticeras spitiense*, *Groebericeras rocardi*, *Berriasella* (*Berriasella*) *jacobi*, *Malbosiceras malbosi*, *Chigaroceras bardensis*, *Tirnovella kayseri*, *Thurmaniceras thurmanni*, *Crioceratites perditum* and *Bochianites* sp. are first registers for Chile. *Lytohoplites paredesi*n. sp., *Lytohoplites zambranoi* n. sp., *Lytohoplites varelae* n. sp. and *Lytohoplites rauloi* n. sp. are new species. The neotype of *Substeueroceras* is designated here and corresponds to the lectotype of *Substeueroceras koeneni*. *Parodontoceras* is here considered a junior synonym of *Substeueroceras*. Other lectotypes were designated for *Micracanthoceras spinulosum*, *Micracanthoceras vetustum* , *Spiticeras acutum*, *Substeueroceras calistoide*, *Argentiniceras fasciculatum*, *Tirnovella kayseri*, *Crioceratites andinum*, *Crioceratites diamantense* and *Crioceratites perditum*. *Spiticeras acutum* is considered a morphologically variable taxon. *Berriasella fraudans* is considered a senior synonym of *B. Jacobi*; nevertheless *B. jacobi* is a widely used index taxon for the base of the Berriasian and the name should be kept. This discussion should be solved through an article in the Bulletin of Zoological Nomenclature.

The following Upper Tithonian to Upper Hauterivian index fossils are used to subdivide the Lo Valdés Formation: *Micracanthoceras microcanthum* (lower Upper Tithonian), *Corongoceras alternans*, *Berriasella jacobi*, *Groebericeras rocardi*, *Substeueroceras koeneni* (lower Lower Berriasian), *Thurmanniceras thurmanni*, *Argentiniceras fasciculatum* and *Crioceratites diamantense*.

Summary of the most important synonymies presented here from Lo Valdés Formation

This study	Previously publications
Pterolytoceras exoticum (Oppel, 1863)	- *Pterolytoceras magnum* Biro (1980)
Aspidoceras rogoznicense (Zeuschner, 1846)	- *Aspidoceras euomphalum* Steuer (1897) - *Aspidoceras cieneguitense* Steuer (1897) - *Aspidoceras andinum* Steuer (1897) - *Aspidoceras euomphaloides*, *Aspidoceras quemadense* Burckhardt (1906) - *Aspidoceras haupti* Krantz (1928) - *Aspidoceras neuquensis* Weaver 1931 - *Aspidoceras* aff. *binodum*, *Aspidoceras* cf. *iphiceroides,* - *Aspidoceras* cf. *iphiceroides* and *Aspidoceras spinosum* described by Collignon (1959)
Aulacosphinctes proximus (Steuer, 1897)	- *Aulacosphinctes wanneri* Krantz (1928) - *Reineckeia mangaensis* Steuer (1897) - *Perisphinctes colubrinus* by Steuer (1897) - *Aulacosphinctes azulensis* Leanza (1945)
Micracanthoceras microcanthum (Oppel, 1865)	- *Micracanthoceras lamberti* A. Leanza (1945) - *Micracanthoceras tapiai* A. Leanza (1945) - *Micracanthoceras aguajitense* Imlay (1939) - *Micracanthoceras alamense* Imlay (1939)
Micracanthoceras spinulosum (Gerth, 1925)	- *Malbosiceras*? *inaequicostatum* (Gerth 1925)
Micracanthoceras vetustum (Steuer 1897)	- *Hoplites Wallichi* by Steuer (1897) - *Berriasella subvetusta* (Steuer 1897) - *Berriasella subprivasensis* Krantz (1926) - *Riasanites rjasanensoides* (Krantz 1926) - *Berriasella* (*R.*) aff. *swistowianus* by Krantz (1926) - *Corongoceras duraznenses* (Krantz 1926) - *Berriasella subprivasensis* Krantz (1926)
Corongoceras alternans (Gerth 1925)	*Berriasella pastorei* A. Leanza (1945) *Corongoceras rigali* A. Leanza (1945)

Corongoceras mendozanum (Behrendsen 1891)	- *Berriasella groeberi* A. Leanza (1945) - *Berriasella delhaesi* A. Leanza (1945) - *Corongoceras submendozana* Krantz (1945)
Spiticeras acutum Gerth (1925)	- *Spiticeras burckhardti* Gerth (1925) - *Spiticeras hauthali* Gerth (1925) - *Spiticeras stultum* A. Leanza (1945) - *Spiticeras andinum* A. Leanza (1945) - *Spiticeras mammatum* A. Leanza (1945)
Spiticeras spitiense (Blanford, 1864)	- ? *Spiticeras obliteratum* A. Leanza (1945) - ? *Negreliceras singulare* (A. Leanza, 1945)
Spiticeras tripartitum (Hupé 1854)	- *Spiticeras*? *tripartitum lovaldensis* Biro (1980) - *Kilianiceras damesi* (Steuer 1897)
Berriasella (*Berriasella*) *jacobi* Mazenot (1939)	- *Berriasella fraudans* (Steuer 1897) - *Parandiceras*? *fallax* (Steuer 1897) - *Berriasella steinmanni* Krantz 1926 - *Andiceras acuticostum* Krantz 1926 - *Berriasella curvicostata* Rivera 1951 - *Berriasella peruviana* n. sp. Rivera 1951
Substeueroceras calistoide (Behrendsen 1891)	- *Substeueroceras ellipsostomum* (Steuer 1897) - *Substeueroceras incertum* (Steuer 1897) - *Substeueroceras intercostatum* (Steuer 1897)
Substeueroceras koeneni (Steuer 1897)	- *Substeueroceras durangense* (Burckhardt) - *Substeueroceras lamellicostatum* (Burckhardt 1912) - *Substeueroceras fasciatum* (Steuer 1897) - *Substeueroceras subfasciatum* (Steuer 1897) - *Substeueroceras permulticostatum* (Steuer 1897) - *Substeueroceras steueri* (Gerth 1925) - *Substeueroceras rotundatum* (Gerth 1925) - *Substeueroceras kelluni* Imlay (1939)
Substeueroceras striolatissimum (Steuer 1897)	- *Paraulacosphinctes striolatus* (Steuer 1897) - *Perisphinctes densestriatus* (Steuer 1897)
Malbosiceras malbosi (Pictet 1867)	- *Neocosmoceras malbosiforme* (Steuer 1897)

Chigaroceras bardensis (Krantz 1928)	- *Chigaroceras gerthi* (Kratnz 1928) - *Chigaroceras wetzeli* Howarth (1992)
Neocosmoceras sayni (Simionescu 1899)	- *Neocosmoceras wichmanni* (Gerth 1925)
Argentiniceras fasciculatum (Steuer 1897)	- *Argentiniceras noduliferum* (Steuer 1897)
Tirnovella kayseri (Steuer 1897)	- *Tirnovella tenera* (Steuer 1897) - *Tirnovella densestriata* (Burckhardt 1912) - *Thurmanniceras discoidale* (Gerth 1925)
Cuyaniceras transgrediens (Steuer 1897)	- *Cuyaniceras inflatum* (Gerth 1925) - *Cuyaniceras mendozanum* A. Leanza (1945) - *Cuyaniceras raripartitum* (Steuer 1897) - *Cuyaniceras acanthicum*. A. Leanza (1945) - *Cuyaniceras argentinum* A. Leanza (1945)
Thurmanniceras thurmanni (Pictet & Campiche 1860)	- *Thurmanniceras duraznense* (Gerth 1925) - *Thurmanniceras duraznense lateumbilicatum* A. Leanza (1945) - *Thurmanniceras chicoensis* (Weaver 1931) - *Thurmanniceras constrictum* (Krantz 1926) - *Thurmanniceras grandium* Chao (1976) - *Thurmanniceras neogaeum* (A. Leanza 1945)
Crioceratites andinum (Gerth 1925)	- *Diamanticeras bederi* (Gerth 1925) - *Crioceras canasense* Neuenschwander & Tavera (1942)

5. Biostratigraphy and Bioevents

Even though the position of the Jurassic-Cretaceous (J/K) boundary has been discussed for more than a century in numerous symposia, no internationally valid position for this boundary has yet been agreed upon (Remane 1991, Zakharov et al. 1996). The Tithonian/Berriasian boundary was recommended by the Lyon/Neuchâtel colloquium of 1973 (Remane 1994), but has not been accepted by all subsequent authors, as a result of the complex situation at the end of the Jurassic and the absence of a well established international standard correlation.

Some authors (e.g. Wiedmann 1980, Rawson 1990, Remane 1990, in Zakharov et al. 1996) "have indicated that the latter boundary could usefully be placed above the Berriasian, at the base of the Valanginian".

Remane (1991) discussed the stratigraphic problems related to the Jurassic-Cretaceous (J-K) as caused by (1) the absence of a significant faunal turnover at both boundaries of the Berriasian, and (2) by extreme faunal provincialism as a consequence of the Purbeckian regression.

In the same article, Remane (1991) pointed out that after dozens of meetings on the J-K boundary, none of these managed to solve the problem, for the following reasons:

- The J-K boundary does not correspond to an important faunal change.
- There has been much futile debate about the intrinsic nature of Berriasian faunas, whether they are more Jurassic or more Cretaceous in character.
- The J-K boundary was originally defined by the Purbeckian regression. This regression was a global event, resulting in very pronounced biogeographic provincialism during Tithonian-Volgian and Berriasian times.
- It is generally agreed that fossils are important markers in Phanerozoic time correlation, but there is no consensus about the exact meaning of zones based on the stratigraphic distribution of fossils.

During the International Working Group on the J-K Boundary in Moscow (1984), some recommendations were given, which are also discussed in Remane (1991):

- The J-K boundary should be defined in marine facies in the Tethyan realm.

- The first candidate for the J-K boundary is the Tethyan Tithonian-Berriasian boundary, which corresponds to the base of a combined *Berriasella jacobi – Pseudosubplanites grandis* Zone.
- Should it be proven impossible to correlate this boundary level from the Tethyan with the Boreal realm, another biozone close to the latter should be preferred; in that case the base of the *Tirnovella occitana* Zone might be a good solution (Hoedemaeker, 1987).
- Pending a final decision on the J-K boundary, the Berriasian should be placed in the Cretaceous.

Remane (op. cit.) concentrated on biochronology and also gave recommendations for future work, such as the possible importance of magnetostratigraphy. Erba (1995, in Zakharov et al. 1996) “challenged palaeontologists to consider the role of magnetostratigraphy, chemostratigraphy, sequence stratigraphy and cyclostratigraphy in defining Cretaceous stage boundaries”.

At a meeting at Brussels (in Zakharov et al. 1996), the Working Group discussed possible Global Stratotype Sections and Points (GSSPs) and concluded that the GSSP for the J/K boundary should be placed either in SE France or SE Spain; in these sections two possible faunal events mark the base of the Berriasian (figure 5.1):

- Base of the *jacobi* ammonite Zone
- Base of the *subalpina* ammonite Subzone (*occitanica* Ammonite Zone).

The faunal event discussed above occurs in the Tethyan Realm and needs to be correlated with the Boreal and Austral faunal realms (figure 5.1). Biozonation with these regions is presently not possible, due to the lack of shared taxa. Part of the problem, on the other hand, may be artificial and caused by palaeontological splitting of taxa. Interestingly, early European palaeontologists working on the South American faunal assemblages (e.g. Steuer 1897-1921, Gerth 1921-1925) recognized major similarities between European and South American taxa. Later, however, in the 1940ies, a new trend in description led towards another direction in the Biostratigraphy and Systematic Palaeontology of South American ammonites. Starting with H. Leanza (1945) a strong descriptive division and introduction of new taxa took place which were mostly based on minor morphological differences. This splitting of taxa led to ammonite assemblages with restricted and mostly endemic distribution. Biozonations based on these taxa are thus of local, or regional value, but do no longer allow for intercontinental correlation. Following present nomenclature, only a few South American taxa are also recorded from outside the South American continent. For instance, *Substeueroceras koeneni* is also known from Mexico and India.

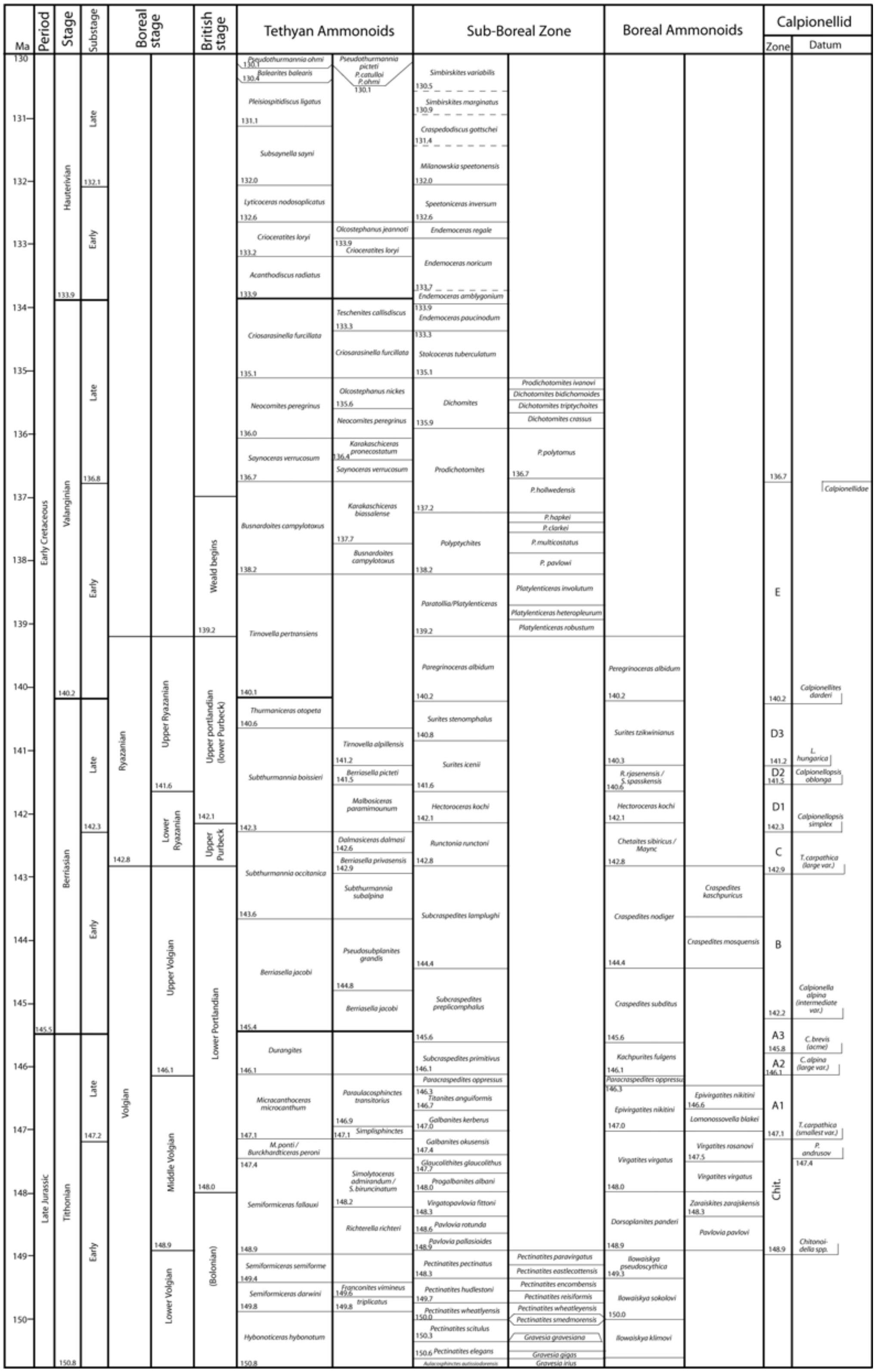


Figure 5.1. Tithonian-Hauterivian biozonations generated by to Time Scale Creator 5.3 based on SEPM 2004. Ammonites Biozones baccording with Thierry et al. (1998, in Hardenbol et al., SEPM charts, 1998), with GTS2004 revisions (Ogg et al. 2004). Calpionellids Remane (1991, in Hardenbol et al., SEPM charts, 1998), with GTS2004 revisions, (Ogg et al. 2004).

In the past 20 years new concepts were introduced to Systematic Palaeontology, such as sexual dimorphism and major intraspecific variability of the morphology. These concepts now allow for a detailed reevaluation of ammonite species present in the Chilean Andes basin. The present review indicates that endemism is still an important factor in the region, but that Tethyan, Boreal, Antarctic and Indian taxa are also present. The biogeographical connections between South America and other regions worldwide are thus much higher than previously known. They now allow for the first direct faunal correlation between Chilean and Tethyan ammonites assemblages.

5.1. The standard zonation

5.1.1. Tithonian

The historical biozonation of the Jurassic is based on ammonites. In addition, brachiopod and bivalve assemblages provide important regional markers in the Tethyan realm. Dinosaurs and palynology are less precise but calibrate terrestrial sections to the marine record (Ogg 2004, in Gradstein et al. 2004).

The GSSP candidate section for the Tithonian is located at Crussol Mountain in southeast France. Other potential GSSP sections are in the Swabian region of south Germany (Atrops 1994, in Gradstein et al. 2004).

The Tithonian-Kimmeridgian boundary in the Tethyan faunal realm is marked by the first occurrence of the ammonite *Hybonoticeras hybonotum* (figure 5.1), followed by the first occurrence of the genus *Gravesia* (Ogg 2004, in Gradstein et al. 2004).

The base of Upper Tithonian in Tethyan faunal domains is assigned to a major turnover in the ammonite assemblage at the base of the *Micracanthoceras microcanthum* Zone, whereas the Uppermost Tithonian is marked by the *Durangites* Zone, characterized by the range of this genus (figure 5.1; Ogg 2004, in Gradstein et al. 2004).

In the Boreal realm, the base of the “Volgian” stage is marked by the first occurrence of *Ilowaiskya klimovi*. The boundary between the Lower and the Middle “Volgian” is assigned to the base of the *Dorsoplanites panderi* ammonite zone (figure 5.1; Ogg 2004, in Gradstein et al. 2004). The base of the Upper “Volgian” is correlated with the base of the Berriasian.

5.1.2. Berriasian

Most authors suggest that the Berriasian should be considered to be the basal stage of the Cretaceous period (e.g. Wiedmann 1980, Rawson 1990, Remane 1990, in Zakharov et al. 1996), Hoedemaeker et al. 2003).

The base of the Berriasian is marked by the first occurrence of *Berriasella jacobi* (Hoedemaeker et al. 1993), and this ammonite biozone corresponds to the base of Calpionellid Zone B (figure 5.1). Based on ammonites of the upper Lower Berriasian is marked by the presence of *Subthurmannia occitanica*. This zone is divided in the *Subthurmannia alpina, Berriasella privasensis* and *Dalmasiceras dalmasi* subzones (figure 5.1; Ogg et al. 2004, in Gradstein et al. 2004).

The Upper Berriasian is marked by the first occurrence of *Subthurmannia boissieri* and is subdivided into a lower subzone characterized by the presence of *Malbosiceras paramimunum* (Zakharov et al. 1996); this level is approximately equivalent to the base of Calpionellid Zone D (figure 5.1). The upper zone of the Upper Berriasian is characterized by the presence of *Thurmaniceras otopeta* (figure 5.1; Ogg 2004, in Gradstein et al. 2004 and Thierry et al., in Hardenbol et al. 1998, Ogg et al. 2004).

5.1.3. Valanginian

The Valanginian Working Group recommends placing the base of the Valanginian at the base of Calpionellid Zone E (Hoedemaeker et al. 2003; figure 5.1), defined by the first occurrence of *Calpionellites darderi* (Aguado et al. 2000, in Ogg et al. 2004). This stratigraphic level coincides with the last record of *Thurmanniceras otopeta* in the Upper Berriasian. A GSSP candidate is located in southeast France and contains well-preserved ammonoids and calpionellids; the first occurrence of *Thurmanniceras pertransiens* is recognized shortly above the proposed boundary level (figure 5.1; Blanc et al. 1996, in Ogg et al. 2004).

The *Busnardoides campylotoxus* Zone is located in the upper part of the Lower Valanginian and is subdivided into the *Busnardoides campylotoxus* Subzone at the base and the *Karakaschiceras biassalense* Subzone at the top (figure 5.1; Hoedemaeker et al. 2003).

The lower part of the Upper Valanginian is marked by the first occurrence of *Saynoceras verrucosum*. This biozone is subdivided in the *Saynoceras verrucosum* and *Karakaschiceras pronecostatum* subzones (figure 5.1). Overlying the *Saynoceras verrucosum* Zone, the *Neocomites peregrinus* Zone was adopted from Reboulet & Atrops (1999; in Hoedemaeker et al. 2003). Thus zone is divided in the *Neocomites peregrinus* and *Olcostephanus* (*O.*) *nicklesi* subzones (figure 5.1; Hoedemaeker et al. 2003). The uppermost zone of the Upper Valanginian is characterized by the presence of *Criosarasinella furcillata*. This zone is subdivided in the *Criosarasinella furcillata* and *Teschenites callidiscus* subzones, as proposed by Reboulet & Atrops (1999; in Hoedemaeker et al. 2003) (figure 5.1).

5.1.4. Hauterivian

The base of the Hauterivian is traditionally defined by the first appearance of the ammonite *Acanthodiscus radiatus* (Birkelund et al. 1984, in Mutterlose et al. 1996). Overlying the *A. radiatus* Zone, *Crioceratites loryi* marks the middle and the *Lyticoceras nodosoplicatus* Zone the upper part of the Lower Hauterivian (figure 5.1; Thierry et al. in Hardenbol et al., 1998, Ogg et al. 2004).

The base of the Upper Hauterivian is defined by *Subsaynella sayni* Zone (Bulot et al. 1993, in Mutterlose et al. 1996). This ammonite zone is followed by the *Pleisiopitidiscus ligatus* and *Balearites balearis* zones. The uppermost part of the Upper Hauterivian is characterized by the presence of *Pseudothurmannia ohmi* (figure 5.1; Thierry et al. in Hardenbol et al., 1998, Ogg et al. 2004).

5.2. South American zones

In South America, ammonites across the Jurassic-Cretaceous boundary (Tithonian-Hauterivian) are well registered in Colombia, Peru, Argentina and Chile (Leanza H. 1981a). The sequence is best studied in Argentinean localities (e.g. Steuer 1897-1921, Gerth 1921-1925, Leanza A. 1945, Leanza H. 1980, Parent et al. 2011a and 2011b).

Harrington (1962, in Leanza H. 1981a) suggested that the Jurassic-Cretaceous boundary in Argentina should best be placed between the Kimmeridgian and the Tithonian stages.

Even though, Leanza H. (1981a) considered the Berriasian to be the last stage of the Jurassic, in contrast to the classical classification of the basal Cretaceous discussed above. This author argued that ammonites of the Berriasian show a phylogenetic continuity with respect to the Tithonian assemblages and that the major faunal turnover is recognized near the Berriasian-Valanginian boundary. Wiedmann (1967, 1968, 1973, 1975, in Leanza H. 1981a) also considered the

Berriasian to be the highest stage of the Jurassic. This interpretation was followed by Volkheimer (1973, 1978, in Leanza H. 1981a) and Leanza H. (1981b).

Nevertheless, subsequent authors on the Jurassic-Cretaceous boundary in Argentina and South America (e.g. Zeiss & Leanza 2010, Parent et al. 2011B) did not follow the interpretation proposed by H. Leanza (1981a), but used the international standard, in which the Tithonian is considered to form the last stage of the Jurassic and the Berriasian the first stage of the Cretaceous (Ogg 2004 and Ogg et al. 2004 in Gradstein et al. 2004).

The South American standard ammonite biozonation across the Jurassic/Cretaceous boundary was proposed by A. Leanza (1945) and later modified by H. Leanza (1980); subsequent adjustments and supplements were added by Riccardi (1988), Zeiss & Leanza (2010) and Parent et al. (2011B). It only includes species endemic to Central Argentina and Chile (figure 5.2). Leanza & Zeiss (2010) proposed a correlation of Argentinean-Chilean ammonite assemblages with other regions, such as the Antarctic Peninsula, Pakistan, the Himalayas, Mexico and South Africa and Northern Europe. However, this correlation is based only on “genera” in common (figure 5.2); at “species” level no valid correlation exists to date between central Argentina-Chile and other regions. In addition, all biozones presented to date for the Jurassic-Cretaceous boundary in South America and other regions only consider the presence and absence of taxa; no statistical analyses exist to date on species richness and abundance, or statistical turnover. We strongly advocate the idea that statistical tests are key to solve or interpret the problem of bioevents and to interpret biostratigraphical changes across the Jurassic-Cretaceous boundary.

5.2.1. Chañarcillo Basin (North Chile)

The Chañarcillo Basin is located in the south part of the Atacama region in northern Chile (figure 5.3). The Chañarcillo group in this basin is Upper Berriasian to Lower Albian in age and composed of the Abundancia, Nantoco, Totoralillo and Pabellón formations. The total thickness of the unit is 2000 m; it consists of calcareous and restricted volcanoclastics layers (Mourgues 2007).

The biostratigraphy in the Chañarcillo basin was studied by Tavera (1956) and Corvalán (1974). Recently Mourgues (2004, 2007) revised the ammonite assemblage and presented a detailed biozonation which indicates that the sediment sequence reaches from the Upper Berriasian to the Lower Albian (figure 5.2). Nevertheless, significant stratigraphic intervals exist in which no ammonites are preserved, and gaps are present in the zonation (figure 5.2). Mourgues (2004, 2007) presented the following biozonation, from bottom to the top:

Malbosiceras Biozone, *Parandiceras* Horizon, *Lissonia* n. sp. Biozone, *Olcostephanus* (*O.*) *atherstoni* Biozone, *Olcostephanus* (*Viluceras*) *permolestus* Biozone, *Crioceratites diamantensis* Biozone, *Paraspiticeras groeberi* Biozone, *Shasticrioceras* Biozone, *Emericiceras* Biozone, *Moutoniceras* Biozone, *Sanmartinoceras africanum insignicostatum* Horizon, *Antarcticoceras domeykanum* Biozone, *Hemihoplites perezi* Biozone, *Ancyloceras* (*Adouliceras*) sp. Horizon, *Hypacanthoplites* sp. Horizon and *Neodeshayesites* sp. Horizon (figure 5.2).

5.2.2. Aconcagua-Neuquén Basin (Central Argentina)

The Aconcagua-Neuquén Basin includes the central part of Argentina and Chile (32° to 40° S latitude) and encompasses two major depocenters, the Aconcagua-Central Chilean basin in the north and the Neuquén Basin, or Embayment, to the south (figure 5.3; Aguirre-Urreta et al. 2007 a). Almost continuous marine sediments from Late Triassic to Early Cretaceous times were recorded from the Neuquén Basin (Aguirre-Urreta et al. 2007a). Outcrops form a narrow belt along the Andes Mountain in the north, covering part of the Chilean and Argentine Main Cordillera (Aguirre-Urreta et al. 2007a).

The Aconcagua-Central Chilean basin is characterized by a complex geological history, with diverse marine and continental deposits controlled by a variable tectonic setting during Late Jurassic to Early Cretaceous times (Mpodozis & Ramos 1990). For this period of time, stratigraphy in the Aconcagua area is similar to the Neuquén embayment (Aguirre-Urreta et al. 2007a). The Aconcagua area is the focus of the present thesis and is thus discussed separately, in chapter 5.3. In the Neuquén basin deposits of the Mendoza Group (Argentina) are divided in the Vaca Muerta, Quintuco, Mulichinco, Agrio and Hitrín formations.

The first biostratigraphic zonation for Neuquén basin was presented by Windhausen (1918, in Aguirre-Urreta et al. 2007); subsequent authors complemented this biozonation, among them Gerth (1921-1925), Weaver (1931), Leanza A. (1945), Leanza H. (1981a, b), Riccardi (1988), Aguirre-Urreta (1993), Aguirre-Urreta et al. (2007 a), Zeiss & Leanza H. (2010) and Parent et al. (2011b).

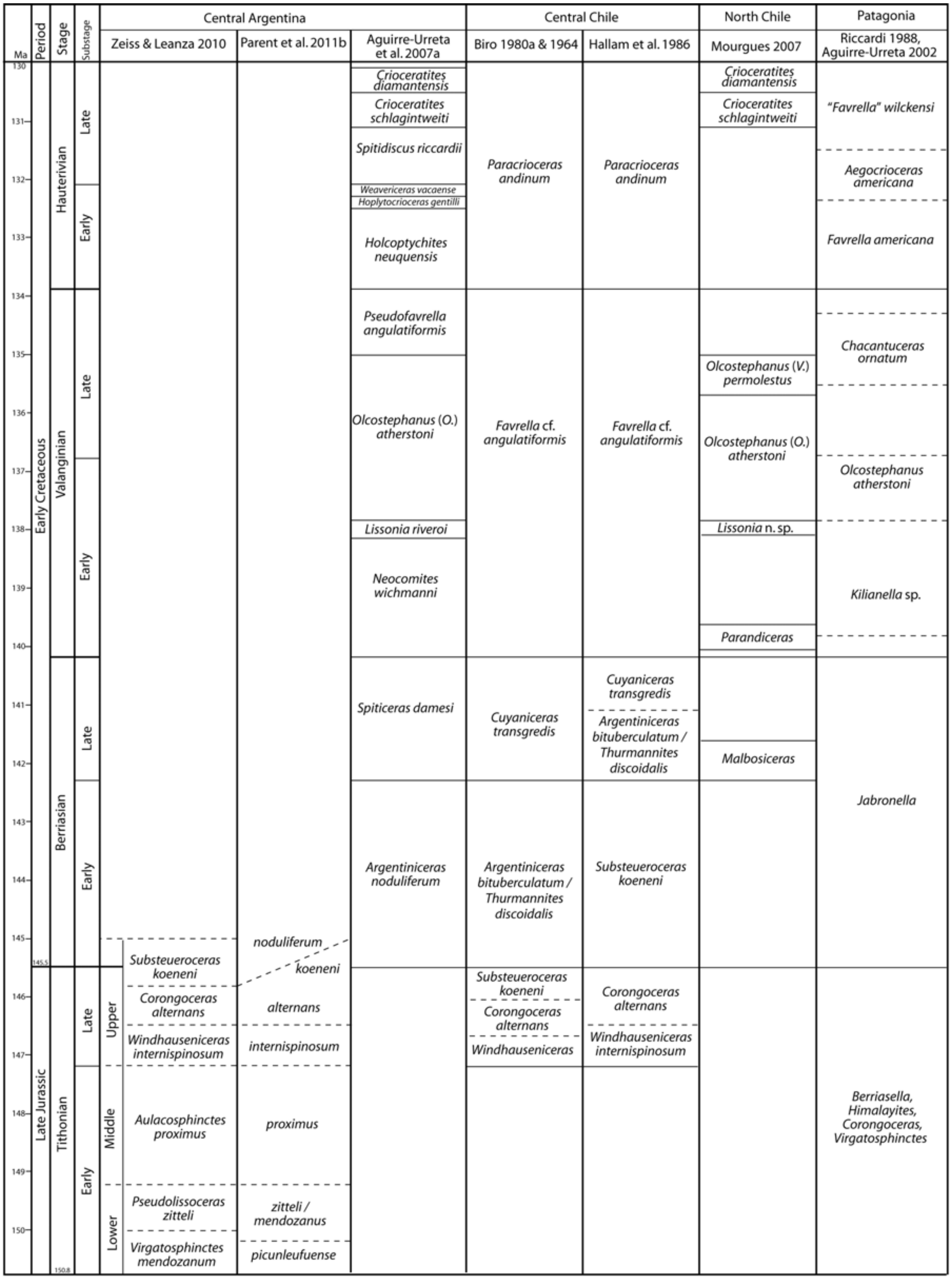


Figure 5.2. Biozonation of Tithonian-Hauterivian in South America. For Central-Argentina according to Zeiss & Leanza (2010), Parent et al. (2011 b) and Aguirre-Urreta et al. (2007a). For Central Chile according to Biro (1964, 1980) and Hallam et al. (1986), in North Chile Mourgues (2007) and Patagonia with Riccardi (1988) and Aguirre-Urreta (2002)

For the Tithonian, the most recent biozonation of the Vaca Muerta Formation is from Parent et al. (2011b). This author differentiated the following biozones, from the bottom to top (figure 5.2):
Lithacoceras picunleufuense Biozone, *Pseudolissoceras zitteli* - *Corongoceras mendozanus* Biozone, *Catuthosphinctes proximus* Biozone, *Windhauseniceras internispinosum* Biozone, *Corongoceras alternans* Biozone. Parent et al. (2011b) considered the *Substeueroceras koeneni* Biozone as part of the Lower Berriasian, stratigraphically under/overlying the *Argentiniceras noduliferum* Biozone (figure 5.2).

The most recent biozonation for the Lower Cretaceous (Berriasian-Hauterivian) was presented by Aguirre-Urreta et al. (2007a) and includes the following biozones, from the bottom to top (figure 5.2):
Argentiniceras noduliferum Biozone, *Spiticeras damesi* Biozone, *Neocomites wichmanni* Biozone, *Lissonia riveroi* Biozone, *Olcosthephanus* (*O.*) *atherstoni* Biozone, *Pseudofavrella angulatiformis* Biozone, *Holcoptychites neuquensis* Biozone, *Hoplitocrioceras gentilii* Biozone, *Weavericeras vacaense* Biozone, *Spitidiscus riccardii* Biozone and *Crioceratites diamantensis* Biozone (figure 5.2).

5.2.3. Austral Basin (Patagonia)

The Patagonian Cordillera is located on the western border of the Magallanes or Austral Basin (Riccardi 1988, figure 5.2). The oldest units in the area include sedimentary and metamorphic rocks from the Paleozoic to Upper Jurassic; the basin was filled by Upper Jurassic-Neogene and mostly marine sediments (Leanza 1971, Riccardi & Rolleri 1980, in Riccardi 1988).
The Upper Jurassic-Lower Cretaceous rocks of the Austral Basin correspond to (from the bottom to top) the Zapata and Punta Barrosa formations in the south, the Spring Hill and Rio Mayer formations in the central part of the basin and the Coyhaique Group in the North (Riccardi 1988).

The Tithonian-Hauterivian biozonation in the Austral Basin is presented in figure 5.2. The Tithonian is characterized by an assemblage of *Berriasella*, *Himalayites*, *Corongoceras* and *Virgatosphinctes*. The Berriasian is identified by the presence of *Jabronella*. *Kilianella* sp., *Olcostephanus atherstoni* and *Chacantuceras ornatum* mark the Valanginian, whereas the Hauterivian is subdivided, from bottom to top, in the *Favrella americana*, *Aegocrioceras* *patagonicum* and *Favrella wilckensi* biozones (figure 5.2; Riccardi 1988, Aguirre-Urreta 2002 and Aguirre-Urreta et al. 2007b).

5.2.4. Remarks

Stratigraphical literature on the south-western margin of Gondwana frequently states the following Upper Jurassic-Lower Cretaceous basins in Chile and Argentina, from the North to the South (figure 5.3):

- Chañarcillo Basin
- Neuquén Basin
- Rio Mayo Embayment - Austral Basin

This division of the Chilean-Argentinean basins is presented by Aguirre-Urreta (1993) and modified by Aguirre-Urreta et al. (2007a). We prefer to denominate these basins under global view point or global scale. We propose referred to Chañarcillo, Aconcagua Central Chile and Neuquén Embayment, denominate here as “Andean Basin” as a whole; and subdivide as (figure 5.3):

Andean Basin:
- Chañarcillo Basin: Chañarcillo or northern Andean basin
- Aconcagua central Chile: Aconcagua or central Andean basin
- Neuquén Embayment: Neuquén or southern Andean basin

The southernmost part of the Chilean-Argentinean basin was also refered to as Rio Mayo embayment, or Austral basin (Aguirre-Urreta et al. 2007). We prefer to use the term “Austral Basin”, and a division into in the Rio Mayo subbasin in the north and Magallanes subbasin in the south (figure 5.3).

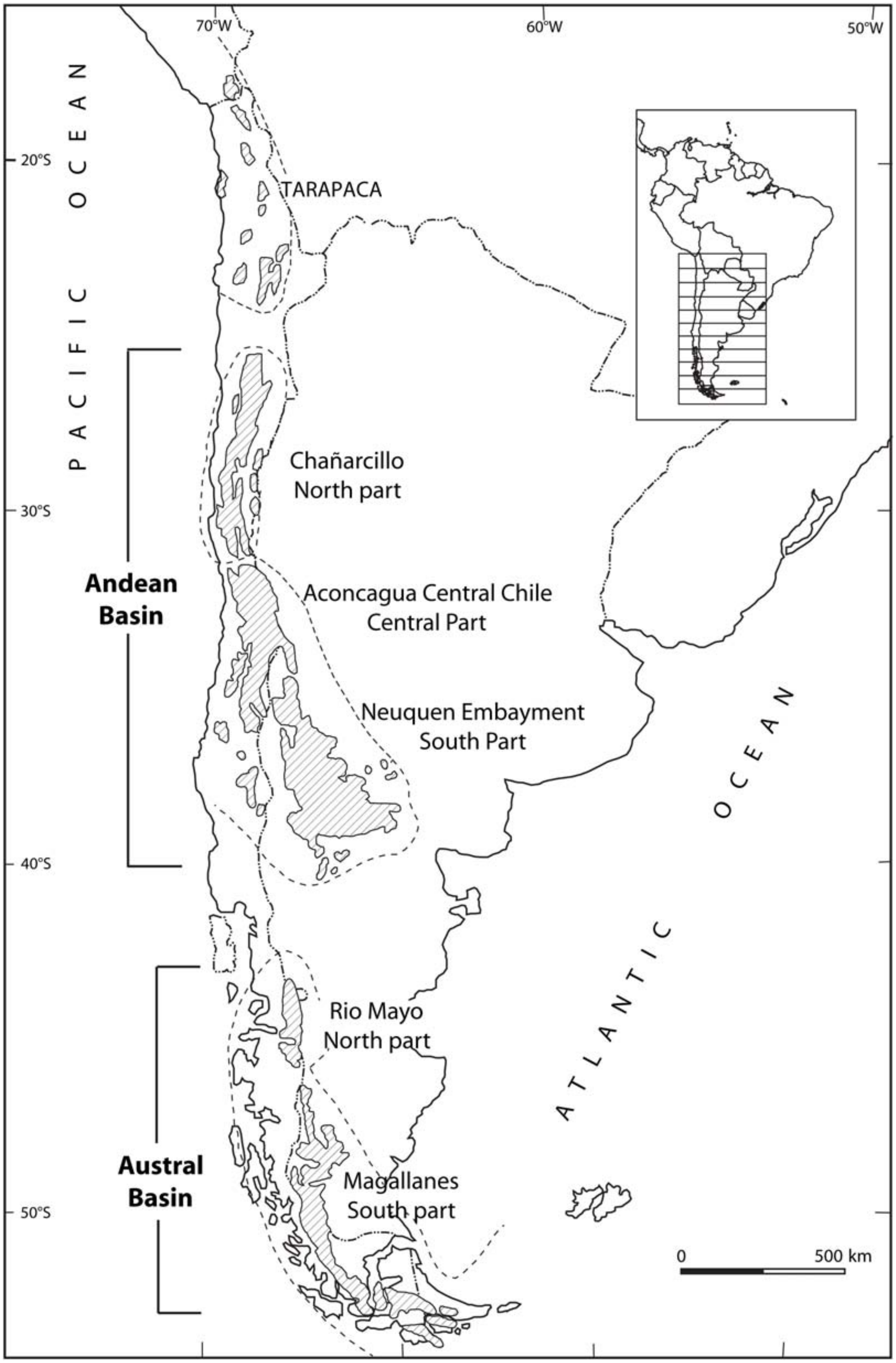


Figure 5.3. Location of the basin in the Southwestern margin of Gondwana. This figure is modified of (Aguirre-Urreta 1993) and Aguirre-Urreta et al. (2007a).

5.3. Andean Basin Zones

In Central Chile, the Jurassic-Cretaceous boundary is well represented by the Baños del Flaco and Lo Valdés formations (e.g. Biro 1964, Covacevich et al. 1976, Biro 1980a, Hallam et al. 1986). For the Baños del Flaco Formation, Covacevich et al. (1976) gave the first approach to the age of the formation based on ammonite assemblages. This author assigned a Lower-Upper Tithonian age to the unit and differentiated, from base to top, the *Virgatosphinctes andesensis*, *Pseudolissoceras zitteli* and *Corongoceras alternas* biozones. Hallam et al. (1986) revised the zonation and differentiated, from bottom to top: *Windhauseniceras internispinosum* biozone, *Corongoceras alternans* biozone and *Substeueroceras koeneni* biozone (figure 5.2). The latter authors assigned a Lower-Middle Tithonian to Lower Berriasian age for the Baños del Flaco Formation.

The most detailed biozonation of the Lo Valdés Formation was presented by Biro (1964) and subsequently used in several other publications on the Lo Valdés Formation, such as Biro (1980a) and Hallam et al. (1986). Biro (1964) established eight faunistic zones based on ammonoids, from bottom to top (figure 5.2):

- Zone I: Assemblages composed by *Aulacosphinctes windhauseni*, *Aulacosphinctes* cf. *proximus*, *Virgatosphinctes andesensis* and *Perisphinctaceae*. This zone is assigned to the Lower-Middle Tithonian

-Zone II: *Windhauseniceras humphreyi* and *Wichmanniceras* aff. *mirum*
The assemblage also contains *Hoplites oppeli* and *Pectinatites striolatus* and was assigned to the lower part of the Upper Tithonian.

- Zone III: *Corongoceras alternans*
The assemblage is composed by *Berriasella australis*, *B. inaequicostata*, *B. spinulosa*, *B. krantzi*, *Corongoceras evolutum*, *C. involutum*, *C. submendozanum*, *Himalayites koellikeri*, *Hoplites* aff. *armatus*, *H. oppeli*, *Lytoceras* cf. *sutile*, *Lytohoplites burckhardti*, *Micracanthoceras lamberti*, *Odontoceras ellipsostomum*, *Spiticeras tripartitus tripartitus*, *S. tripartitus lovaldensis* and *Steueroceras permulticostatum* and corresponds to the middle part of the Upper Tithonian.

- Zone IV: *Substeueroceras koeneni*.

The assemblage contains *Aulacosphinctes azulensis*, *A. proximus*, *Berriasella fraudans*, *B. privasensis*, *Himalayites koellikeri*, *Hoplites oppeli*, *H. malbosiformis*, *Lytoceras sutile*, *Odontoceras beneckei*, *O. ellipsostomum*, *Pectianites striolatus*, *Reineckeia incerta*, *Spiticeras tripartitus tripartitus*, *S. tripartitus lovaldensis*, *Steueroceras lamellicostatum*, *S. steueri*, and *Virgatosphinctes contigus* and is assigned to upper part of Upper Tithonian.

- Zone V: *Argentiniceras bituberculatum* and *Thurmannites discoidalis*.

The assemblage is composed by *Andesites fasciculatus*, *Argentiniceras bituberculatum*, *Berriasella inaequicostata*, *Himalayites* sp., *Hoplites malbosiformis*, *Odontoceras callistoides*, *Spiticeras tripartitus tripartitus* and *S. tripartitus lovaldensis*. This zone was assigned to the Lower Berriasian.

- Zone VI: *Cuyaniceras transgredis*.

The assemblage contains *Andesites* cf. *curvatus*, *Berriasella inaequicostata*, *Spiticeras* cf. *andinum*, *S.* (*Kilianiceras*) *gigas*, *S. tripartitus tripartitus*, *S. tripartitus lovaldensis*, *Steueroceras permulticostatum*, *Thurmannites duraznensis* and *T. neogaeus*. This zone was assigned to the Upper Berriasian.

- Zone VII: *Favrella* cf. *angulatiformis*.

This zone was assigned to the Valanginian

- Zone VIII: *Paracrioceras andinum*

The assemblage is composed by *Crioceras diamantense*, *C. perditum*, *C. schlagintweiti* and *C. bederi* and corresponds to the Hauterivian.

The Lo Valdés Formation thus corresponds to the Lower-Middle Tithonian to Hauterivian (Biro 1964, Biro 1980a and Hallam et al. 1986). Zones I and II belong to the Spilite member, which is here formally excluded from the Lo Valdés Formation and separated as the Cerro Catedral Formation.

5.3.1. Biozones of the Baños del Flaco Formation

Ammonites of the Baños del Flaco Formation were collected by Lajos Biro in the year 1965 the from Rio Maitenes section (figure 1.1). They are described and discussed in chapter 4.1. All specimens were collected *in situ* and layer-by-layer, as indicated by the fossil field code in the original field book.

The vertical distribution of ammonites encountered in the Baños del Flaco Formation is summarized in Figure 5.4. This figure is based on the lithological and biostratigraphical sequence at Rio Maitenes.

At Rio Maitenes 223 specimens were collected and referred to 12 species. *Windhauseniceras internispinosum* is the most abundant ammonite (57 specimens), followed by *Aulacosphinctes proximus* (46 specimens), *Micracanthoceras microcanthum* (35 specimens), *Micracanthoceras spinulosum* (27 specimens) and *Corongoceras evolutum* (26 specimens) (figure 5.5).

Hallam et al. (1986) differentiated three biozones, *Windhauseniceras internispinosum*, *Corongoceras alternans* and *Substeuroceras koeneni*, but without specifying other ammonite species or indicating first and last appearances in the stratigraphic column.

Here we differentiate the following four biozones, from bottom to top (figure 5.4): *Virgatosphinctes scyticus* / *Pseudolissoceras zitteli* zone, *Windhauseniceras internispinosum* zone, *Micracanthoceras microcanthum* / *Corongoceras alternans* zone and *Substeueroceras koeneni* zone.

***Virgatosphinctes scyticus* / *Pseudolissoceras zitteli* zone:** This zone is recognized in the lower part of the Lower Member, specifically in the lower part of the sandstone/calcareous sandstone unit (figure 5.4) of the Baños del Flaco Formation. It is characterized by the presence of *Virgatosphinctes scyticus* and *Pseudolissoceras zitteli*. Ammonites associated with the two index species are *Euvirgalithacoceras malarguense*, *Choisisphinctes windhauseni* and a single specimen of *Aulacosphinctes proximus* (figure 5.4). No ammonites were registered in the basal conglomerate, the calcareous sandstone/sandy limestone and grainstone units (figure 5.4).

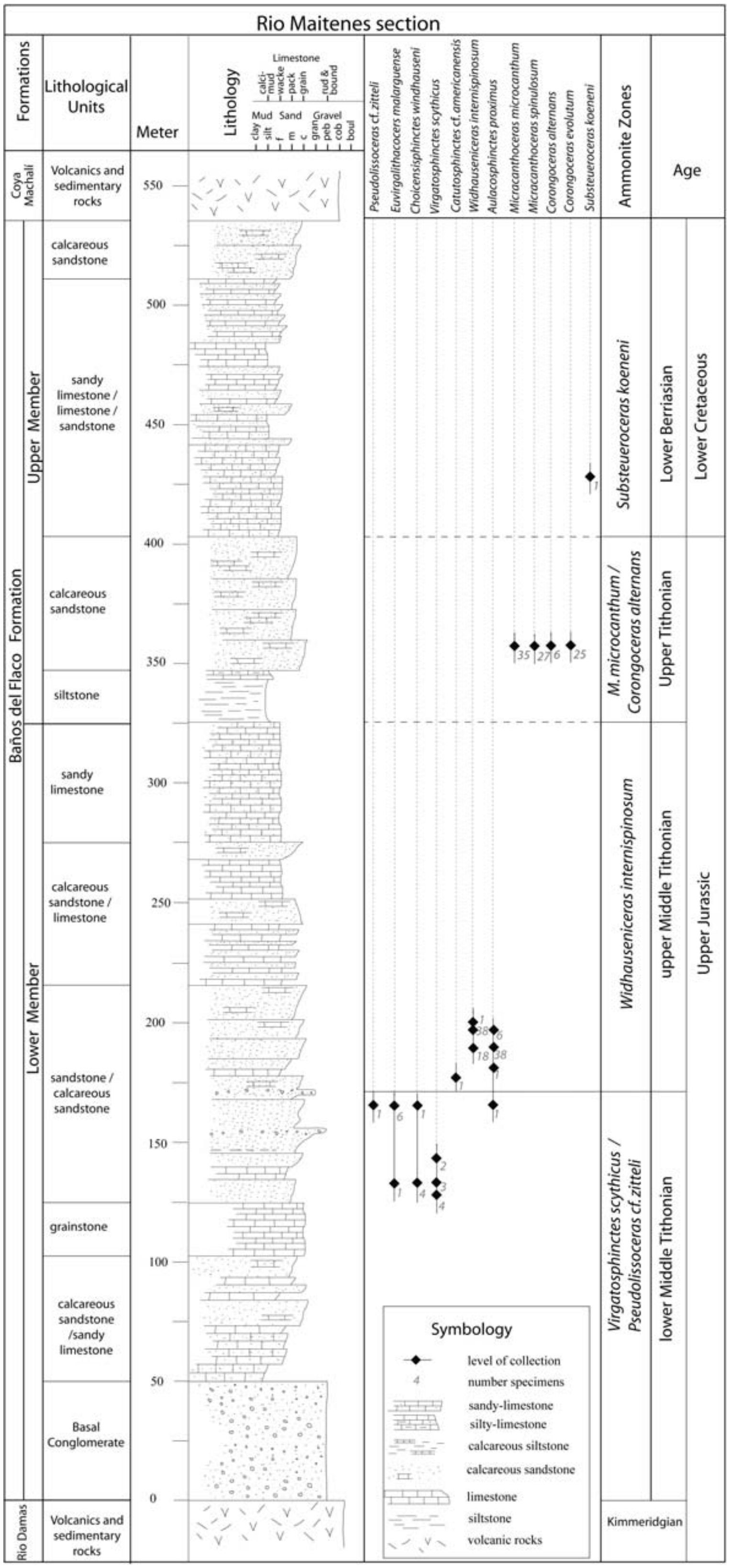


Figure 5.4. Baños del Flaco Formation in Rio Maitenes section, with ages, lithological units, ammonite zones, ranges of ammonite species and abundance of ammonites in every level.

***Windhauseniceras internispinosum* zone:** This zone is based on the presence of *Windhauseniceras internispinosum* in the upper part of the Lower Member of the Baños del Flaco Formation, in the upper part of sandstone/calcareous sandstone unit (figure 5.4). The sandy limestone upsection from this unit has not yielded ammonites (figure 5.4). Ammonites associated with *Windhauseniceras internispinosum* are *Catutosphinctes* cf. *americanensis* and *Aulacosphinctes proximus* (figure 5.4).

***Micracanthoceras microcanthum* / *Corongoceras alternans* zone:** This zone is characterized by the occurrence of *Micracanthoceras microcanthum* and *Corongoceras alternans* in the lower part of the Upper member of the Baños del Flaco Formation, specifically in the calcareous sandstone unit (figure 5.4). Other ammonites in this zone are *Micracanthoceras spinulosum* and *Corongoceras evolutum* (figure 5.4).

***Substeueroceras koeneni* zone:** This zone is recognized by the presence of a single specimen of *Substeueroceras koeneni* (figure 5.4) in the upper part of the Upper member of the Baños del Flaco Formation, in the sandy limestone / limestone / sandstone unit (figure 5.4).

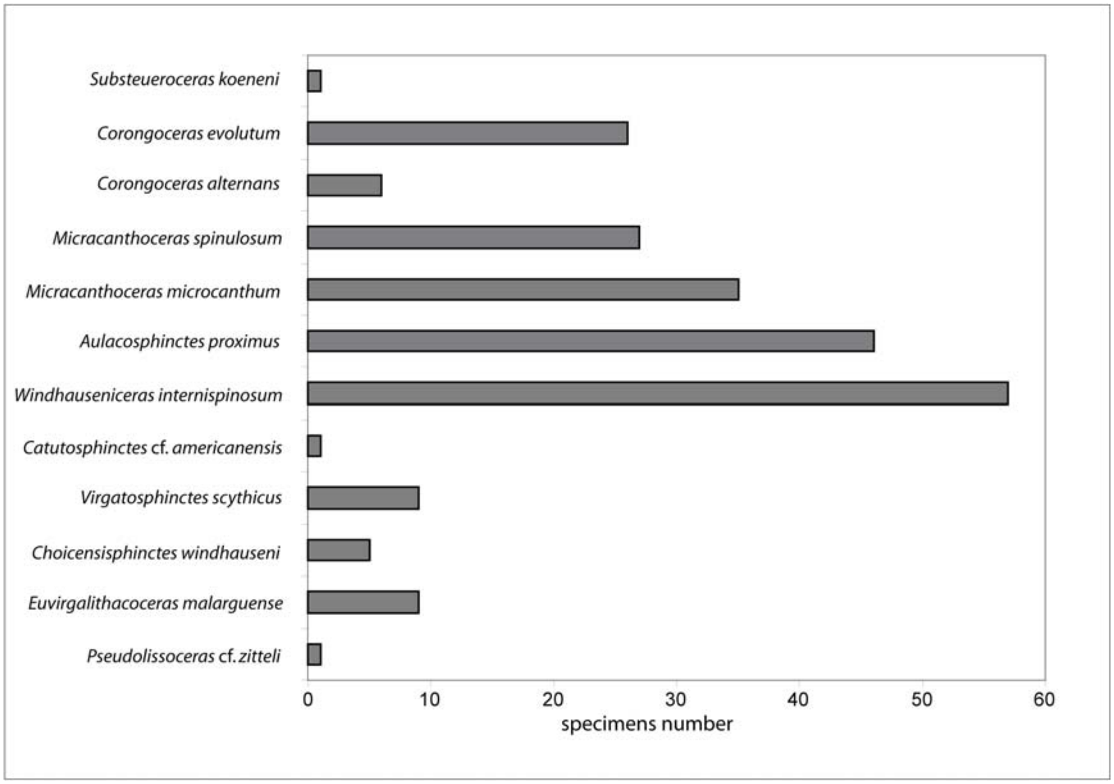


Figure 5.5. Abundance of the ammonites recorded in Rio Maitenes section, Baños del Flaco Formation.

5.3.2. Biozones of the Lo Valdés Formation

Ammonites of the Lo Valdés Formation were collected from sections at Lo Valdés, Cajón del Maipo and at Cruz de Piedra (figure 1.1) and are described and discussed in chapter 4.2 of this thesis. Field campaigns were executed in the years 2007, 2008 and 2009. Most fossils were collected *in situ*, but a small number of fossils were picked up from the debris adjacent to the sections. The approximate position of these latter specimens was estimated within the stratigraphic column, based on the fossil assemblage associated with the ammonites and lithological characteristics of the bed rock.

The ranges and distribution of ammonites of the Lo Valdés Formation are summarized in Figures 5.6 to 5.8. These figures present the lithological and biostratigraphical sequence at Lo Valdés (LV), Cajón del Maipo (CM) and Cruz de Piedra (CP).

A total of 1206 ammonites were collected in the Lo Valdés Formation (LV, CM and CP) and these specimens were assigned to 39 species. *Spiticeras tripartitum* (148 specimens) is the most abundant species, followed by *Substeueroceras koeneni* (104 specimens), *Aulacosphinctes proximus* (100 specimens), *Corongoceras alternans* (72 specimens), *Lytohoplites rauloi* n. sp. (72 specimens) and *Thurmanniceras thurmanni* (66 specimens) (figure 5.9).

Biro (1964, 1980a) and Hallam et al. (1986) proposed 8 biozones based on the ammonite assemblage, but the authors did not indicate first and the last appearances in the stratigraphic column.

Here we describe six biozones, using index taxa with a wide geographical distribution (no endemics) and high abundancy, from bottom to top: Zone 1 *Micracanthoceras microcanthum* / *Corongoceras alternans*, Zone 2 *Substeueroceras koeneni* (*Berriasella jacobi* sub-zone and *Groebericeras rocardi* sub-zone), Zone 3 *Thurmaniceras thurmanni* / *Argentiniceras fasciculatum*, Zone 4, Zone 5 and Zone 6 *Crioceratites diamantense* (figures 5.6, 5.7 and 5.8).

Zone 1 *Micracanthoceras microcanthum* / *Corongoceras alternans*: This zone is characterized by the range of *Micracanthoceras microcanthum* and *Corongoceras alternans*, in the Sandstone Member of the Lo Valdés and Cajón del Morado sections (figures 5.6 and 5.7), and in the lower part of the Siltstone Member at Cruz de Piedra (figure 5.8). Zone 1 also contains *Aspidoceras* *rogoznicensis*, *Micracanthoceras spinulosum*, *Corongoceras evolutum*, *Corongoceras involutum*, *Corongoceras lotenoense*, *Corongoceras mendozanum*, *Substeuroceras calistoide*, a single specimen of *Chigaroceras bardensis*, *Lytohoplites paredesi* n. sp., *Lytohoplites zambranoi* n. sp., *Lytohoplites varelae* n. sp., *Lytohoplites rauloi* n. sp. and *Bochianites* sp. (figures 5.6, 5.7 and 5.8).

Zona 2 *Substeueroceras koeneni*: This zone is identified by the presence of *Substeueroceras koeneni* (figures 5.6, 5.7 and 5.8). Within Zone 2, two subzones are recognized:

- Subzone 2A *Berriasella jacobi*: This subzone is identified in the lower part of the Siltstone Member at Lo Valdés and Cajón del Morado (figures 5.6 and 5.7), and the middle part of the siltstone member at Cruz de Piedra (figure 5.8); the subzone is characterized by the presence of *Berriasella jacobi*, but *Pterolytoceras exoticum*, *Aspidoceras rogoznicensis*, *Aulacosphinctes proximus*, *Micracanthoceras spinulosum*, *Micracanthoceras vetustum*, *Corongoceras koellikeri*, *Corongoceras mendozanum*, *Spiticeras acutum*, *Spiticeras tripartitum*, *Substeuroceras calistoide*, *Substeuroceras striolatissimum*, *Tirnovella kayseri*, *Cuyaniceras transgrediens*, *Malbosiceras malbosi* and *Chigaroceras bardensis* are also present (figures 5.6, 5.7 and 5.8).

- Subzone 2B *Groebericeras rocardi*: This subzone is identified in the upper part of the Siltstone Member in all sampled sections and is characterized by the presence of *Groebericeras rocardi* (figures 5.6, 5.7 and 5.8). *Spiticeras spitiense*, *Spiticeras tripartitum*, *Spiticeras acutum*, *Cuyaniceras transgrediens*, *Substeuroceras striolatissimum*, *Neocosmoceras sayni* and *Frenguelliceras magister* are also present (figures 5.6, 5.7 and 5.8).

Zona 3 *Thurmaniceras thurmanni* / *Argentiniceras fasciculatum*: This zone was identified in the uppermost part (last 12 m) of the Siltstone (figure 5.6) and lower part of the Limestone Member at Lo Valdés, and in the upper part of the Siltstone Member at Cajón del Morado (figure 5.7). In addition to the index taxa *Spiticeras pricei*, *Spiticeras spitiense*, *Spiticeras tripartitum*, *Frenguelliceras magister* and *Pseudofavrella angulatiformis* are also present (figure 5.6 and 5.7).

Zone 4: At Lo Valdés and at Cajón del Morado field work in this zone of the section was extremely difficult to access. Even though ammonoids are present in the layers, individual specimens could not be extracted (figure 5.6 and 5.7). In this zone only were collected fragmentary unclassified ammonites that are different with the upper zone 5

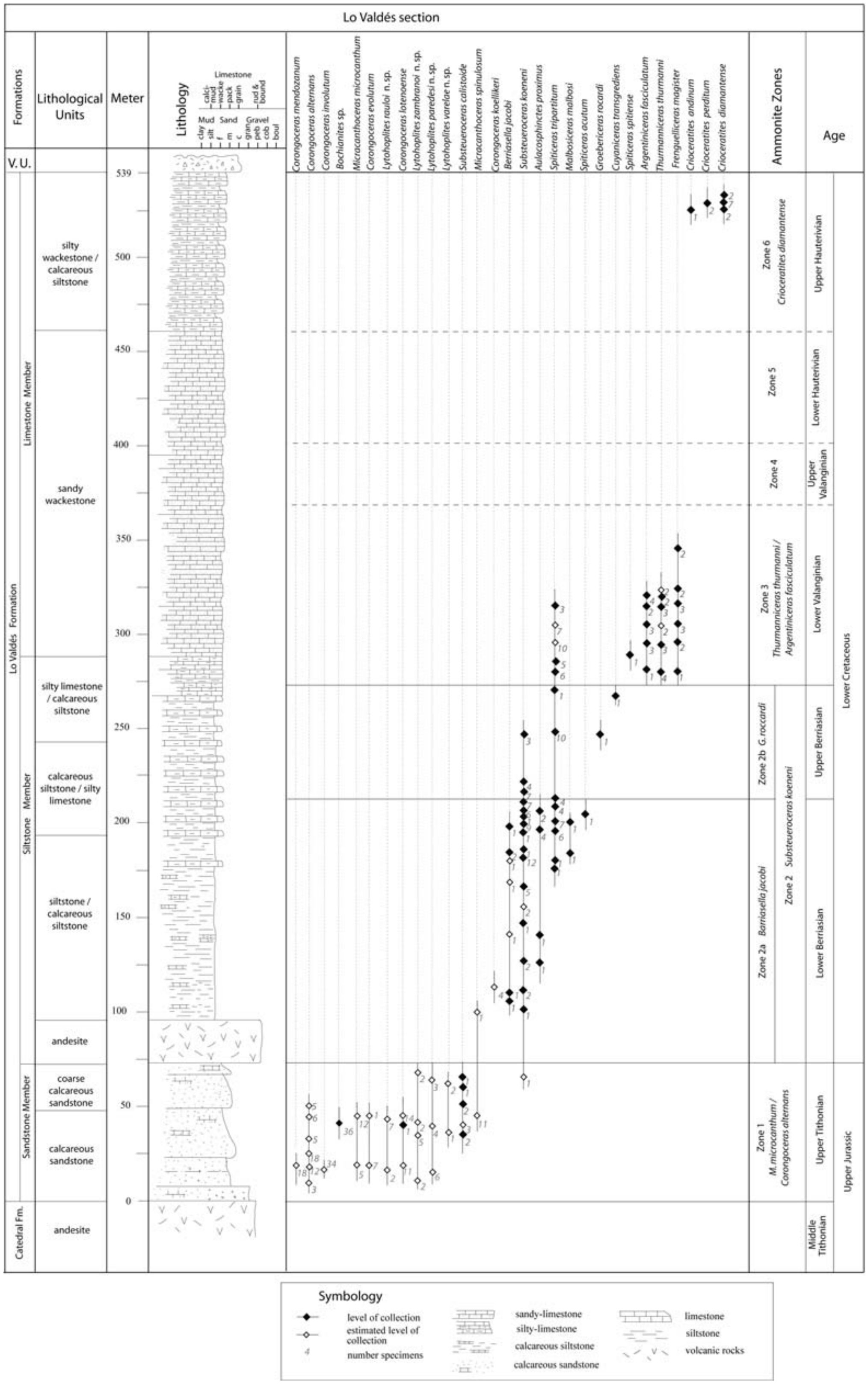


Figure 5.6. Lo Valdés Formation in Lo Valdés type section, with ages, lithological units, ammonite zones, ranges of ammonite species and abundance of ammonites in every level.

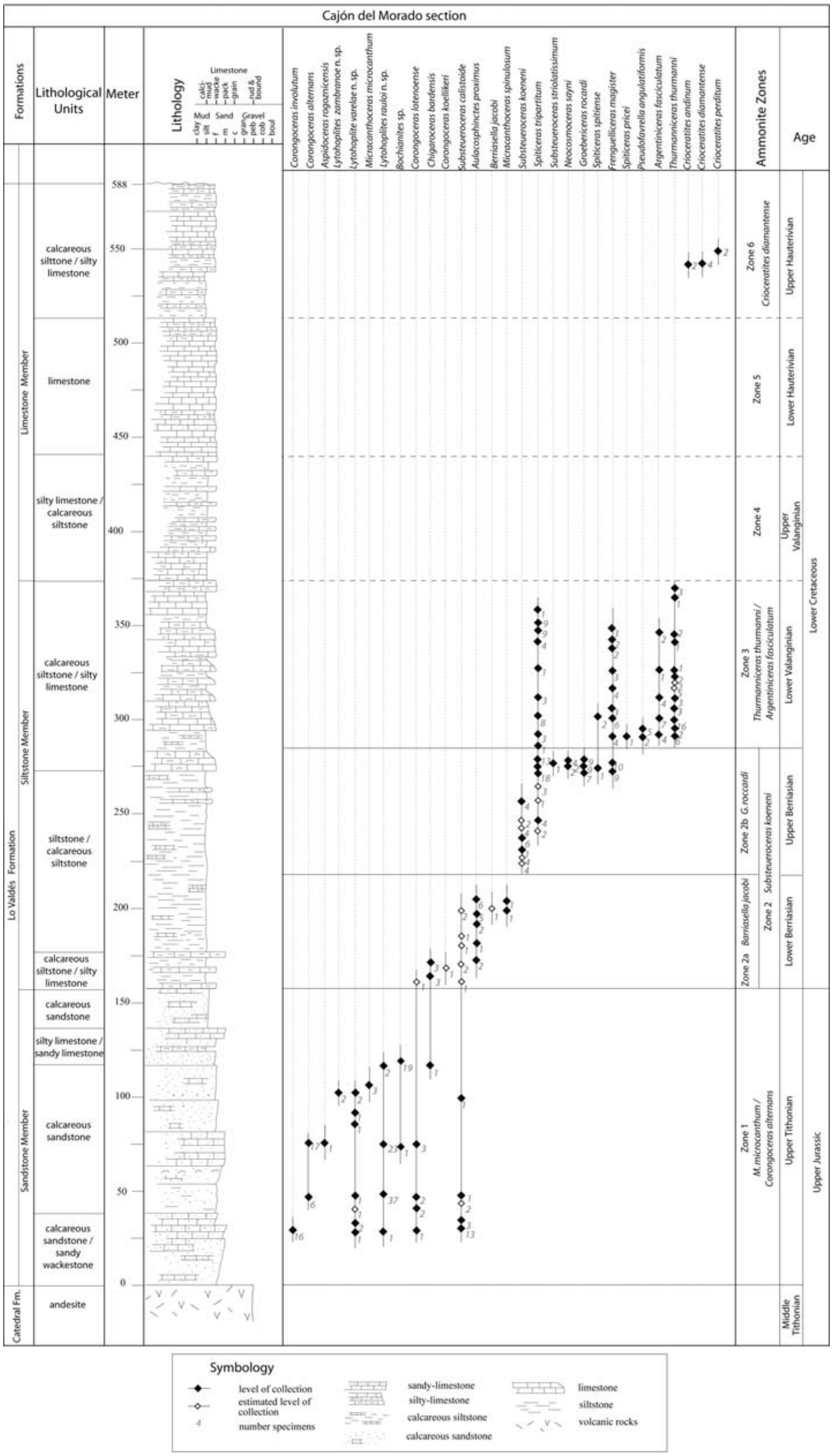


Figure 5.7. Lo Valdés Formation in Cajón del Morado section, with ages, lithological units, ammonite zones, ranges of ammonite species and abundance of ammonites in every level.

Zone 5: Access to this sector of the section was extremely difficult in the Lo Valdés and Cajón del Morado sections and no ammonites were extracted from the layers, even though they are present. (figures 5.6 and 5.7). Only non in situ fragmentary ammonites were collected, that is different of the zone 4.

Zone 6 *Crioceratites diamantense*: This zone is characterized by the range of *Crioceratites diamantense* in the upper part of the Limestone Member at Lo Valdés and Cajón del Morado (figure 5.6 and 5.7). *Crioceratites andinum* and *Crioceratites perditum* are also present (figure 5.6 and 5.7).

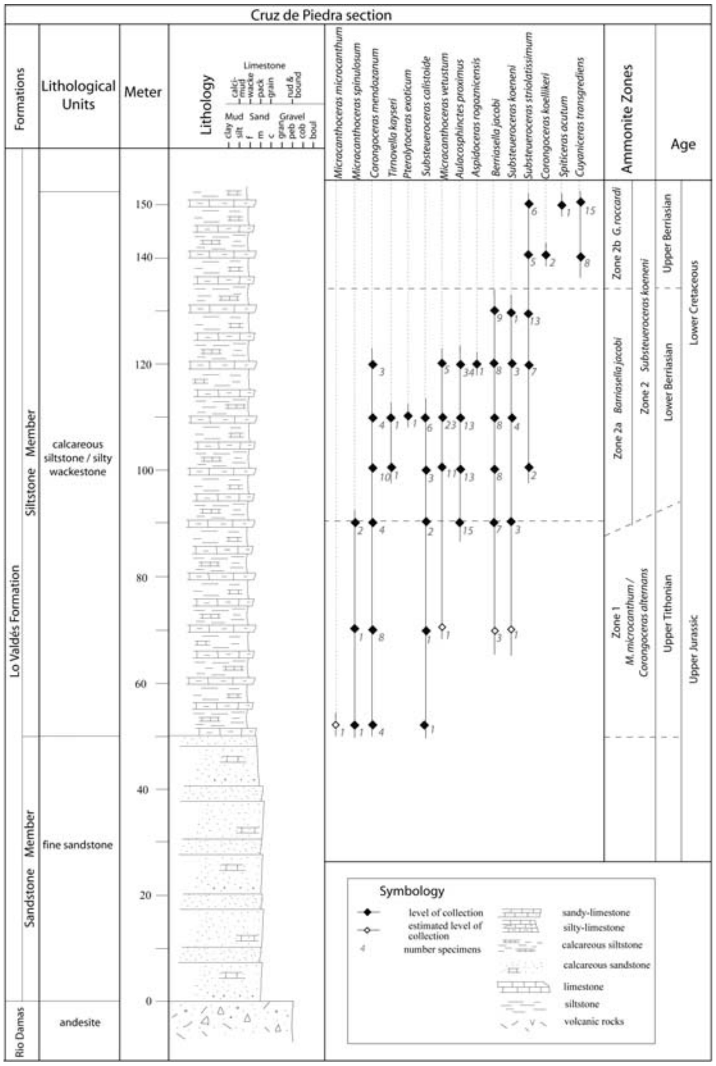


Figure 5.8. Lo Valdés Formation in Cruz de Piedra section, with ages, lithological units, ammonite zones, ranges of ammonite species and abundance of ammonites in every level.

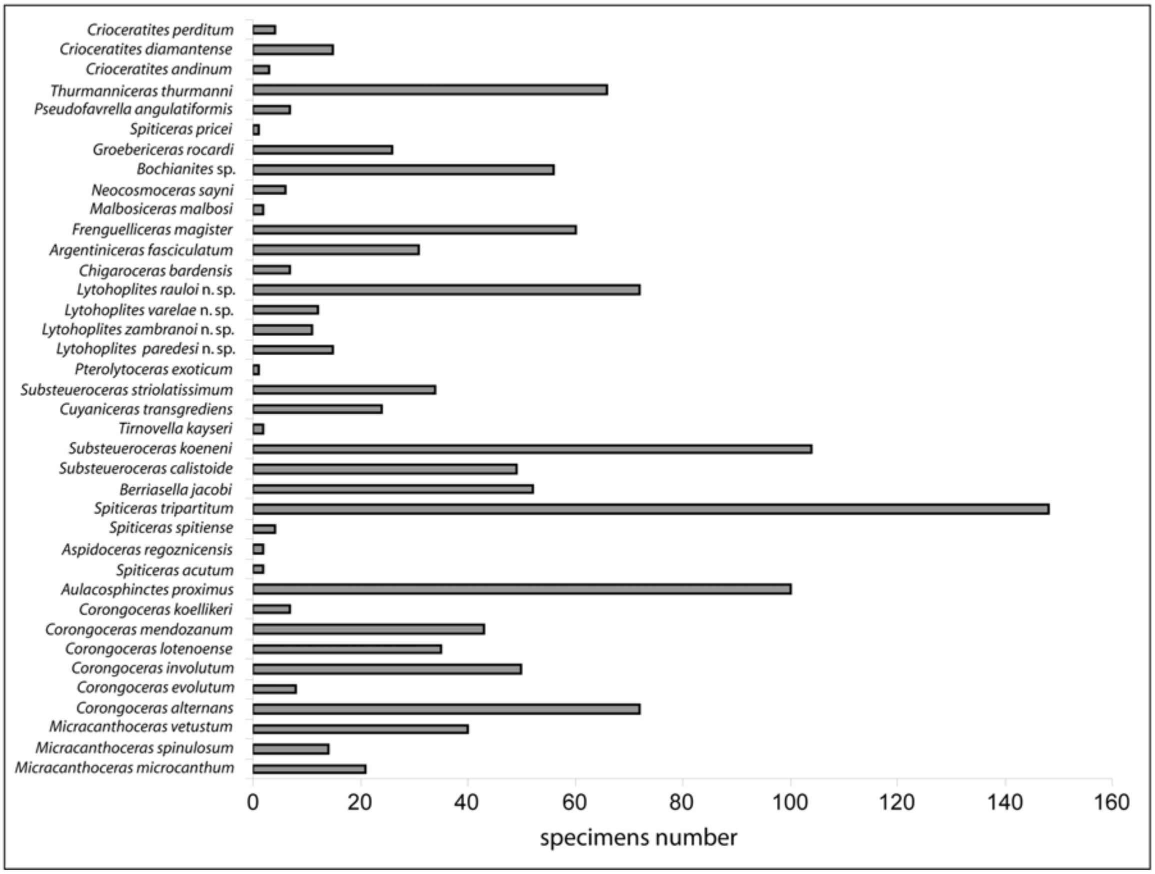


Figure 5.9. Abundance of the ammonites recorded in Lo Valdés Formation.

5.4. Age and Biozonations

Biozonations in the Tethyan and Boreal realms are based on ammonite occurrences (figure 5.1) and reflect the results of dozens of meetings of different stratigraphic "Working Groups" (e.g. Hoedemaeker et al. 1993, Zakharov et al. 1996, Mutterlose et al. 1996, Thierry et al. in Hardenbol et al. 1998, Ogg 2004 in Gradstein et al. 2004).

A global biozonation for the Jurassic-Cretaceous transition has never been presented for reasons outlined in chapter 5.1. For South America, ammonite zonation is currently based on taxa endemic to the region (figure 5.2), with *Substeueroceras* as a sole exception. This genus was also registered in Mexico and India. In addition to the general difficulty in the correlation of stages and substages within the Tithonian-Hauterivian period, difficulties also arise from the absence of calpionellids and the scare occurrence of planktonic foraminifers in the Chilean sections (Lo Valdés and Baños del Flaco formations). This may result from the dominance of siliciclastic lithologies in which calcareous shells are frequently dissolved, from the predominance of nearshore environments and, in the case of calpionellids, from cold water conditions unsuited for these warm water microfossils.

5.4.1. Baños del Flaco Formation

In this chapter the biozonation of Hallam et al. (1986) of the Baños del Flaco Formation is modified by the use of first and last ammonite appearances, in addition to the use of assemblages for each biozone (figure 5.4). We suggest the following biozonation of the Baños del Flaco Formation, from base to top: *Virgatosphinctes scyticus* / *Pseudolissoceras zitteli* zone, *Windhauseniceras internispinosum* zone, *Micracanthoceras microcanthum* / *Corongoceras alternans* zone and *Substeueroceras koeneni* zone (figure 5.4 and 5.10).

Virgatosphinctes scyticus / _Pseudolissoceras zitteli_ zone

***Virgatosphinctes scyticus*:** The importance of this taxon is discussed in chapter 4.1, *Virgatosphinctes scyticus* is here considered to be a senior synonym of *Virgatosphinctes mendozanus*, *V. mexicanus* and *V. andesensis*. In our interpretation, the taxon was first recorded for the Lower Tithonian of Far East Russia (Sey et al. 1992). In Poland it was assigned to the Lower to Middle Volgian stage (Kutek & Zeiss 1994), or to the Middle Volgian by Rogov (2004). In Russia, the taxon is assigned to the Lowermost Middle Volgian (Rogov 2010). For the Boreal realm *V. scythicus* is considered an index fossil of the Lowermost Middle Volgian stage, within the *Dorsoplanites panderi* zone (Rogov 2010). In Central Chile and Argentina, synonyms of *Virgatosphinctes scyticus* have been recorded for the Lower Tithonian (Corvalán & Pérez 1958, Corvalán 1959, Biro 1980a, Hallam et al. 1986, Weaver 1931, Indians 1954, Leanza 1980). For Alexander Island, Antarctica, the taxon was assigned to the Lowermost Tithonian (Thomson 1979, Howlett 1989).

Virgatosphinctes scyticus is thus a widespread taxon in both boreal and austral regions and allows for direct correlation between the Lowermost Middle Volgian (Rogov 2010 and Ogg 2004 in Gradstein et al. 2004), or the Lowermost Middle Tithonian.

Pseudolissoceras zitteli is well known from the Middle Tithonian of Argentina (Burckhardt 1903, Leanza 1980, Parent 2001, Parent et al. 2011a), the Middle Tithonian of Mexico (Cantu-Chapa 1967), the Lower Tithonian of Cuba (Myczynski 1990; in Parent 2001), and the Middle Tithonian of East Russia (Sey & Kalacheva 1997). *Pseudolissoceras zitteli* is here also considered to be geographically widespread and an index for the Lowermost Middle Tithonian. The

Virgatosphinctes scyticus / *Pseudolissoceras zitteli* zone is thus considered here to be Lowermost Middle Tithonian in age (figure 5.10).

Windhauseniceras internispinosum **zone**

Windhauseniceras internispinosum was previously registered in South America from Argentina, Chile and Colombia. In Argentina, records are from the upper part of the Middle Tithonian (Leanza 1945, Leanza 1980, Leanza & Zeiss 1990-1992), and in central Chile from the Middle-Upper Tithonian (Corvalán 1959, Aguirre-Urreta & Charrier 1990). In Colombia, the species was tentatively recorded from the Upper Tithonian (Bürgl 1960). In the Baños del Flaco Formation, the presence of *W. internispinosum* is indicative of the upper part of the Middle Tithonian (figure 5.10).

Micracanthoceras microcanthum **/** ***Corongoceras alternans*** **zone**

Micracanthoceras microcanthum was previously recorded in the Tethys and in México. In the Tethys region, the taxon is considered an index fossil of the lowermost Upper Tithonian *M. microcanthum* Zone (Enay & Geyssant 1975, Tavera 1985 and Ogg 2004), with records at Stromberg in Germany, the Italian Alps (Zittel 1868), south-east France (Mazenot 1939), south Spain (Tavera 1985), Bulgary (Sapunov 1979), Hungary (Fözy 1990), Sicily in Italy (Fözy 1995), Pakistan (Fatmi & Zeiss 1999), and Western India (Shome & Bardhan 2009). In Mexico *M. microcanthum* was recorded from the Tithonian (Burckhardt 1919). Records in Argentina are from the Mendoza region and were assigned to the Tithonian (Steuer 1897-1921) or the Upper Tithonian (Leanza 1945). *M. microcanthum* is here considered to be a senior synonym of *M. lamberti*.

Corongoceras alternans was recorded from the Upper Tithonian of Argentina (Gerth 1925, Leanza 1945, Parent 2001) and the Upper Tithonian of Alto Palena (Fuenzalida 1966) and middle part of the Upper Tithonian at Lo Valdés (Biro 1964) in Chile.

The *Micracanthoceras microcanthum* / *Corongoceras alternans* zone is here assigned to the Upper Tithonian (figure 5.10).

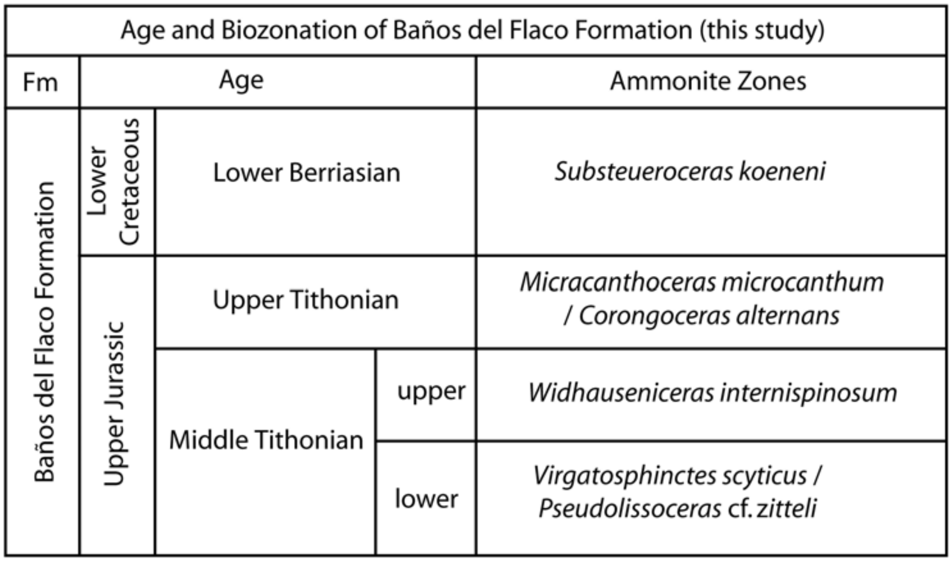
Substeueroceras koeneni **zone**

S. koeneni was recorded mainly from Argentina and Chile, but also from Perú, Mexico, Yemen and East Russia. In Argentina and Chile, the taxon was considered an index for the Upper Tithonian (Leanza 1945, Corvalán 1959, Biro 1964, Leanza 1981b, Parent & Capello 1999, Parent 2001). Nevertheless, Zeiss (1983), Hallam et al (1986) and Zeiss & Leanza (2010) proposed that *Substeueroceras koeneni* may be of basal Berriasian age.

In Perú *S. koeneni* was registered for the Upper Tithonian (Rivera 1951), in Colombia for the Upper Berriasian (Haas 1960), and in Mexico for the Upper Tithonian (Imlay 1939, Verma & Westermann 1973). Adatte et al (2004, 2006) later suggested an early Berriasian age, based on associated calpionellid assemblages. *S. koeneni* was recorded from the Upper Tithonian of Pakistan (Fatmi & Zeiss 1999), the Upper Tithonian *Durangites* and Berriasian *Occitanica* Zones of Yemen (Howarth 1998) and the Berriasian of Far East Russia (Sey & Kalacheva 1999, 2001).

The *S. koeneni* zone is here considered to be of early Berriasian age (figure 5.10).

The Baños del Flaco Formation thus reaches from the lower part of the Middle Tithonian to the lowermost part of the Lower Berriasian (figure 5.10).



Age and Biozonation of Baños del Flaco Formation (this study)

Fm	Age			Ammonite Zones
Baños del Flaco Formation	Lower Cretaceous	Lower Berriasian		*Substeueroceras koeneni*
	Upper Jurassic	Upper Tithonian		*Micracanthoceras microcanthum* / *Corongoceras alternans*
		Middle Tithonian	upper	*Widhauseniceras internispinosum*
			lower	*Virgatosphinctes scyticus* / *Pseudolissoceras* cf. *zitteli*

Figure 5.10. Age and Biozonation proposed here in this study for Baños del Flaco Formation

5.4.2. Lo Valdés Formation

Biozonations for the Lo Valdés Formation have been proposed by Biro (1964,1980a) and Hallam et al. 1986) (figure 5.2). They were based on ammonite assemblages, without the consideration of first or last appearances of ammonites, and on endemic taxa recorded only from Chile and Argentina (except for the *Substeuroceras koeneni* zone). Here we modify this biozonation and propose the following zones, from base to top: Zone 1 *Micracanthoceras microcanthum* / *Corongoceras alternans*, Zone 2 *Substeueroceras koeneni* (*Berriasella jacobi* and *Groebericeras rocardi* sub-zone), Zone 3 *Thurmaniceras thurmanni* / *Argentiniceras fasciculatum*, Zone 4, Zone 5 and Zone 6 *Crioceratites diamantense* (figure 5.11).

Zona 1 *Micracanthoceras microcanthum* / *Corongoceras alternans*

Micracanthoceras microcanthum was considered an index fossil of the Upper Tithonian by Enay & Geyssant (1975), Tavera (1985) and Ogg (2004). In the Tethys region, *M. microcanthum* is recorded from Stromberg, Germany, the Italian Alps (Zittel 1868), Sicily in Italy (Följy 1995), south-east France (Mazenot 1939), southern Spain (Tavera 1985), Bulgary (Sapunov 1979), Hungary (Fözy 1990), and Pakistan (Fatmi & Zeiss 1999). In Mexico, the taxon is registered for the Upper Tithonian (Burckhardt 1919, Imlay 1939). In the south hemisphere it is recorded for the Upper Tithonian in western India (Shome & Bardhan 2009) and in Argentina (= *M. lamberti*). The significance of the index fossils and age of this zone is discussed above in the context of the Banos del Flaco Formation.

Corongoceras alternans is an endemic fossil registered in Central Chile-Argentina and in South of Chile. *C. alternans* was recorded by Biro (1964) from the middle Upper Tithonian at Lo Valdés, and from the Upper Tithonian of Alto Palena (Fuenzalida 1966). In Argentina, the taxon was recorded from the lower Upper Tithonian of Mendoza (Gerth 1925, Leanza 1945, Parent 2001).

The *Micracanthoceras microcanthum* / *Corongoceras alternans* is considered here to be Upper Tithonian in age (figure 5.11).

Zone 2 *Substeueroceras koeneni* zone. The stratigraphical distribution of the index fossil is discussed above, in the chapter on the Banos del Flaco biozones. The *S. koeneni* zone is considered here to be Berriasian in age (figure 5.11).

This biozone is divided into two sub-zones:

- **Subzone 2A *Berriasella jacobi*:** In the Tethys Realm, *B. jacobi* is considered an index fossil for the Lowermost Berriasian (Ogg 2004), with records in South France (Mazenot 1939, Hégarat &

Remane 1968), Spain (Barthel et al. 1966, Hoedemarker 1982, Tavera 1985), Tunisia (Arnould-Saget 1953, Memmi 1967), Bulgary (Sapunov 1979), Poland (Wierzbowski & Remane 1992), Hungary (Horvath & Knauer 1986), Tibet (Liu & Wang 1987), the Caucasus (Khimchiashvili 1989, Kvantaliani 2000), Far East Russia (Sey & Kalacheva 1990) and Iraq (Horwarth 1992). The presence of *B. jacobi* in South America is much discussed (see chapter 4.2) The taxon is here considered to be a synonym of *B. fraudans*, which has been recorded in Chile for the Upper Tithonian (Biro 1964). In Argentina *B. fraudans* was also recorded for the Upper Tithonian (Steuer 1897-1921, A. Leanza 1945). *Berriasella jacobi* is here assigned to the Lower Berriasian (figure 5.11), based on for the well-known Tethyan ranges.

- Subzone 2B *Groebericeras rocardi*: The taxon is well recorded for the Upper Berriasian of Algeria (Pomel 1889), south-east Spain (Hoedemaeker 1982), ?Nepal, western Canada and Iraq (Howarth 1992). For Argentina, *G. bifrons* is here considered to be a junior synonym; this taxon was registered for the ?lower Berriasian (Leanza 1945, Aguirre-Urreta & Alvarez 1999).

Subzone 2B *Groebericeras rocardi* is here assigned to the Upper Berriasian (figure 5.11).

- Zona 3 *Thurmaniceras thurmanni* / *Argentiniceras fasciculatum*

In Argentina, "*T. duraznensis*" is a junior synonym of ***Thurmaniceras thurmanni*** and was registered for the Upper Berriasian (Leanza 1945). Elsewhere, *T. thurmanni* was recorded for the Lower Valanginian of Perú (Lisson 1907), México (Burckhardt 1906, Gonzalez-Arreola et al. 1995), south France (Pictet & Campiche 1860, Roman 1938), south Germany (Baumberger 1906a), south Spain (Hoedemaeker 1982) and Bulgary (Nikolov 1960). In south Spain (Company 1987) and south-west Marrocco (Wippich 2001, 2003) *Thurmanniceras thurmanni* is recorded from the *T. pertransiens* Zone of the lower Early Valanginian.

Argentiniceras fasciculatum was recorded from Argentina (Steuer 1897-1921) for the Upper Tithonian, Valanginian (Gerth 1925, Weaver 1931), and for the Lower Berriasian (Leanza 1945). Elsewhere the taxon was recorded from the Berriasian of Antarctica (Tavera 1970), Colombia (Royo y Gómez 1945) and Canada (Jeletzky 1984).

The Zone 3, or *Thurmaniceras thurmanni* / *Argentiniceras fasciculatum* zone is considered here to be of Lower Valanginian age (figure 5.11).

- Zone 4

Even though ammonites are present in this interval, collection was hampered by access to steep cliffs and vertients. From the fragmentary ammonite collected and stratigraphic position, the interval is assigned to the Upper Valanginian (figure 5.11).

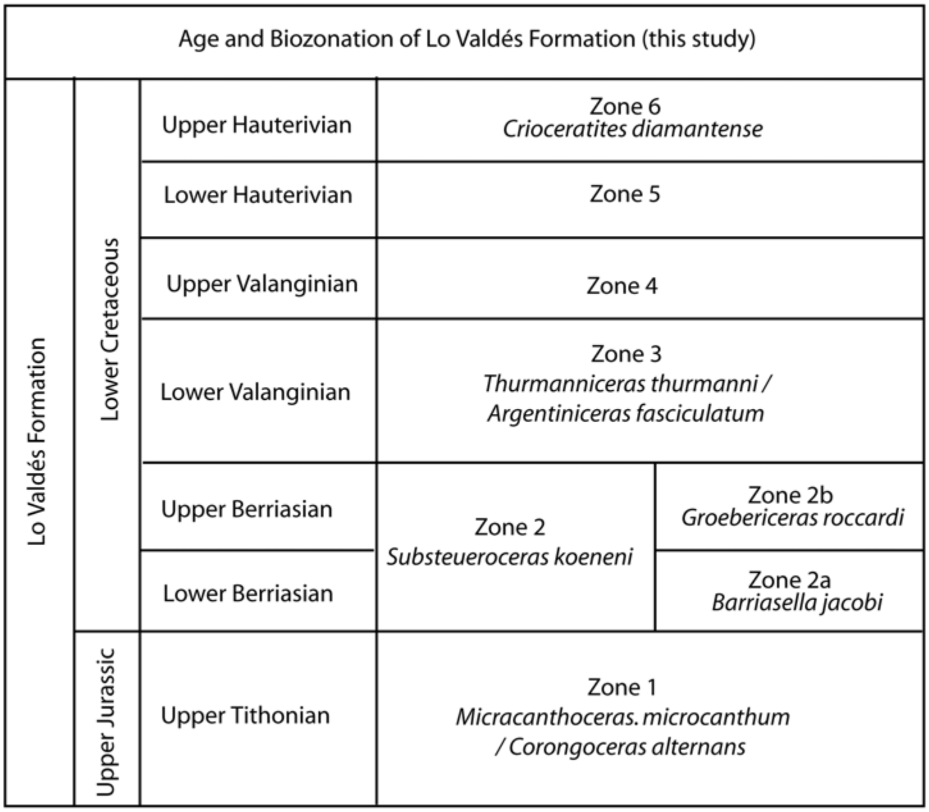
- Zone 5

In this zone was difficult and risky obtain fossils, was possible obtain scare fragments of ammonites. It was possible observed in the layers ammonites, but difficult to obtain. Based on the stratigraphic distribution of the layers, this zone is tentatively assigned to the Lower Hauterivian (figure 5.11).

Zone 6 *Crioceratites diamantense*

C. diamantense is endemic to Chile and Argentina and was assigned to the Upper Hauterivian (Biro 1964, Corvalán 1974, Mourgues 2004, Mourgues 2007, Aguirre-Urreta 1993, Aguirre-Urreta et al. 1999 and Aguirre-Urreta et al. 2005). This assignation to the Upper Hauterivian is kept here (figure 5.11).

The Lo Valdés Formation thus reaches from the upper part of the Upper Tithonian to the Upper Hauterivian (figure 5.11).



Age and Biozonation of Lo Valdés Formation (this study)				
Lo Valdés Formation	Lower Cretaceous	Upper Hauterivian	Zone 6 *Crioceratites diamantense*	
		Lower Hauterivian	Zone 5	
		Upper Valanginian	Zone 4	
		Lower Valanginian	Zone 3 *Thurmanniceras thurmanni / Argentiniceras fasciculatum*	
		Upper Berriasian	Zone 2 *Substeueroceras koeneni*	Zone 2b *Groebericeras roccardi*
		Lower Berriasian		Zone 2a *Barriasella jacobi*
	Upper Jurassic	Upper Tithonian	Zone 1 *Micracanthoceras. microcanthum / Corongoceras alternans*	

Figure 5.11. Age and Biozonation proposed here in this study for Lo Valdés Formation

5.5. Bioevents and palaeoecology

In this chapter statistical analyses and interpretations are discussed for each section of the Baños del Flaco and Lo Valdés Formations. These analyses include the “relative abundance” (accounted as relative number of specimens), “relative richness” (accounted as relative number of species) and as well as the “Evenness” and “Shannon” diversity indices. The data are integrated in a faunal turn-over analysis.

Species turn-over was quantified as the similarity between neighboring (overlying/underlying) layers using the Jaccard index (related to the richness) and Bray-Curtis index (related to the abundance) which varies between 100 % (identity in the species composition) and 0 % (no common species between compared layers). Increasing values in these indices thus represent decreasing, or increasing, species turn-over (Koleff et al. 2003). The calculations were performed using the Diversity Calc software (Möseler et al. 2009).

5.5.1. Baños del Flaco Formation

In the Baños del Flaco Formation, at Rio Maitenes, a total of 223 specimens were collected and referred to 12 different species. *Windhauseniceras internispinosum* is the most abundant taxon (57 specimens), followed by *Aulacosphinctes proximus* (46 specimens), *Micracanthoceras microcanthum* (35 specimens), *Micracanthoceras spinulosum* (27 specimens) and *Corongoceras evolutum* (26 specimens) (figure 5.5).

“Relative abundance” is highest in the sandstone/calcareous sandstone unit of the Lower Member, with a total of 128 specimens (figure 5.12). 94 specimens were sampled in the lower part of the calcareous sandstone unit of the Upper Member (figure 5.12). The highest “relative abundance” is reached in the lower part of the calcareous sandstone unit of the Upper Member (at meter 354 of the stratigraphical column), with 94 specimens (figure 5.12), followed by the unit between 188 and 195 meters of the stratigraphic column (figure 5.12), with 56 specimens registered at 188 meters and 44 specimens at 195 meters (figure 5.12).

The “relative richness” is highest at 354 and at 166 meters, with 4 species registered in each level (figure 5.12).

The “Evenness diversity index” shows two points of highest diversity, at 354 meters in the calcareous sandstone unit of the Upper Member (figure 5.12), and at 188 meters in the sandstone/calcareous sandstone unit (figure 5.12). The “Shannon diversity index” also indicates highest diversity at 354 (figure 5.12), followed by the 166 meter-level in the sandstone/calcareous sandstone unit (figure 5.12).

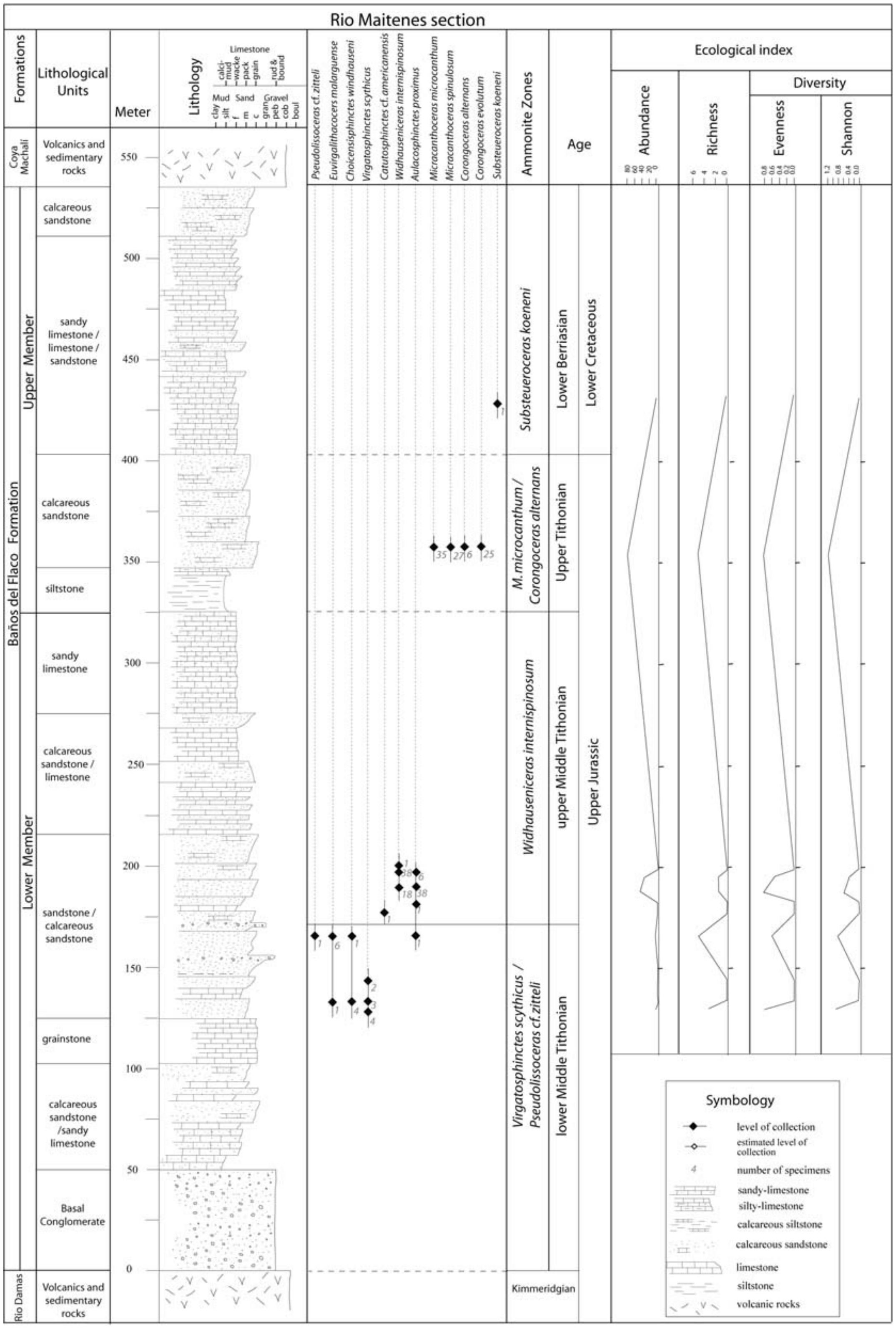


Figure 5.12. Baños del Flaco Formation at Rio Maitenes section, Ecological index (Abundance, Richness and Diversity), also are included ages, lithological units, ammonite zones, ranges of ammonite species and abundance of ammonites in every level.

Ammonoids at Rio Maitenes (Baños del Flaco Formation) are thus discontinuously distributed. They are most abundant and distributed continuously in the sandstone/calcareous sandstone unit, with 128 specimens referred to 7 species; this interval was dated to the Middle Tithonian (figure 5.12). No ammonites are present in the units overlying this interval and up to the 354 meter-level, in the calcareous sandstone unit, where 94 specimens referred to 4 species were identified and assigned to the Upper Tithonian (figure 5.12). The uppermost record of ammonites is at 428 meter of the section in the sandy limestone / limestone / sandstone unit, but only a single specimen was discovered and assigned to the Lower Berriasian (figure 5.12). The three data points do not share any species in common.

The ecological indices (“relative abundance”, “relative richness” and the diversity index of “Evenness” and “Shannon”) show that abundance, richness and diversity increase in the Baños del Flaco Formation (RM) from the Middle Tithonian to Upper Tithonian, but decrease, abruptly from the Upper Tithonian to Lower Berriasian (figure 5.12). The highest abundance, richness and diversity is at meter 354 (Upper Member, calcareous sandstone unit) in the Upper Tithonian (figure 5.12).

5.5.2. Lo Valdés Formation

1206 ammonite specimens were collected in the Lo Valdés Formation (LV, CM and CP) and referred to 39 species. The most abundant taxa are *Spiticeras tripartitum* (148 specimens), *Substeueroceras koeneni* (104 specimens), *Aulacosphinctes proximus* (100 specimens), *Corongoceras alternans* (72 specimens), *Lytohoplites rauloi* n. sp. (72 specimens) and *Thurmanniceras thurmanni* (66 specimens) (figure 5.9).

At Cruz de Piedra, the “relative abundance” is highest at meters 110 and 120, with 60 and 61 specimens collected (figure 5.13) and at 100 meters of the section, with 48 specimens registered (figure 5.13). The “relative richness” is high at meter 100, 110 and 120, with 7, 8 and 7 species respectively (figure 5.13).

The “Evennesss diversity index” indicates that diversity is highest at meter 100, followed by the meter 90 meter level (figure 5.13). The “Shannon diversity index” suggests that diversity is highest at meter 100, followed by the 90 and 120 meter levels (figure 5.13).

The stratigraphical record at Cruz de Piedra section is continuous, without a visible interruption (figure 5.13). Highest diversity is reached near the base of the Lower Berriasian (meter 100), whereas richness and abundance are highest between110 and 120 meters of the section, also in the Lowermost Berriasian, figure 5.13). A major bio-event was detected in the transition between the Uppermost Tithonian (*Micracanthoceras microcanthum* zone) to the Lowermost Berriasian

(*Substeueroceras koeneni* zone). *Micracanthoceras microcanthum* and *M. spinulosum* are registered only in the Uppermost Tithonian (figure 5.13) while *Corongoceras mendozanum* is equally present in both the *M. micracanthum* and *S. koeneni* zones. *S. callistoide* is also recorded in both zones, but is more abundant in the *S. koeneni* zone. From 120 to 140 meters, diversity declines gradually (figure 5.13).

The transition between the Upper Tithonian and Lowermost Berriasian is thus characterized by a gradual change of the ammonite assemblage, with highest rates for abundance, richness and diversity in the Lowermost Berriasian, and a subsequent decline of the ecological index during the Upper Berriasian (figure 5.13).

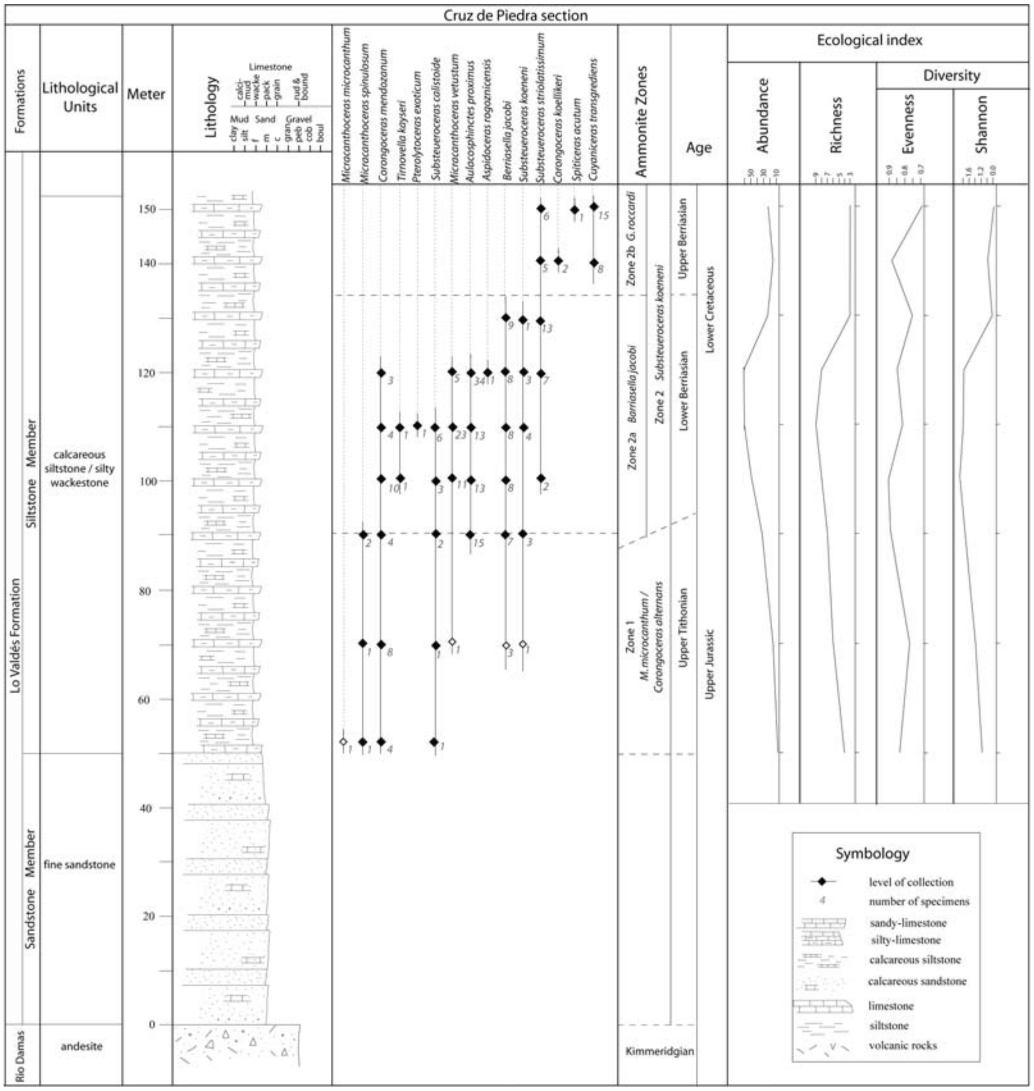


Figure 5.13. Lo Valdés Formation at Cruz de Piedra section, Ecological index (Abundance, Richness and Diversity), also are included ages, lithological units, ammonite zones, ranges of ammonite species and abundance of ammonites in every level.

At Cajón del Morado “relative abundance” and “relative richness” show abundance peaks between 50 and 77 meters in the *M. microcanthum* / *C. alternans* zone (zone 1; Upper Tithonian, figure 5.14); and between 277 and 309 meters, in the lower part of the *Thurmanniceras thurmanni* / *Argentiniceras fasciculatum* zone (zone 3; Lower Valanginian, figure 5.14). Other significant peaks of the “relative richness” are identified around the 200 meter-level of the section in the *Berriasella jacobi* zone (Subzone 2a; Lower Berriasian, figure 5.14). Four levels with high diversity are identified using the “Evenness diversity index”, at 30 meters, between 100 and 120 meters, 160 to 210 meters, and between 240 and 320 meters (figure 5.14). Two levels with high diversity are recognized using the “Shannon diversity index”, between 160 and 210 meters and between 290 and 310 meters (figure 5.14).

Ammonoids are therefore continuously present at Cajón del Morado between the *M. microcanthum* / *C. alternans* zone of the Upper Tithonian to the *T. thurmanni* / *A. fasciculatum* zone of the Lower Valanginian, figure 5.14). The interval between this latter zone and the *C. diamantense* zone of the Upper Hauterivian remains stratigraphically undefined (zones 4 and 5), because ammonites are rare or even absent and the “relative abundance”, “relative richness” and diversity indices are consequently low (figure 5.14).

“Relative abundance”, “relative richness” and diversity are high in the lower part of the Upper Tithonian (figure 5.14) and lower in the upper part of the Upper Tithonian (figure 5.14). The transition between the Upper Tithonian and the Lower Berriasian (Subzone 2a) is marked by an abrupt change; only two of the eleven species recorded from the Upper Tithonian are also present in the Lowermost Berriasian (figure 5.14) and the ecological index is lower in the Lower Berriasian (Subzone 2a) (figure 5.14). During the Upper Berriasian (Subzone 2b) the “relative abundance”, “relative richness” and the diversity increase gradually and reach high values for the Lower Valanginian (Zone 3, figure 5.14). Subsequently, however, in the upper part of the Lower Valanginian, ammonites temporarily disappear or are exceedingly scare during the Upper Valanginian to Lower Hauterivian, figure 5.14). It must be said, however, that this biostratigraphical “hiatus” was extremely difficult to access during field campaigns and the abundance of ammonites may actually be higher than figured here. During the Upper Hauterivian ammonites are again recorded but the ecological index is low (figure 5.14).

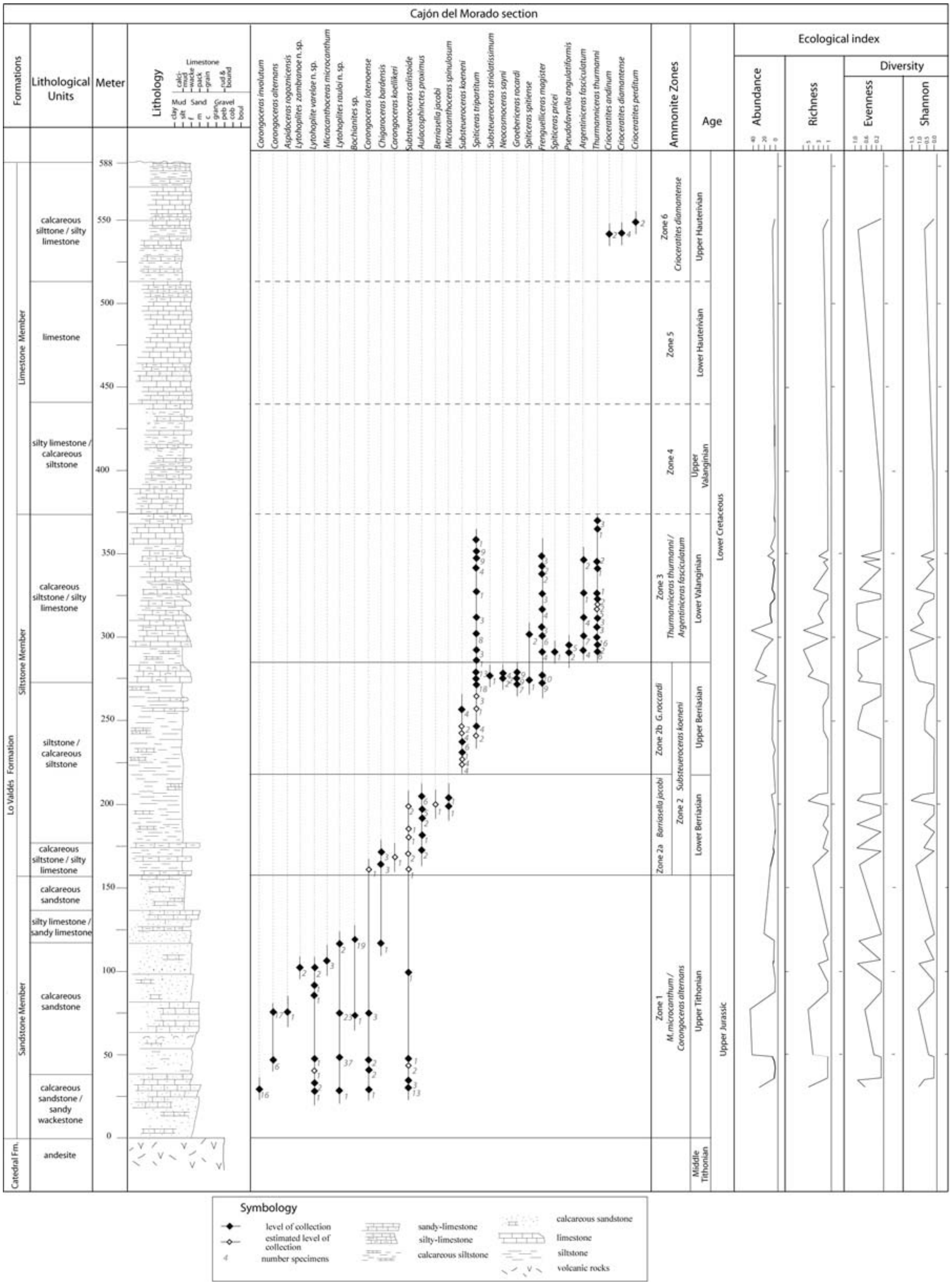


Figure 5.14. Lo Valdés Formation at Cajón del Morado section, Ecological index (Abundance, Richness and Diversity), also are included ages, lithological units, ammonite zones, ranges of ammonite species and abundance of ammonites in every level.

Two peaks of the “relative abundance” and “relative richness” are identified at Lo Valdés section, between 15 and 18 and between 40 and 44 meters, in the *M. microcanthum* / *C. alternans* zone of the Upper Tithonian (figure 5.15). Five peak abundances are recognized using the “Evenness diversity index”, between 15 and 18 and 40 to 44 meters in the *M. microcanthum* / *C. alternans* zone of the Upper Tithonian, between 100 and 150 meters in the *Berriasella jacobi* zone of the Lower Berriasian, at 275 meters and between 300 and 325 meters in the *T. thurmanni* / *A. fasciculatum* zone of the Lower Valanginian, figure 5.15). Four levels of high diversity are present using the “Shannon diversity index”, between 15 to 18 and 40 to 44 meters in the *M. microcanthum* / *C. alternans* zone of the Upper Tithonian, and at 280 meters and between 290 to 325 meters in the *T. thurmanni* / *A. fasciculatum* zone of the Lower Valanginian, figure 5.15).

At Lo Valdés, the distribution of ammonites is therefore continuous from the *M. microcanthum* / *C. alternans* zone (Upper Tithonian) to the *T. thurmanni* / *A. fasciculatum* zone (Lower Valanginian, figure 5.15). Upsection, the Upper Valanginian to Lower Hauterivian remains unzoned due to the scarcity of ammonites. The *C. diamantense* zone (Upper Hauterivian) is characterized by a low ecological index (figure 5.15).

The ecological index shows highest values during the Upper Tithonian (figure 5.15) but marks a significant drop in the transition between the Upper Tithonian and the Lower Berriasian (Subzone 2a); only a single specimen of a possible Tithonian ammonite was registered in the lowermost Berriasian, and only a single specimen of a typically Berriasian ammonite was identified from Uppermost Tithonian strata (figure 5.15). The ecological index is low in the lower early Berriasian (Subzone 2a) but increases gradually within the upper part of the early Berriasian (figure 5.15). During the late Berriasian (Subzone 2b) the ecological index is low (figure 5.15), but increases in the Lower Valanginian (Zone 3). Upsection, only scare ammonites are registered during the Upper Valanginan and Lower Hauterivian (Zone 5, figure 5.15). In the Upper Hauterivian (Zone 6) only a few ammonites are present and the ecological index is low (figure 5.15).

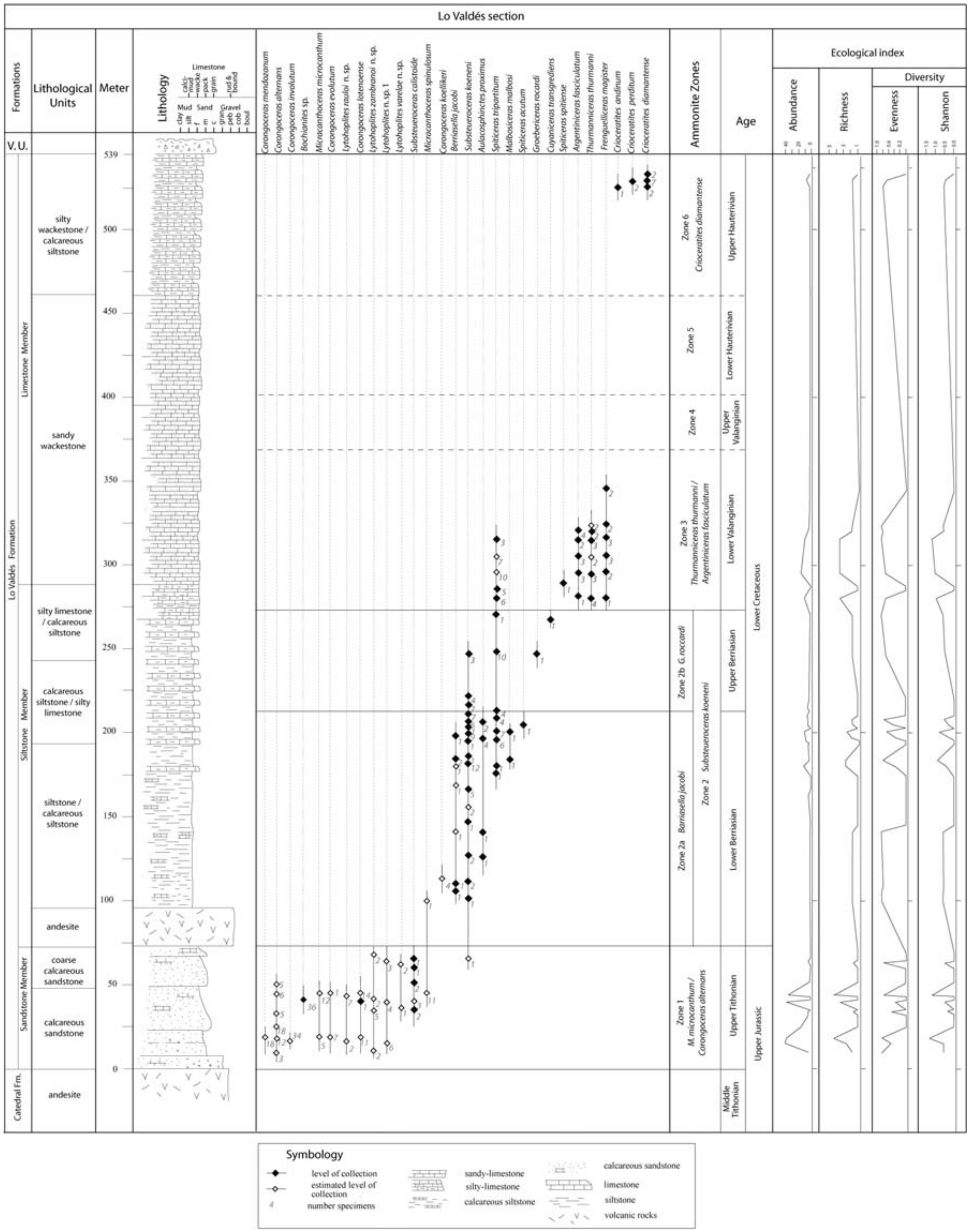


Figure 5.15. Lo Valdés Formation at Lo Valdés type section, Ecological index (Abundance, Richness and Diversity), also are included ages, lithological units, ammonite zones, ranges of ammonite species and abundance of ammonites in every level.

5.5.3. Summary

Data of “relative abundance”, “relative richness” and “Evenness, as well as the Shannon diversity index” of the Baños del Flaco and Lo Valdés formations (Rio Maitenes, Cruz de Piedra, Cajón del Morado and Lo Valdés sections) are integrated in figure 5.16 and 5.17. The data set was grouped in stratigraphic intervals, which correspond to the 9 biozones identified.

The “relative abundance” increases gradually from the lower part of the Middle Tithonian to the Upper Tithonian, with the highest values reached during the Upper Tithonian. From the Upper Tithonian to the Upper Valanginian the “relative abundance” decreases gradually. Ammonites are rare to absent in the Upper Valanginian to Lower Hauterivian interval and the “relative abundance” drops to low values or even zero but rises again to low “relative abundance” levels in the Upper Hauterivian (figure 5.16).

Values for the “relative richness” are high during the Middle and Upper Tithonian and into the Lower Berriasian (figure 5.16). During this latter stage numbers decrease to the Lower Valanginian. No ammonites were identified for the Upper Valanginian and Lower Hauterivian interval. “Relative richness” is low for the Upper Hauterivian (figure 5.16).

The “Evenness factor” is considered to be a proxy for the relative diversity and shows high values from the lower part of the Middle Tithonian to the Lower Valanginian, with peak values in the Upper Tithonian. The “Shannon factor” is also a proxy for the relative abundance and suggests that diversity increased from the lower part of Middle Tithonian to the Upper Tithonian, with highest diversity values during the Upper Tithonian. From this peak, diversity declined gradually to the lower Valanginian (figure 5.16). Again, no ammonites were recovered from the Upper Valanginian to Lower Hauterivian interval, but low ammonite diversity is recognized during the Upper Hauterivian.

Our species turn-over analysis of ammonites across the Jurassic-Cretaceous boundary in central Chile is thus based on sections of both the Baños del Flaco and Lo Valdés formations (Rio Maitenes, Cruz de Piedra, Cajón del Morado and Lo Valdés sections), quantifying the similarity between neighboring (overlying/underlying) biozones. We used the Jaccard and Bray-Curtis indices, which vary between 100 % (identity in the species composition) and 0 % (no common species between compared levels). Increasing values in the Jaccard and Bray-Curtis indices thus represent decreasing species turn-over and vice versa (Koleff *et al.* 2003). Calculations were performed using the Diversity Calc software (Möseler *et al.* 2009). Figure 5.16 indicates “zero”

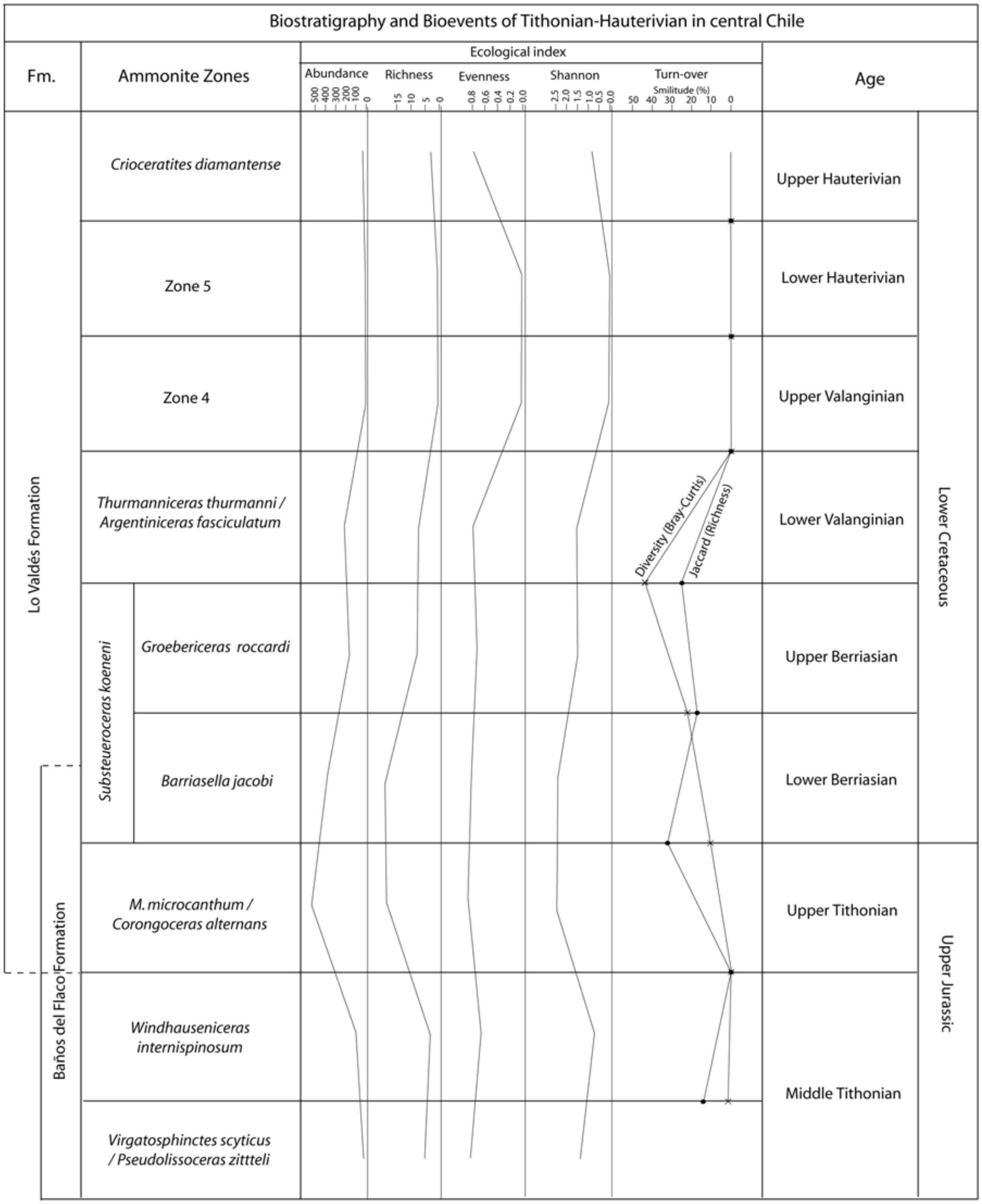


Figure 5.16. Table that integrated the data of “relative abundance”, “relative richness” and “Evenness and Shannon diversity index” of the Baños del Flaco and Lo Valdés formations (Rio Maitenes, Cruz de Piedra, Cajón del Morado and Lo Valdés sections). The data of these sections are grouped in intervals, which correspond to the 9 biozones identified and the age.

similarity between the lower and the Middle Tithonian; from the Upper Tithonian to the Upper Berriasian, Bray-Curtis similarity values increase gradually, coincident with the gradual decline of the diversity. Jaccard values indicate highest similarity values during the Upper Tithonian, coincident with a high diversity; similarity declines (to 20%) during the Lower Berriasian as most taxa registered in the Upper Tithonian are absent during the Lower Berriasian.

Ammonite distribution is thus continuous during the Middle-Upper Tithonian, with a sharp drop in the lowermost Berriasian. Only *Substeueroceras callistoide* is registered in both the Upper Tithonian and Lower Berriasian. Diversity changes are continuous and show gradually increasing values from the Lower Berriasian to the Lower Valanginian. During this interval of the geological time species richness decreases, but according to both turn-over analyses without “abrupt” changes (figure 5.16). No ammonites were recovered for the Upper Valanginian and Lower Hauterivian, and only three taxa were identified from the Upper Hauterivian (figure 5.16).

Ecological indices, such as “relative abundance”, “relative richness”, “evenness” and the “Shannon” diversity index, show that the highest relative abundance and diversity were reached during the Middle to Upper Tithonian, with the main bioevent at the end of the Upper Tithonian (figure 5.16). The ecological index is still high for the Lower Berriasian, with the highest richness, but taxa differ between these stages, with the exception of *Substeueroceras callistoide*, and the Jaccard index is low.

In the pie graphic (figure 5.17), are represented the relative richness and relative abundance of Baños del Flaco and Lo Valdés formations, during the Tithonian to Hauterivian. Both ecological index shows similar values during the Tithonian and Berriasian; 41% and 41% relative richness and 43% and 42% relative abundance (figure 5.17). During the Valanginian the richness and abundance decrease abruptly to values 12% and 13% respectively (figure 5.17). During the Hauterivian the values are lower, due to low ammonites collected in the sections.

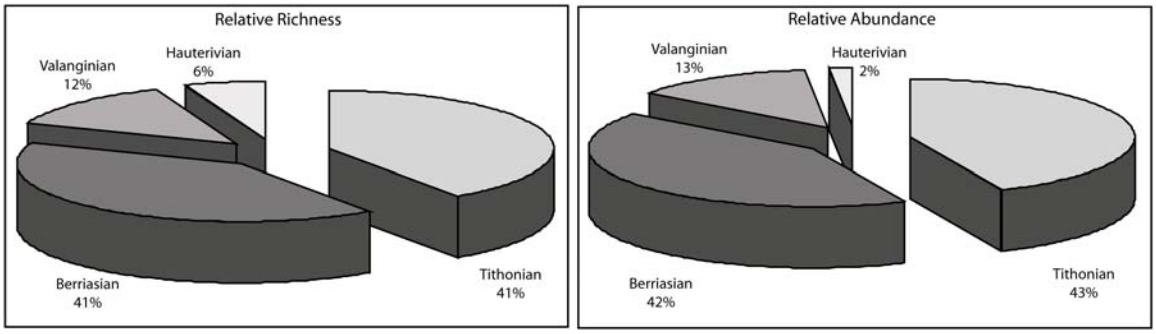
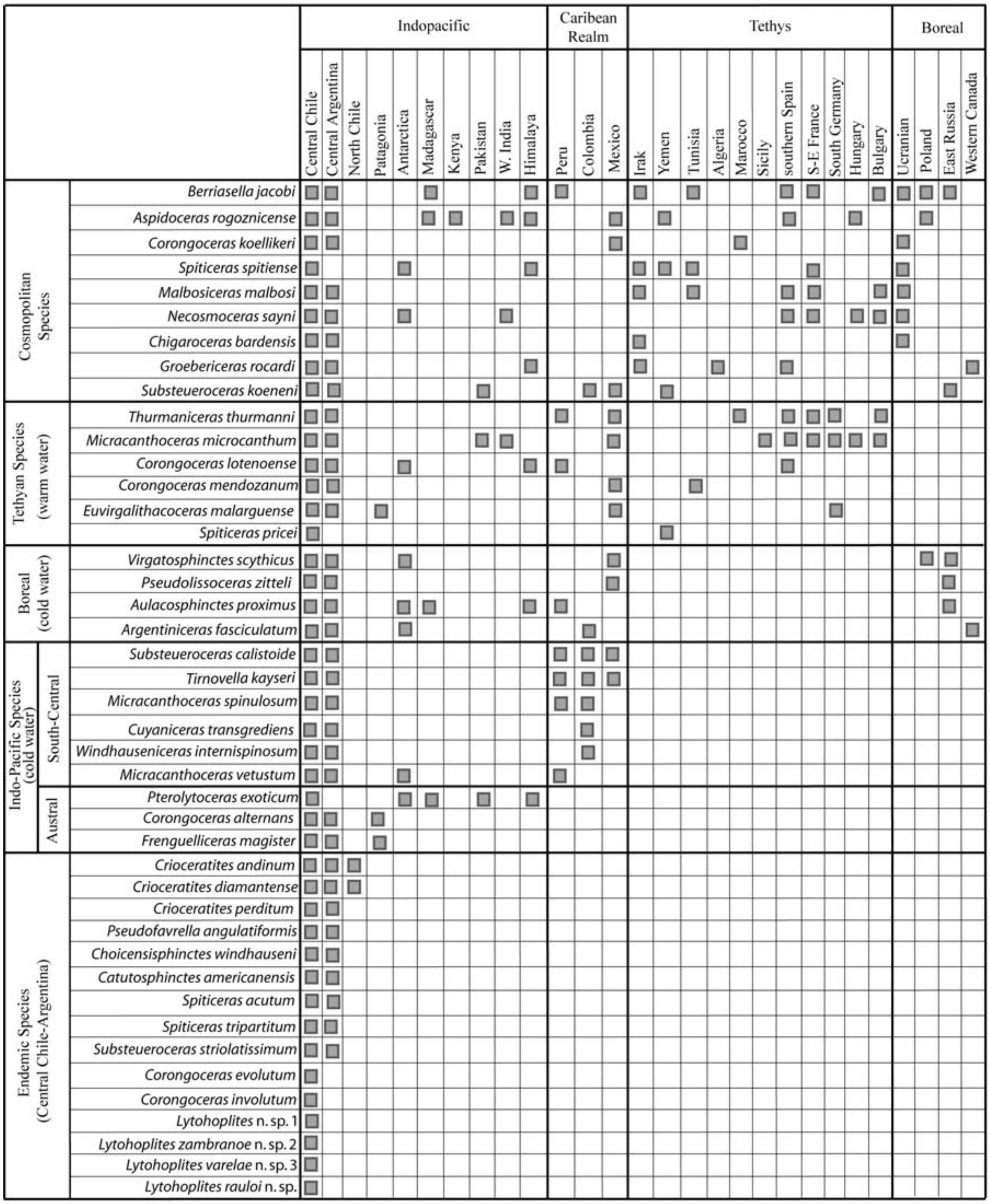


Figure 5.17. Pie graphic that represent the relative Richness and Abundance of the ammonoids in perceptual terms, age by age.

6. Palaeobiogeography

During the Late Jurassic-Early Cretaceous, the break-up of Gondwana caused the formation of a narrow seaway between South America, Africa and Antarctica while another marine connection opened between the eastern Pacific and the Tethys across Central America. Migration between faunal realms could therefore have occurred via these two possible corridors: (1) A northern route through the Mexican basin and the Caribbean region (*Hispanic corridor*) has frequently been proposed based on brachiopod, ammonite, plesiosaurid and crocodilian affinities (e.g. Riccardi 1991, Gasparini and Fernandez, 1997) (figure 6.13), although this idea has recently been challenged by the discovery of endemic Late Jurassic marine reptile assemblages in Mexico (Frey et al., 2002; Buchy et al., 2006; Buchy 2007), with the exception of *Ophtalmosaurus icenicus* (Buchy, 2007). Direct and long-term faunal exchange and transatlantic correlation was not achieved in this region until the middle Berriasian, as indicated by the appearance in eastern Mexico of abundant calpionellid assemblages and typically Mediterranean ammonites (Adatte et al., 1994, 1996). (2) Alternatively, a southern route, called the Indo-Madagascar sea-way, has been proposed by Cecca (1999). This marine corridor opened near the Jurassic/Cretaceous boundary and thus prior to the South Atlantic breakup through interconnected grabens that developed south of Africa and connected Patagonia and the Tethys via a system of grabens through Mozambique, Somalia, Madagascar, eastern India and eastern Antarctica (figure 6.13). The existence of this Indo-Austral seaway is indicated by the presence of the ammonite *Chigaroceras* in both the Andes and in Iraq (Leanza, 1996), and by marine reptiles common in both regions (e.g. Gasparini and Fernandez, 1997).

Our taxonomical and stratigraphic revision of Central Chilean ammonites of the Baños del Flaco and Lo Valdés formations may give important additional information regarding the opening of these marine corridors. We suggest that some Late Jurassic ammonites known from South America may be taxonomically close, or even conspecific, with Tethyan forms and even with taxa from the Northern Boreal realm. The occurrence of these Tethyan ammonites in central Chile further supports the existence of a southern seaway that connected the Pacific with the Tethys around the southern end of South America as was earlier suggested by Leanza (1981a, b) and Cecca (1999), among other authors.



			Indopacific										Caribean Realm			Tethys											Boreal			
			Central Chile	Central Argentina	North Chile	Patagonia	Antarctica	Madagascar	Kenya	Pakistan	W. India	Himalaya	Peru	Colombia	Mexico	Irak	Yemen	Tunisia	Algeria	Marocco	Sicily	southern Spain	S-E France	South Germany	Hungary	Bulgary	Ucranian	Poland	East Russia	Western Canada
Cosmopolitan Species		*Berriasella jacobi*	■	■				■				■	■			■		■				■	■			■	■	■	■	
		Aspidoceras rogoznicense	■	■				■	■		■	■			■		■					■			■			■		
		Corongoceras koellikeri	■	■											■					■							■			
		Spiticeras spitiense	■				■					■				■	■	■					■				■			
		Malbosiceras malbosi	■	■												■		■				■	■			■	■			
		Necosmoceras sayni	■	■			■				■											■	■		■	■	■			
		Chigaroceras bardensis	■	■												■											■			
		Groebericeras rocardi	■	■								■				■			■			■								■
		Substeueroceras koeneni	■	■						■				■	■		■												■	
Tethyan Species (warm water)		*Thurmaniceras thurmanni*	■	■									■		■					■		■	■	■		■				
		Micracanthoceras microcanthum	■	■						■	■				■						■	■	■	■	■	■				
		Corongoceras lotenoense	■	■			■					■	■									■								
		Corongoceras mendozanum	■	■											■			■												
		Euvirgalithacoceras malarguense	■	■		■									■									■						
		Spiticeras pricei	■														■													
Boreal (cold water)		*Virgatosphinctes scythicus*	■	■			■								■													■	■	
		Pseudolissoceras zitteli	■	■											■														■	
		Aulacosphinctes proximus	■	■			■	■				■	■																■	
		Argentiniceras fasciculatum	■	■			■							■																■
Indo-Pacific Species (cold water)	South-Central	*Substeueroceras calistoide*	■	■									■	■	■															
		Tirnovella kayseri	■	■									■	■	■															
		Micracanthoceras spinulosum	■	■									■	■																
		Cuyaniceras transgrediens	■	■										■																
		Windhauseniceras internispinosum	■	■										■																
		Micracanthoceras vetustum	■	■			■						■																	
	Austral	*Pterolytoceras exoticum*	■				■	■		■		■																		
		Corongoceras alternans	■	■		■																								
		Frenguelliceras magister	■	■		■																								
Endemic Species (Central Chile-Argentina)		*Crioceratites andinum*	■	■	■																									
		Crioceratites diamantense	■	■	■																									
		Crioceratites perditum	■	■																										
		Pseudofavrella angulatiformis	■	■																										
		Choicensisphinctes windhauseni	■	■																										
		Catutosphinctes americanensis	■	■																										
		Spiticeras acutum	■	■																										
		Spiticeras tripartitum	■	■																										
		Substeueroceras striolatissimum	■	■																										
		Corongoceras evolutum	■																											
		Corongoceras involutum	■																											
		Lytohoplites n. sp. 1	■																											
		Lytohoplites zambranoe n. sp. 2	■																											
		Lytohoplites varelae n. sp. 3	■																											
		Lytohoplites rauloi n. sp.	■																											

Figure 6.1. Palaeobiogeographic distribution of ammonites present in the Baños del Flaco and Lo Valdés formations. Only localities are included which contain taxa in common.

During the Tithonian-Hauterivian period (Late Jurassic-Early Cretaceous), ammonite taxa are generally differentiated into four major faunal realms: Cosmopolitan, Tethyan, Boreal, Indo-Pacific. In addition, endemic taxa are frequently recognized. Figure 6.1 lists important localities and regions world wide, from which Central Chilean (Lo Valdés and Baños del Flaco formations) ammonite species have been recorded. The Indo-Pacific region is here divided into two faunal provinces, the Indo-Austral province which includes Patagonia, Antarctica, Madagascar, Kenya, Pakistan, Western India and the Himalayas (figure 6.1), and the South- Central Pacific province which includes the Caribbean (e.g. Mexico, Colombia and Peru) and the South Pacific coastal region of north and Central Chile and Argentina) (figure 6.1).

The palaeobiogeographical affinities of the Central Chilean ammonite assemblages are here interpreted stage by stage, from the Tithonian (figure 6.2-6.3), Berriasian (Figure 6.4-6.5), Valanginian (figure 6.6-6.7) to the Hauterivian (figure 6.8). For each stage, the geographical distribution of common Central Chilean species in other regions is figured, and concepts of relative species richness and abundance are applied to conclude on palaeobiogeographical relationships. These data are also summarized in figure 6.1. Palaeobiogeographic affinities of taxa from Central Chile are then established using the Ruggiero index (Koleff at al. 2003) (figure 6.11).

6.1. Tithonian

21 ammonite species are recorded in the Lo Valdés and Baños del Flaco formations of Central Chile (figure 6.2), of which 38% are considered to be endemic to the region, 19% show Indo-Pacific affinities, 19% are Tethyan, 14% Boreal, and 10% are Cosmopolitan taxa (figure 6.3a). Indo-Pacific affinities are differentiated into 14% Central-South Pacific and 5% of Indo-Austral taxa (figure 6.3a). When the relative abundance is considered in terms of number of specimens per taxon, affinities are highest with the Indo- Pacific (36%), followed by Endemics (33%), Tethyan (21%), Boreal (10%) and Cosmopolitan species (<1%) (figure 6.3b). The Indo-Pacific affinities are divided in South-Central Pacific with 23% and Indo-Austral with 12% (figure 6.3b). The endemic taxa *Choicensisphinctes windhauseni* and *Catutosphinctes americanensis* are also registered in Central Argentina (figure 6.2). Endemic species are dominant in Central Chile, followed by taxa of Indo-Pacific affinities. Within this group, a South-Central Pacific influence is important (figure 6.2-6.3), showing a good connection with the Caribbean Realm (figure 6.2). Indo-Austral affinities are low; only *Corongoceras alternans* is registered in this region and in Chile (figure 6.2). The Tethyan fauna is well represented (19% richness and 21% abundance) and may possibly connect this region with central Chile via the Hispanic corridor (figure 6.13). The Boreal influence of the Central Chilean ammonite assemblage is unexpected; it is indicated by the presence of *Virgatosphinctes scythicus*, *Peudolissoceras zitteli* and *Aulacosphinctes proximus*. These taxa are also recorded in the Caribbean Realm (figure 6.2), which further strengthens the

idea that a seaway connection may have existed between the northern and southern hemisphere (figure 6.2 and 6.13). A Cosmopolitan influence is only indicated by *Aspidoceras regoznicense* and *Chigaroceras bardensis*. Their major records are from the Indo-Austral province (Indo-Pacific region) (figure 6.2) which suggests that their pathway to Central Chile may have been through this region.

			Indopacific										Caribean Realm			Tethys											Boreal			
			Central Chile	Central Argentina	North Chile	Patagonia	Antarctica	Madagascar	Kenya	Pakistan	W. India	Himalaya	Peru	Colombia	Mexico	Irak	Yemen	Tunisia	Algeria	Marocco	Sicily	southern Spain	S-E France	South Germany	Hungary	Bulgary	Ucranian	Poland	East Russia	Western Canada
Cosmopolitan Species		*Aspidoceras rogoznicense*	■	■				■	■		■	■			■		■					■			■			■		
		Chigaroceras bardensis	■	■												■											■			
Tethyan (warm water)		*Micracanthoceras microcanthum*	■	■						■	■				■						■	■	■	■	■	■				
		Corongoceras lotenoense	■	■			■					■	■									■								
		Corongoceras mendozanum	■	■											■			■												
		Euvirgalithacoceras malarguense	■	■		■									■									■						
Boreal (cold water)		*Virgatosphinctes scythicus*	■	■			■								■													■	■	
		Pseudolissoceras zitteli	■	■											■														■	
		Aulacosphinctes proximus	■	■			■	■				■	■																■	
Indo-Pacific Species (cold water)	South-Central	*Substeueroceras calistoide*	■	■									■	■	■															
		Micracanthoceras spinulosum	■	■									■	■																
		Windhauseniceras internispinosum	■	■										■																
	Austral	*Corongoceras alternans*	■	■		■																								
Endemic Species (Central Chile-Argentina)		*Choicensisphinctes windhauseni*	■	■																										
		Catutosphinctes americanensis	■	■																										
		Corongoceras evolutum	■																											
		Corongoceras involutum	■																											
		Lytohoplites n. sp. 1	■																											
		Lytohoplites zambranoi n. sp. 2	■																											
		Lytohoplites varelae n. sp. 3	■																											
		Lytohoplites rauloi n. sp.	■																											

Figure 6.2. Palaeobiogeographic distribution of ammonites recorded for the Tithonian in Central Chile. Only localities are included which contain taxa in common.

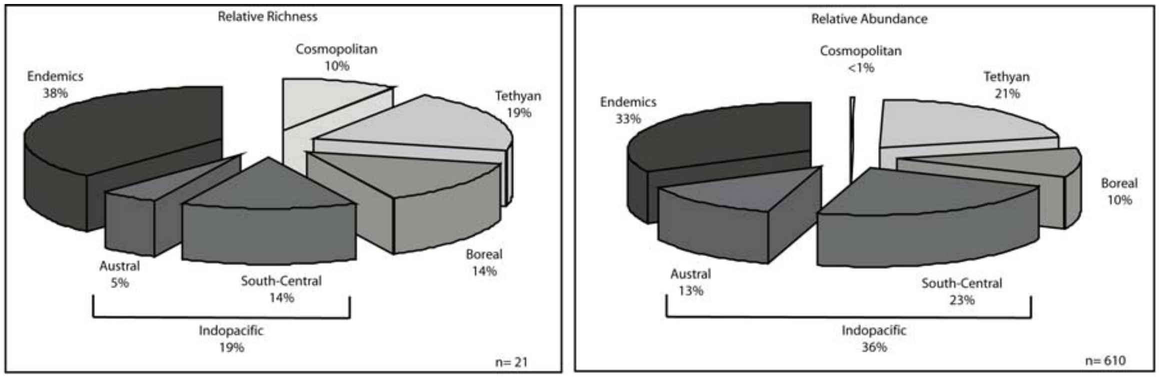
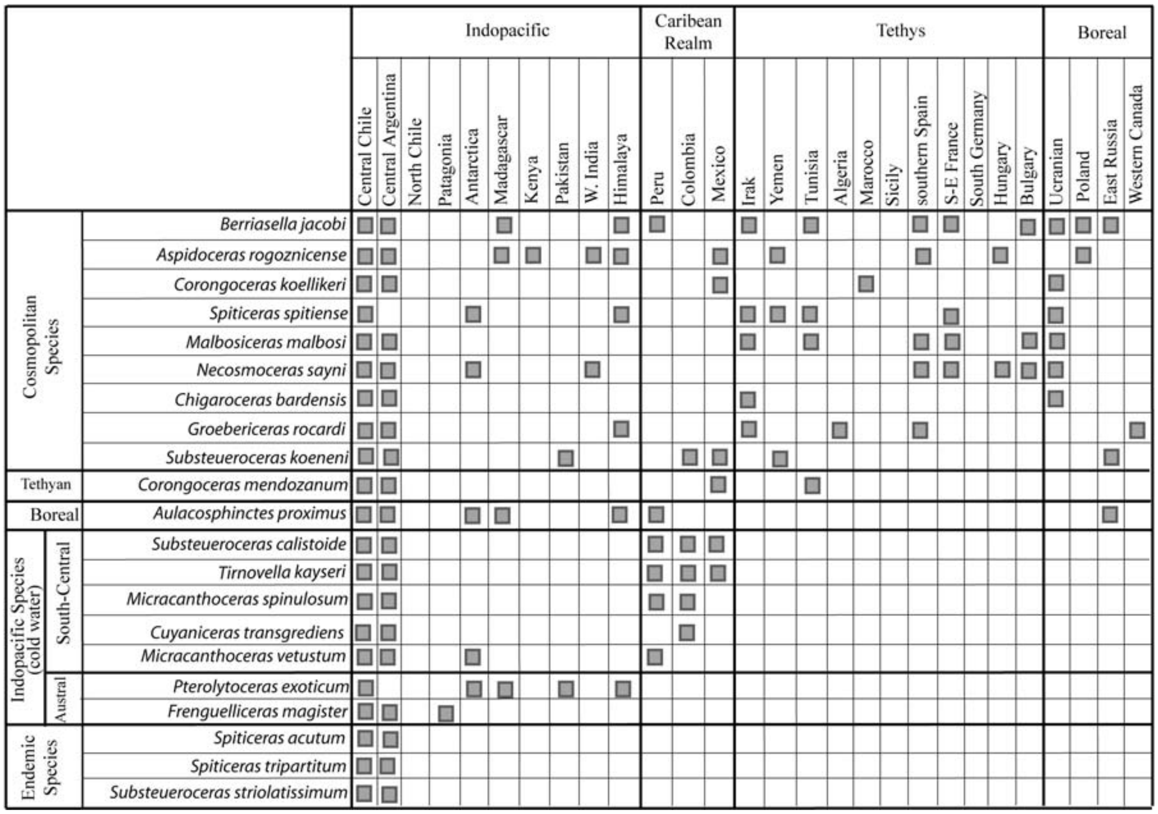


Figure 6.3. Pies graphic that represent the relative Richness and Abundance of the ammonoids registered during the Tithonian in Central Chile.

6.2. Berriasian

21 species of ammonites are registered in central Chile for the Berriasian (figure 6.4). Cosmopolitan taxa dominate by 42% of relative species richness, followed by 34% of taxa with Indo-Pacific influence, 14% of Endemic species, 5% of Boreal and 5% of Tethyan affinities (figure 6.5a). The Indo-Pacific influence is divided in 24% with South-Central Pacific and 10% with Indo-Austral affinities. The relative abundance is also marked by a dominance of 35% Cosmopolitan and 26% of Endemic species, 21% of Indo-Pacific (18% South-Central Pacific and 3% Indo-Austral), 5% of Boreal and 5% of Tethyan affinities (figure 6.5b).



			Indopacific										Caribean Realm			Tethys											Boreal			
			Central Chile	Central Argentina	North Chile	Patagonia	Antarctica	Madagascar	Kenya	Pakistan	W. India	Himalaya	Peru	Colombia	Mexico	Irak	Yemen	Tunisia	Algeria	Marocco	Sicily	southern Spain	S-E France	South Germany	Hungary	Bulgary	Ucranian	Poland	East Russia	Western Canada
Cosmopolitan Species		*Berriasella jacobi*	■	■				■				■	■			■		■				■	■			■	■	■	■	
		Aspidoceras rogoznicense	■	■				■	■		■	■			■		■					■			■			■		
		Corongoceras koellikeri	■	■											■					■							■			
		Spiticeras spitiense	■				■					■				■	■	■					■				■			
		Malbosiceras malbosi	■	■												■		■				■	■			■	■			
		Necosmoceras sayni	■	■			■				■											■	■		■	■	■			
		Chigaroceras bardensis	■	■												■											■			
		Groebericeras rocardi	■	■								■				■			■			■								■
		Substeueroceras koeneni	■	■						■				■	■		■												■	
Tethyan		*Corongoceras mendozanum*	■	■											■			■												
Boreal		*Aulacosphinctes proximus*	■	■			■	■				■	■																■	
Indopacific Species (cold water)	South-Central	*Substeueroceras calistoide*	■	■									■	■	■															
		Tirnovella kayseri	■	■									■	■	■															
		Micracanthoceras spinulosum	■	■									■	■																
		Cuyaniceras transgrediens	■	■										■																
		Micracanthoceras vetustum	■	■			■						■																	
	Austral	*Pterolytoceras exoticum*	■				■	■		■		■																		
		Frenguelliceras magister	■	■		■																								
Endemic Species		*Spiticeras acutum*	■	■																										
		Spiticeras tripartitum	■	■																										
		Substeueroceras striolatissimum	■	■																										

Figure 6.4. Palaeobiogeographic distribution of ammonites recorded for the Berriasian in Central Chile. Only localities are included which contain taxa in common.

The Cosmopolitan influence is thus much higher during the Berriasian than during the Tithonian; these Cosmopolitan species are homogeneously registered in the Indo-Pacific, Tethyan and Boreal regions (figure 6.4). Endemism is still important for the Berriasian (figure 6.5a-b). Indo-Pacific taxa increase in relative species richness but decrease in relative abundance (figure 6.5a-b). Indo-Pacific and Caribbean realms appear to have been well connected (figure 6.4). Tethyan and Boreal affinities, on the other hand, are lower than in the Tithonian (figure 6.4-6.5). It is important to note that Cosmopolitan species increased in abundance during the Berriasian as compared with the Tithonian, likely due to the opening or a better connection via the Indo-Austral seaway (figure 6.13), or the Hispanic corridor (figure 6.13. Only 3 endemic species are recognized for the Berriasian, Spiticeras acutum, *Spiticeras tripartitum* and *Substeueroceras striolatissimum* (figure 6.4).

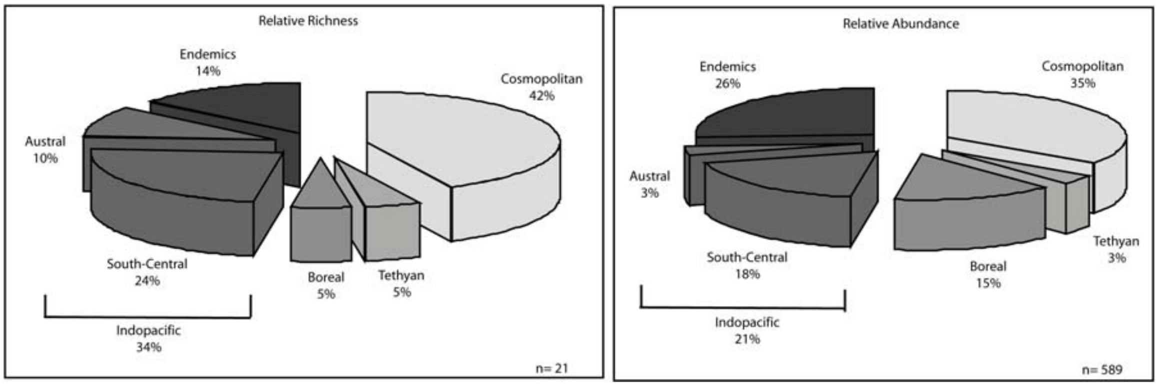


Figure 6.5. Pies graphic that represent the relative Richness and Abundance of the ammonoids registered during the Berriasian in Central Chile.

6.3. Valanginian

In Central Chile, the Valanginian ammonite records are restricted to the Lower Valanginian. 7 species are differentiated (figure 6.6), of which 29% are considered Endemics, 29% show Tethyan affinities, 14% are Cosmopolitans, 14% are Indo-Pacific (Austral) and 14% present a Boreal influence (figure 6.7a). The relative abundance is dominated by 34% of species with Tethyan affinities, followed by 25% of Endemics, 22% with Indo-Pacific (Austral) influence, 17% with Boreal affinities and only 2% are Cosmopolitan species (figure 6.7b).

Tethyan affinities are highest during the Valanginian, where *Thurmaniceras thurmanni* is also recorded in the Caribbean realm; a marine pathway connection likely existed via the Hispanic Corridor (figure 6.13). *Spiticeras pricei* (figure 6.6) may have migrated to Chile via the Indo-Austral seaway (figure 6.13). *Spiticeras spitience* is a cosmopolitan and also recorded from Boreal, Tethyan and Indo-Pacific regions, but without a record from the Caribbean realm. This indicates that pathways from the Tethys to the Indo-Pacific region for this latter taxon was via the Indo-Austral seaway (figure 6.13).

A possible Boreal influence is suggested by the presence of *Argentiniceras fasciculatum*, with records in Western Canada, Colombia, central Chile-Argentina and Antarctica. Records of this taxon are thus entirely from the east Pacific and mostly restricted to cold water. *Frenguelliceras magister* is registered en Central Chile-Argentina and Antarctica and thus also considered an

Indo-Austral species (figure 6.6). Taxa considered to be Endemic to Central Chile-Argentina are *Pseudofavrella angulatiformis* and *Spiticeras tripartitum* (figure 6.6).

		Indopacific										Caribean Realm			Tethys											Boreal			
		Central Chile	Central Argentina	North Chile	Patagonia	Antarctica	Madagascar	Kenya	Pakistan	W. India	Himalaya	Peru	Colombia	Mexico	Irak	Yemen	Tunisia	Algeria	Marocco	Sicily	southern Spain	S-E France	South Germany	Hungary	Bulgary	Ucranian	Poland	East Russia	Western Canada
Cosmopolitan	*Spiticeras spitiense*	■				■					■				■	■	■					■				■			
Tethyan Species	*Thurmaniceras thurmanni*	■	■									■		■					■		■	■	■		■				
	Spiticeras pricei	■														■													
Boreal	*Argentiniceras fasciculatum*	■	■			■							■																■
I-P. Austral	*Frenguelliceras magister*	■	■		■																								
Endemic Species	*Pseudofavrella angulatiformis*	■	■																										
	Spiticeras tripartitum	■	■																										

Figure 6.6. Palaeobiogeographic distribution of ammonites recorded for the Valanginian in Lo Valdés Formation. Only localities are included which contain taxa in common.

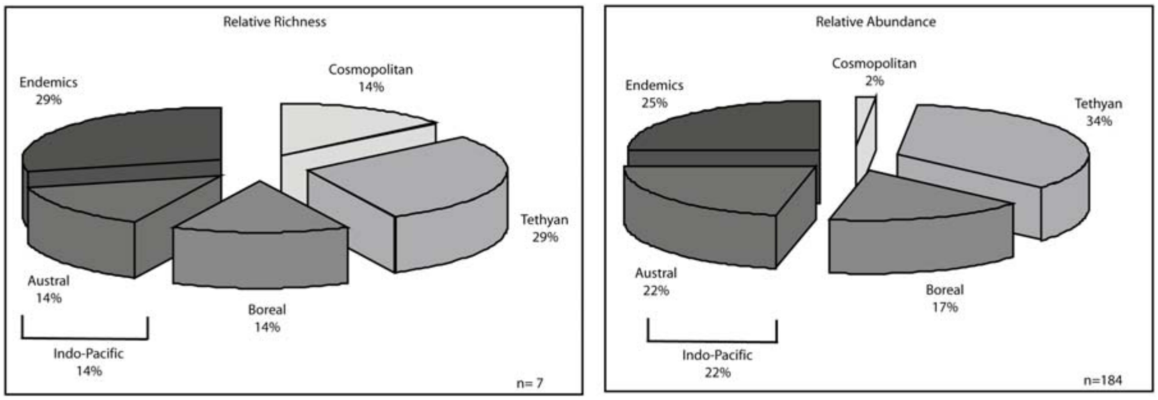
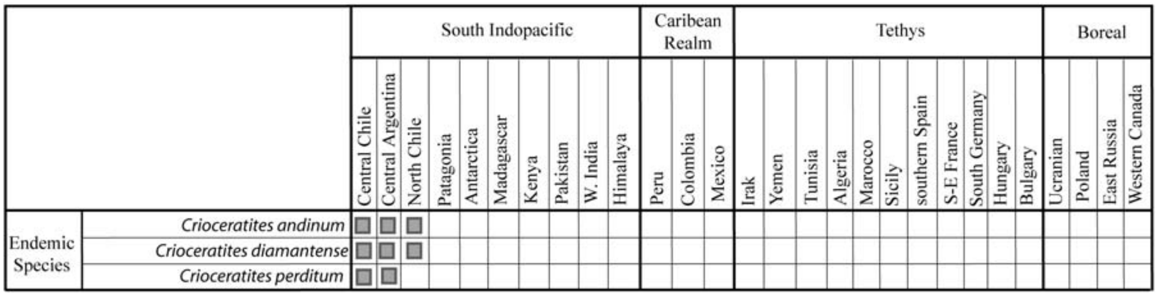


Figure 6.7. Pie graphic that represent the relative Richness and Abundance of the ammonoids registered during the Valanginian in Lo Valdés Formation.

6.4. Hauterivian

Records of the Hauterivian in Central Chile are restricted to the Upper Hauterivian and only include three taxa endemic to the region. This assemblage is thus of low relative Richness and Abundance (figure 6.8). Hauterivian layers were difficult to access and were not exhaustively sampled; in consequence data presented here must be regarded with caution.



		South Indopacific										Caribean Realm			Tethys											Boreal			
		Central Chile	Central Argentina	North Chile	Patagonia	Antarctica	Madagascar	Kenya	Pakistan	W. India	Himalaya	Peru	Colombia	Mexico	Irak	Yemen	Tunisia	Algeria	Marocco	Sicily	southern Spain	S-E France	South Germany	Hungary	Bulgary	Ucranian	Poland	East Russia	Western Canada
Endemic Species	*Crioceratites andinum*	■	■	■																									
	Crioceratites diamantense	■	■	■																									
	Crioceratites perditum	■	■																										

Figure 6.8. Palaeobiogeographic distribution of ammonites recorded for the Hauterivian in Lo Valdés Formation. Only localities are included which contain taxa in common.

6.5. Palaeobiogeographic Influences

Five faunal realms were recognized in the Central Chilean ammonite assemblages across the Jurassic-Cretaceous boundary, from the Tithonian to Hauterivian: Cosmopolitan, Tethyan, Boreal, Indo-Pacific, and Endemics to Chile-Argentina. Relative species Richness and Abundance of these affinities varies considerably during this interval of the geological time and presents both abrupt and gradual changes.

The Cosmopolitan faunal assemblage of the Jurassic-Cretaceous boundary transition in Central Chile corresponds to twelve species (figure 6.1), but this picture changes notably when individual stages are reviewed: Only 12% of the ammonites recorded from the Tithonian are cosmopolitans, but in the Berriasian this group increases sharply to 75% of the total record. A sharp drop is recognized for the Valanginian, with only 8% of the fauna corresponding to cosmopolitans, whereas in the Hauterivian cosmopolitan taxa are completely absent and the number thus drops to zero (figure 6.9a). In terms of relative Abundance, the situation is even more accentuated: During the Tithonian, Cosmopolitan species only reach about 1% of the fauna, but the number increases abruptly to 98% in the Berriasian. In the Valanginian, numbers drop again to 1% and to zero in the Hauterivian (figure 6.9b).

Tethyan affinities are recognized in Central Chile by seven species (figure 6.1). The major importance of this group is reached during the Tithonian with a total of 57% of the fauna. Numbers decrease to 14% in the Berriasian, then increase to 29% in the Valanginian. No Tethyan species are present in Central Chile during the Hauterivian (figure 6.9c). Numbers of the relative abundance of Tethyan species are similar to the relative species richness and reach 61% during the Tithonian, decreasing to 9% in the Berriasian and again increasing to 30% during the Valanginian. No Tethyan taxa are known from Central Chile in the Hauterivian (figure 6.9d).

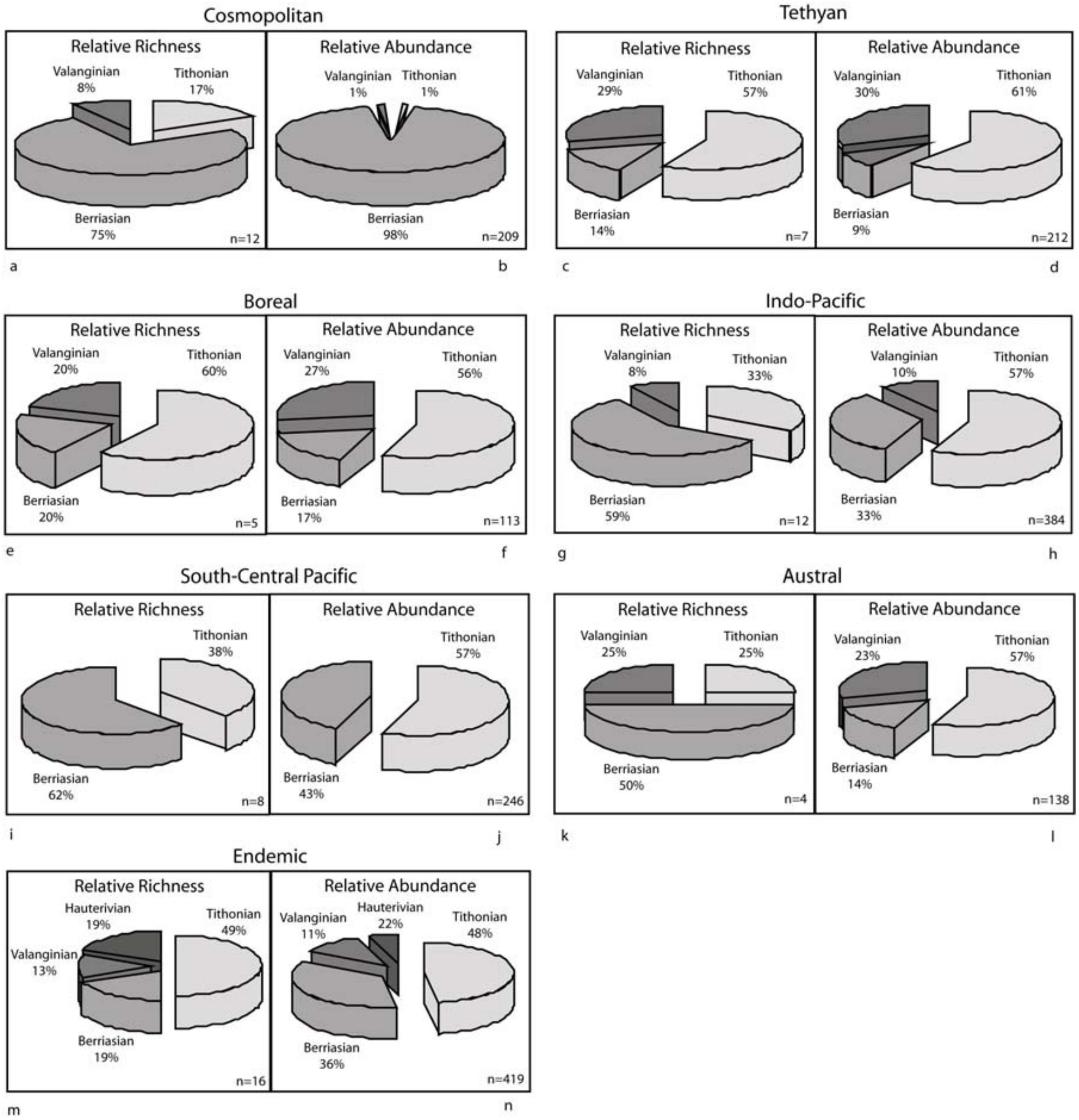


Figure 6.9. Pie graphics that show the percentages of the palaeobiogeographical regions defined here, during the Tithonian-Hauterivian in Central Chile.

Only three species of Boreal ammonites are recognized in Central Chile. Relative species richness of this group reaches 60% in the Tithonian, decreases to 20% during the Berriasian and to 20% in the Valanginian; during the Hauterivian no Boreal ammonites are registered (figure 6.9e). Numbers of the relative abundance of Boreal species is similar, reaching 56%, during the Tithonian, decreasing to 17%, during the Berriasian and increasing slightly to 27% in the Valanginian; there are no records of Boreal species in the Hauterivian (figure 6.9f).

Indo-Pacific ammonites are represented by twelve species; their relative species richness reaches 33% during the Tithonian. It increases to 59% in the Berriasian and decreases to 8% in the

Valanginian; there are no Hauterivian records (figure 6.9g). The relative abundance in the Tithonian approximates 57%, decreases to 33% in the Berriasian and to 10% in the Valanginian. No Indo-Pacific species are present during the Hauterivian (figure 6.9h). As described earlier, the Indo-Pacific realm is here subdivided in a South-Central Pacific and an Austral province. The influence of the South-Central Pacific faunal province is important in Central Chile during the Tithonian-Hauterivian interval and reflected in the relative species richness, with a total of eight taxa present. They reach 38% during the Tithonian and 62% in the Berriasian (figure 6.9i). Relative abundance is highest in the Tithonian with 57% and decreases to 43% during the Berriasian (figure 6.9i). Four species of Austral provenience are registered. Their relative richness reaches 25% during the Tithonian, increasing abruptly to 50% in the Berriasian and decreasing to 25% in the Valanginian. Relative abundance changes are somewhat different, with 57% in the Tithonian, 14% in the Berriasian and 23% in the Valanginian (figure 6.9l).

Endemic taxa are also important in the Central-Chilean ammonite assemblages, with sixteen species recorded. Relative species richness reaches 49% in the Tithonian, decreases to 19% in the Berriasian, to 13% in the Valanginian and to 19% in the Hauterivian (figure 6.9m). Their relative abundance changes are similar: endemics are the dominant group in the Tithonian with 48%, decrease to 36% during the Berriasian and to 11% in the Valanginian, and then rise again to 22% in the Hauterivian.

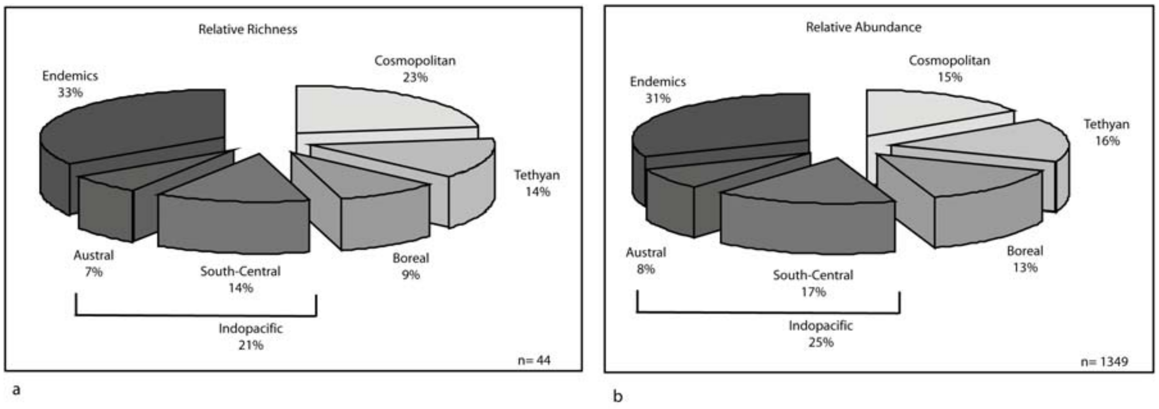


Figure 6.10. Pie graphic that represent the relative Richness and Abundance of the ammonoids registered during the Tithonian-Hauterivian in Central Chile.

An integration of the set of data outlined above allows us to evaluate the influence of the five palaeobiogeographical faunal regions (Cosmopolitan, Tethyan, Boreal, Indo-Pacific and Endemics) on Central Chilean ammonite assemblages in terms of relative Richness and

Abundance of taxa. For the Tithonian to Hauterivian stages, the relative richness is represented by 43 species (and *Bochianites* spp.). Endemics are the dominant group with a 33% of the entire assemblage, followed by Indo-Pacific taxa with 21% (14% South-Central Pacific and 7% Austral). Cosmopolitans are represented by 23% of the faunal assemblage, Tethyan ammonites by 14% and Boreal taxa by 9% (figure 6.10a). When the relative abundance is considered in terms of number of specimens per taxon, Endemic taxa dominate (31%), followed by Indo-Pacific affinities (25%), divided in 17% of South-Central Pacific and 8% of Austral influence, Tethyan (16%), Cosmopolitan (15%) and Boreal (13%) influences (figure 6.10b). Richness and abundance of Central Chilean ammonites of the Baños del Flaco and Lo Valdés formations thus show a general Endemic character, but with an important percentage of Indo-Pacific, Cosmopolitan and Tethyan taxa, and a low Boreal influence.

6.6. Palaeobiogeographical Pathways

An evaluation of the palaeobiogeographical affinities of Middle Tithonian to Lower Valanginian ammonite assemblages may yield important information on the formation of possible palaeobiogeographical pathways associated with the disruption of Pangaea. For this interval of the geological time the ammonite record is continuous and diversity is high in Central Chile. The Hauterivian is excluded here, due to the fact that only few specimens of three endemic species were identified.

Figure 6.1 lists the localities and regions from which Central Chilean ammonite species have been described and recorded. Palaeobiogeographical affinities of taxa from the Baños del Flaco and Lo Valdés formations are established using the Ruggiero index (Koleff et al. 2003). This method considers the similarity of faunal assemblages, using the number of taxa which are shared with other regions (for details see Koleff et al. 2003, Möseler et al. 2009). Figure 6.11 shows that affinities of Central Chilean ammonites of the Baños del Flaco and Lo Valdés formations are highest with Central Argentina which forms part of the same marine basin. Mexico and Ucrania-Poland localities are also well represented, followed by Antarctica, Peru and Southern Spain. Faunal influences from the Himalayas, Colombia, South Germany-France, Tunisia-Algeria, Hungary-Bulgary, Western India and Iraq are less accentuated; faunal elements from Madagascar, Yemen, East Russia, Patagonia, Western Canada, Morocco and Kenya are little represented (figure 6.11). Grouping the localities/provinces into regions, it is possible to establish that the highest affinities of the Central Chilean fauna are with the Indo-Pacific region, followed by the Caribbean Realm, Tethys and Boreal regions (figure 6.11).

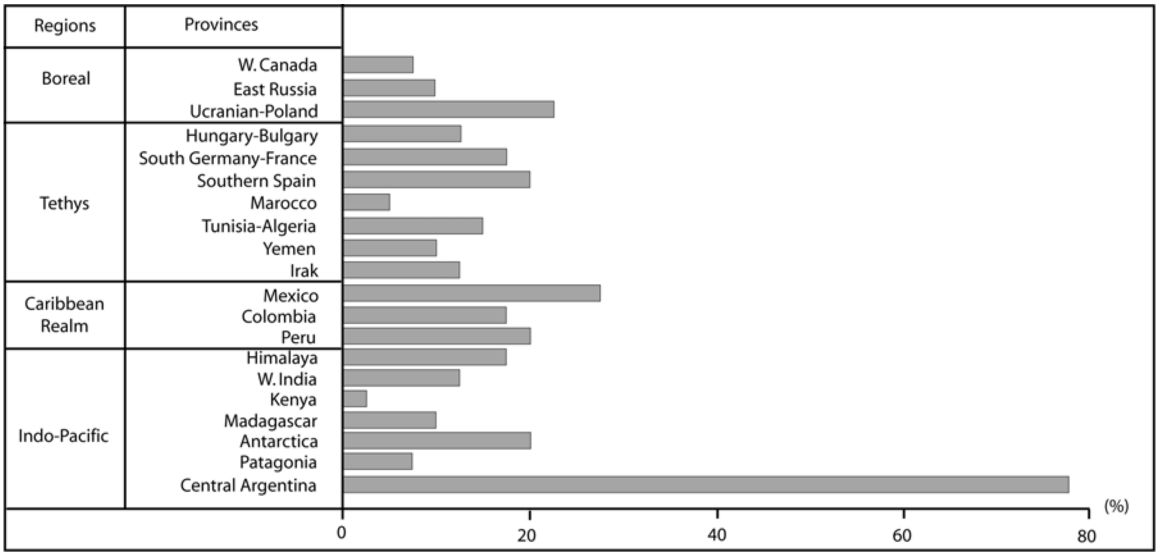


Figure 6.11. Ammonite taxa in common between the Baños del Flaco and Lo Valdés formations and other important Tithonian-Hauterivian localities/provinces worldwide, using the Ruggiero index.

Cladistic biogeography (also called vicariance biogeography) deals with the classification of patterns and processes of a changing Earth and its biota through geological time (Humphries 2005). The Dendrogram is a “tree” diagram frequently used to illustrate the arrangement of the clusters (Humphries 2005).

Figure 6.12 is a Cluster Dendogram where species present in Central Chile (Baños del Flaco and Lo Valdés formations) are grouped by similarity with others provinces/localities that share species in common. This Cluster Dendrogram (figure 6.12) was established by “R” software environment for statistical computing and graphics. Similarity is closest with coeval assemblages from Central Argentina (figure 6.12). The association Central Chile – Argentina is linked with a branch composed by East Russia – Mexico, Colombia – Peru and Morocco (figure 6.12), and subsequently with Patagonia – Western Canada (figure 6.12). This branch suggests that ammonites from Central Chile are closely associated with associations from the South-Central Pacific, from the Caribbean Realm and from Morocco, but that additional influences exist from the Boreal Region (East Russia and Western Canada) (figure 6.12). This primary main branch is linked with the secondary branch composed by Himalaya – Madagascar, Antarctica, Yemen – W. India-Pakistan and Kenya (figure 6.12). This secondary branch is composed by Indo-Pacific ammonites (Indo-Austral) (figure 6.12). The third main branch is composed by an association of SE France – S Germany, southern Spain, Ucrania-Poland and Iraq–Tunisia-Algeria (figure 6.12). This branch characterizes a Tethyan influence and the Boreal provinces of Ucrania-Poland (figure 6.12).

Figure 6.12 indicates that Central Chilean ammonite associations of Middle Tithonian to Lower Valanginian age show an Indo-Pacific influence, but that they also allow for an exchange of faunal elements with the Caribbean Realm and the Indo-Austral region. Influence from the Tethyan and the Boreal realm is also notable.

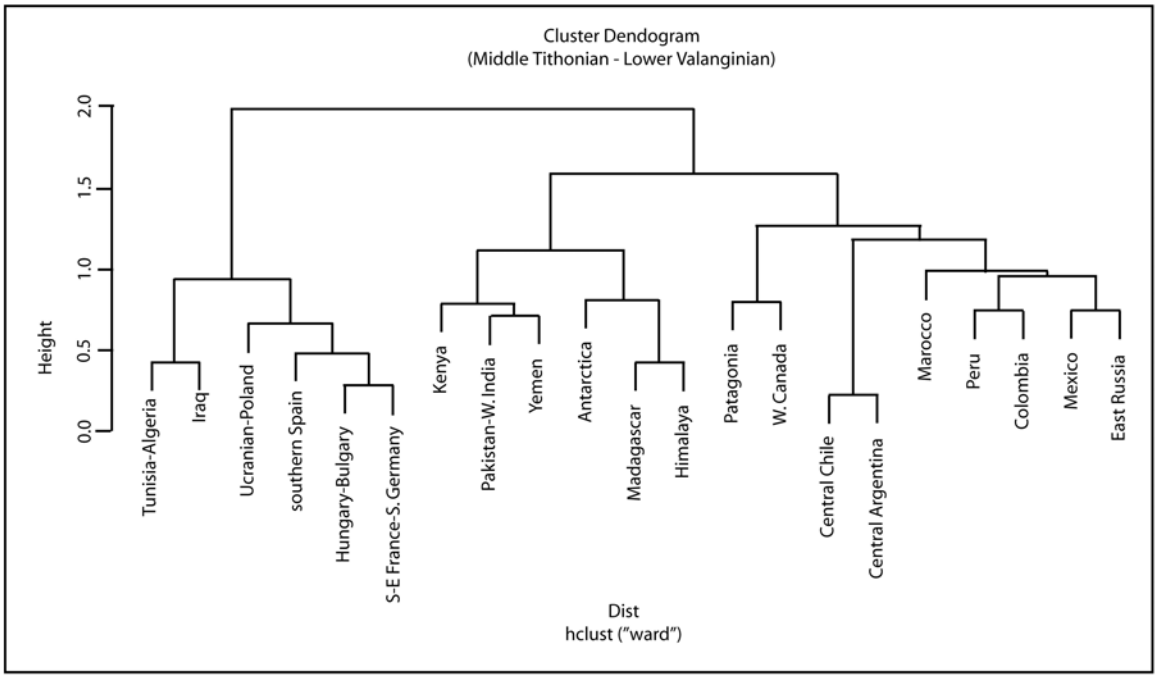


Figure 6.12. Cluster Dendogram make by "R" software environment for statistical computing and graphics. This cluster show the affinities of Central Chile ammonites with other localities/provincies worldwide during the Middle Tithonian to Lower Valanginian.

6.7. Summary

For decades the Late Jurassic – Lower Cretaceous ammonite assemblages in South America have been considered to be dominated by endemic taxa (e.g. Leanza. H. 1980, Aguirre-Urreta et al. 2007), complemented by a minor Tethyan influence. The latter was based on the hypothesis of a Hispanic Corridor as the principal seaway that connected Europe and the East Pacific (e.g. Riccardi 1991, Gasparini & Fernandez 1997).

Our analysis of Middle Tithonian to Lower Valanginian ammonites of Central Chile (Baños del Flaco and Lo Valdés formations) also indicates a high degree of endemism, but Indo-Pacific, Caribbean, Tethyan and Boreal influences are much stronger than previously thought (figure 6.1, 6.9, 6.10, 6.11 and 6.12). Endemic and Indo-Pacific taxa dominated during the Tithonian, but connections with the Indo-Austral province, the Tethyan and the Boreal regions are also notable (figure 6.3). In the Berriasian endemic ammonites decrease and cosmopolitan taxa dominate whereas the Indo-Pacific influence remains important (figure 6.5). The Valanginian is characterised by a decrease in Cosmopolitan ammonites. During this time the Tethyan influence dominates in the region. Endemic, Indo-Pacific and Boreal influences are still present (figure 6.7). The Hauterivian is not well represented; only three species are recorded with low abundances (figure 6.8). Figure 6.10 summarizes these data and shows that the Middle Tithonian to Lower Valanginian is dominated by Endemic species (33% Richness and 31% Abundance), followed by Indo-Pacific (21% Richness and 25% Abundance), and Tethyan affinities (14% Richness and 16% Abundance). A Boreal influence is less evident but is still represented by 9% species Richness and 13% Abundance (figure 6.10).

Taxa endemic to Central Chile and Argentina and Tethyan species are the dominant ammonites during the Tithonian (figure 6.2-6.3), changing abruptly during the Berriasian where the Cosmopolitan and Indo-Pacific influences increase and these taxa form the dominant group (figure 6.4-6.5), while Tethyan and Endemic ammonites dominate during the Valanginian (figure 6.6-6.7). This abundance of endemic taxa during the Tithonian suggests that Central Chile may not have been well connected with the Tethyan region (figure 6.2-6.3 and that the Hispanic Corridor was closed (figure 6.13). An early Berriasian opening of this seaway was postulated earlier by Adatte et al. (1994, 1996), based on calpionellid and ammonite assemblages in Mexico. Indo-Pacific affinities, on the other hand, result from an open Indo-Austral seaway (figure 6.13). During the Berriasian, the dominance of Cosmopolitan and increasing abundance of Indo-Pacific taxa suggests (figure 6.4-6.5) that new pathways opened between Antarctica and South America – Africa. These connections were likely established via the Indo-Austral seaway and the new connection through the Hispanic Corridor (figure 6.13). Subsequently during the Lower Valanginian (figure 6.6-6.7), Tethyan, Indo-Pacific (Indo-Austral) and Boreal taxa are present in Central Chilea and Endemic ammonites are equally abundant (figure 6.10). This may correspond to a similar grade of exchange through both the Hispanic Corridor and the Indo-Austral seaway (figure 6.13).

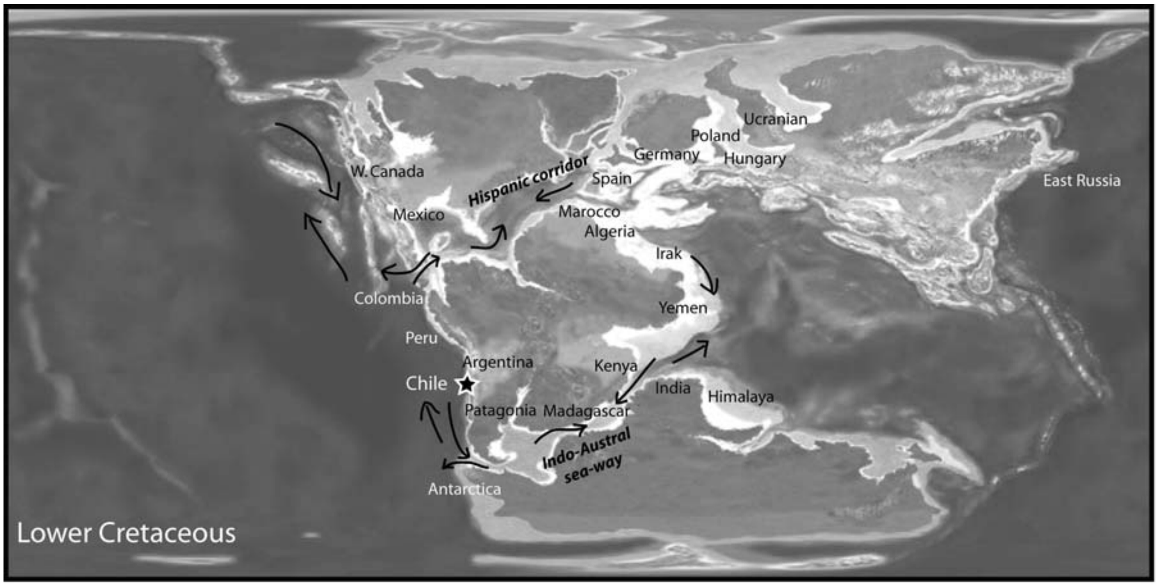


Figure 6.13. Palaeogeographic map for the Lower Cretaceous with ammonite localities (Blakey, 2002) and tentative paleoceanographic current model.

7. Depositional facies of the Lo Valdés and Baños del Flaco Formations

The Lo Valdés and Baños del Flaco formations consist of andesite, conglomerate, sandstone, siltstone and limestone. These rocks are interpreted to represent the shoreface, offshore transition and offshore environments (Figure 7.1). In this chapter, depositional facies are described based on lithofacies (macro and microfacies) and fossil content. These characteristics are summarized in summary (see chapter 7.5) and resumed in a depositional model presented in Figure 7.1.

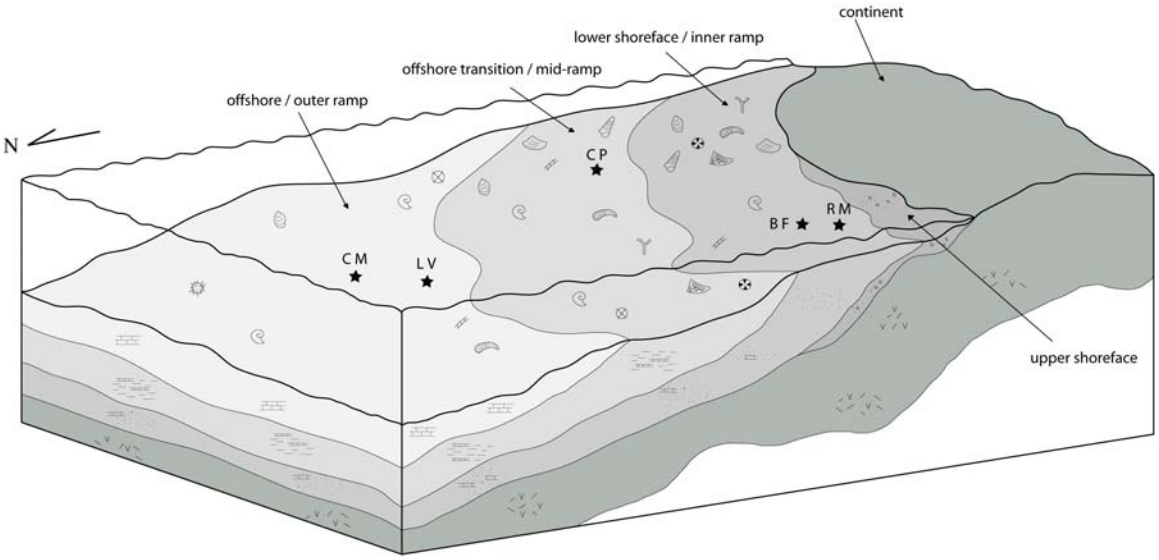


Figure 7.1. Depositional model of Lo Valdés and Baños del Flaco formations as a progradational sequence, during the Tithonian-Hauterivian.

7.1 Shoreface facies (Inner ramp)

Shoreface environment are divided here into upper and lower shoreface environments.

- Upper Shoreface facies

Conglomerate units are present in the Baños del Flaco Formation (Rio Maitenes and Baños del Flaco sections) and reach a maximum thickness of 50 m. Clasts are subangular to subrounded, well sorted, and mainly consist of andesite and lithified sandstone, as well as mineral debris such as quartz and plagioclase. The matrix consists of unfossiliferous fine grained sandstone with glauconite. Volcanic rock and sandstone clasts are likely reworked from the underlying Rio Damas Formation. They are here interpreted to represent upper shoreface high energy environments (figure 7.1).

- Lower Shoreface facies

Lower shoreface facies environments are represented by calcareous sandstone, sandy limestone and occasional limestone with abundant fossils.

In the Cajón del Morado, Lo Valdés and Cruz de Piedra sections of the Lo Valdés Formation, calcareous sandstone (figure 7.2 a,b,c) is widely distributed and characterized by cross lamination and horizontal bedding. This indicates high energy transport. In the calcareous sandstone, grains are subangular to subrounded, well sorted, and consist of volcanics rocks fragments, bioclasts and plagioclase. The matrix contains glauconite. The fauna encompasses ammonoids, abundant oysters, trigoniids, inoceramids and other bivalves as well as scare gastropods, rare fragments of bryozoans (figure 7.2 d), red algae (figure 7.2 e, f) (*Marinella lugeoni* figure 7.3 a), green algae (dasycladalean, figure 7.3 b) and corals (Family Placocoeniidae, figure 7.3 c).
Sandy limestone is interpreted as sandy packstone and wackestone. Sandy packstone (figure 7.3 d, e, f) is frequently cross- or horizontally laminated and contains sparse transported ooids probably allochthonous. Sandy wackestone (figure 7.3 g, h) is biomicrite. The fossil assemblage consists of ammonoids, abundant inoceramids, trigoniids, oysters (figure 7.3 f), and others bivalves (figure 7.3 e), as well as scare fragments of gastropods, corals (*Cladophyllia qiebulaensis*, figure 7.4 a, *Actinastrea scyphoidea*), bryozoans (figure 7.4 b), sponges and algae (figure 7.3 e, 7.4 c).

The lower shoreface facies environments characterize the main part of the lower and upper members of the Baños del Flaco Formation at Baños del Flaco and Rio Maitenes sections. Lithologies there correspond to calcareous sandstone, sandy wackestone and limestone (calci-mudstone, wackestone and grainstone). Calcareous sandstone (figure 7.4 d, e) grains are subangular to subrounded, well sorted, include fragments of volcanic rock, bioclasts, plagioclase, layers with cross-lamination, few ooids; in the upper member calcareous sandstone concretions are present. The sandy wackestone (figure 7.4 f, g) corresponds to biomicrite and biosparite with rare ooids (figure 7.4 h). The wackestone (figure 7.5 a, b) is biomicrite (figure 7.5 c, d) and also contains rare ooids (figure 7.5 e). Grainstone (figure 7.5 f, g, h) is restricted to the lower member. The fauna mainly comprises fragments of bivalves, such as oysters, inoceramids (figure 7.6 a), trigoniids, but ammonoids, scare corals, algae (figure 7.6 b), echinoderms (figure 7.4 g), calcispheres and serpulids (figure 7.6 c) are also present.

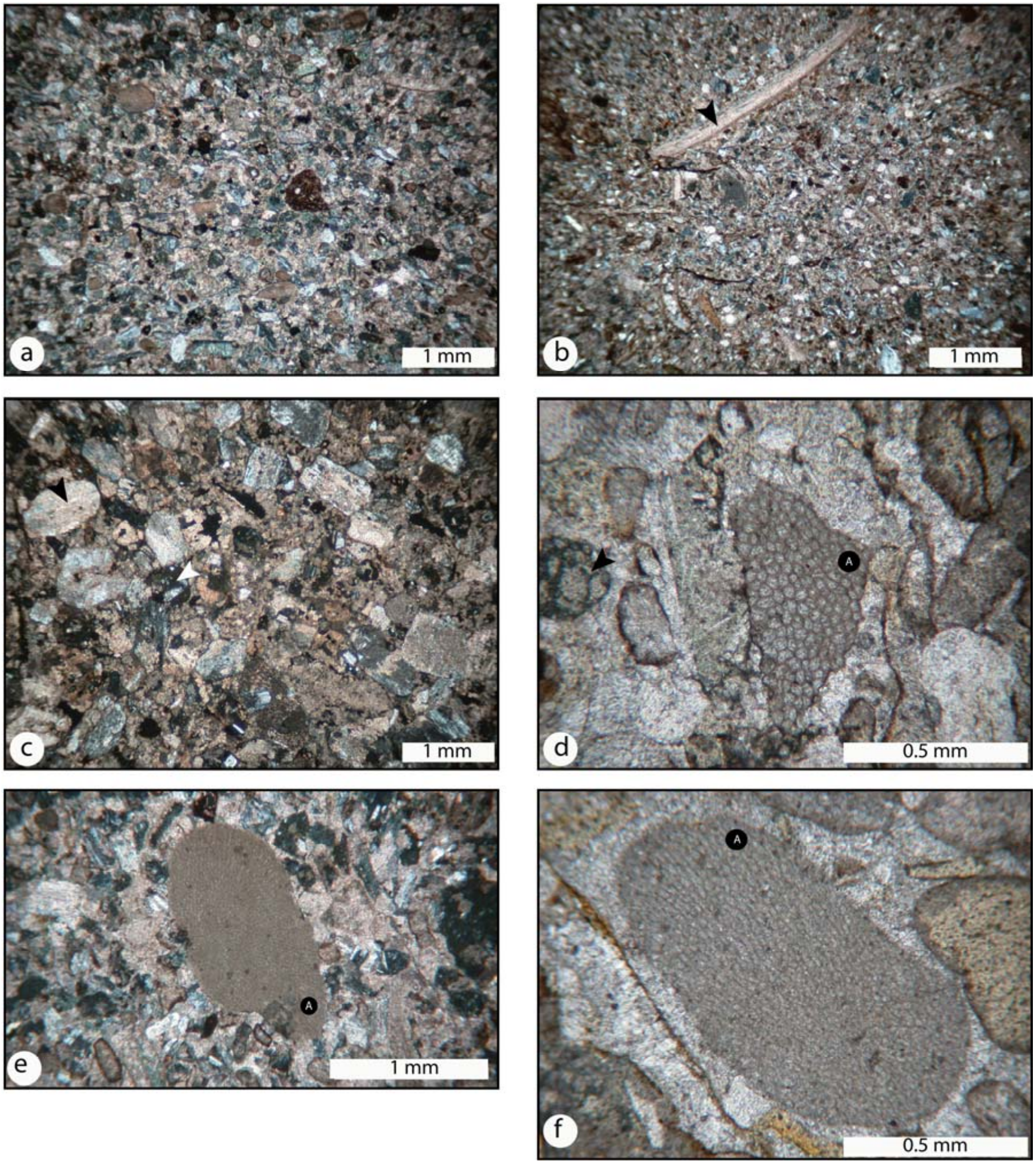


Figure 7.2. Microphotography from thin sections of the lithologies and fragmentary fossils of Lo Valdés Formation. **a-b:** Calcareous sandstone. **c:** Calcareous Sandstone. Plagioclse (white arrow), volcanics rocks fragment (black arrow) **d:** Clacareous Sandstone. **A**. Bryozoans, volcanics rocks fragments (black arrow) **e:** calcareous Sandstone. **A.** Red Algae. **f:** Calcareous Sandstone. **A.** Bryozoans.

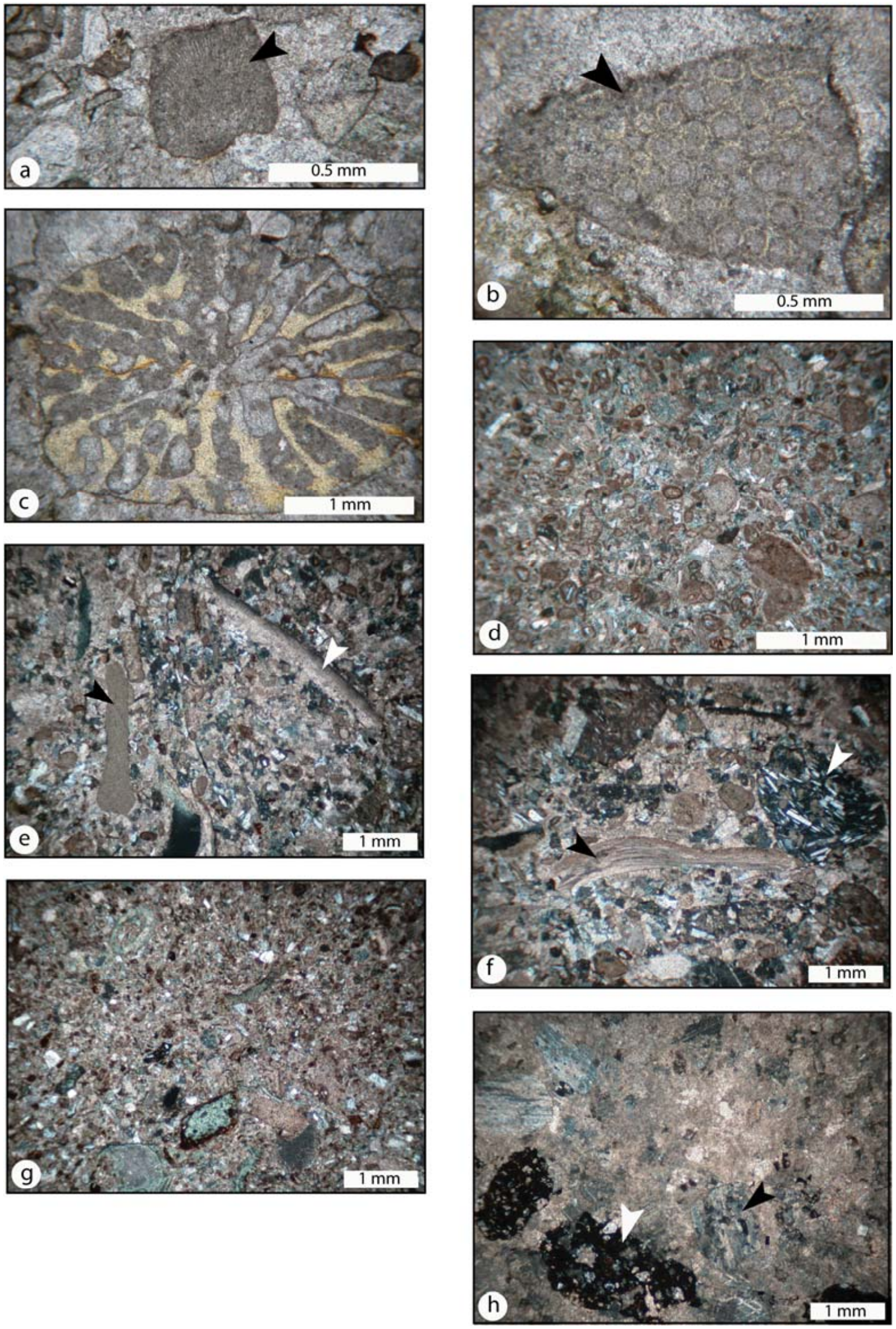


Figure 7.3. Microphotography from thin sections of the lithologies and fragmentary fossils of Lo Valdés Formation. **a:** Red algae ancestral rhodophyte Marinella lugeoni Pfender (black arrow). **b:** Green Algae tangencial section dasycladalean algae. **c:** Coral Faceloide, family Placocoeniidae **d:** Sandy packstone. **e:** Sandy packstone, Algae (black arrow), Bivalve fragment (white arrow). **f:** Sandy Packstone, Oyster (black arrow), volcanic rock fragment (white arrow). **g:** Sandy wackestone. **h:** Sandy Wackestone, volcanic rock fragment (white arrow), plagioclase (black arrow).

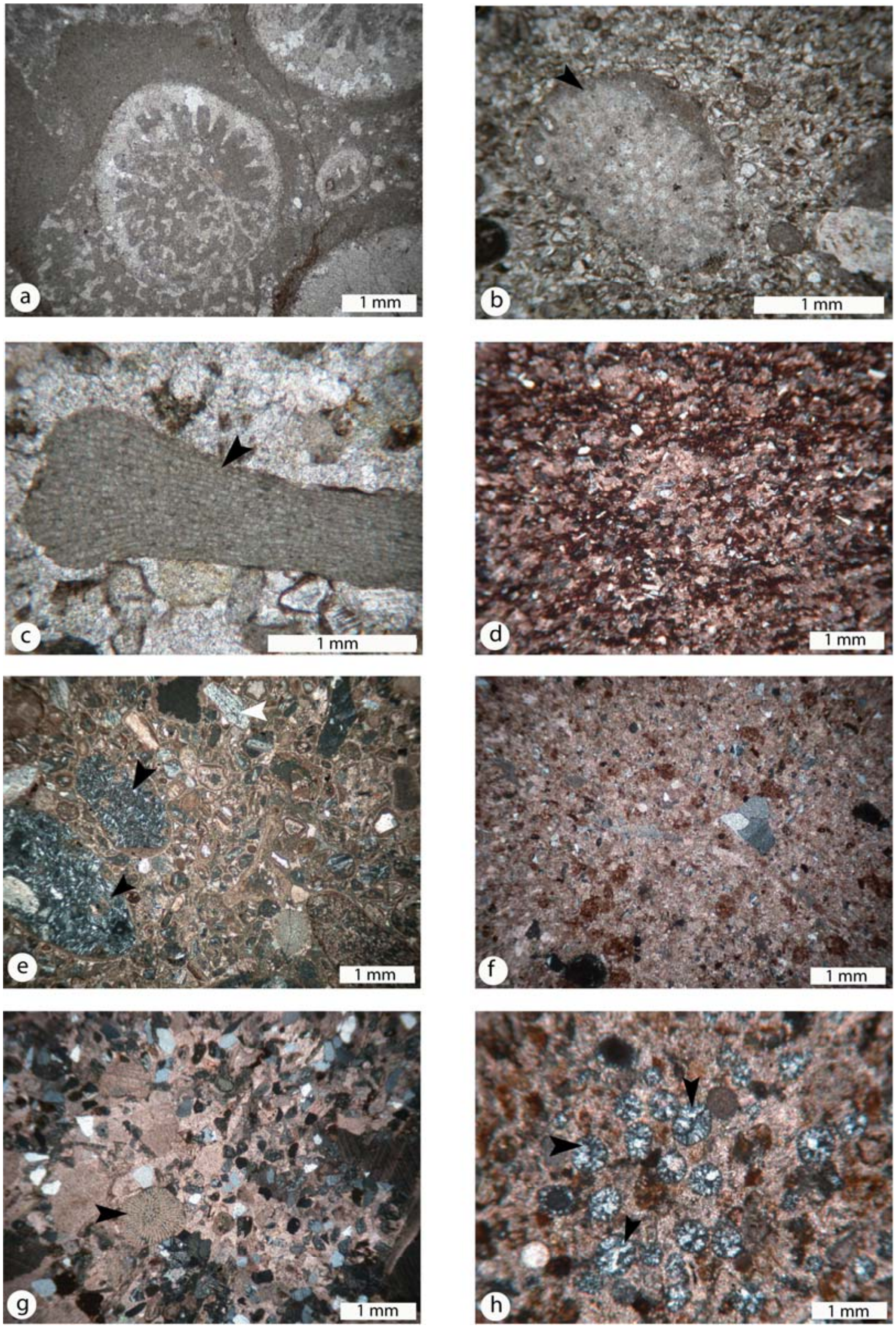


Figure 7.4. Microphotography from thin sections of the lithologies and fragmentary fossils of Lo Valdés and Baños del Flaco formations. **a:** Coral, *Cladophyllia qiebulaensis* Liao 1982. **b:** Sandy Packstone. Bryozoan (black arrow). **c:** red algae (black arrow). **d:** Calcareous Sandstone. **e:** Calcareous Sandstone. Volcanic fragments rock (black arrow), plagioclase (white arrow). **f:** Sandy Wackestone. **g:** Sandy wackestone. Echinoderms (black arrow). **h:** ooids (black arrow).

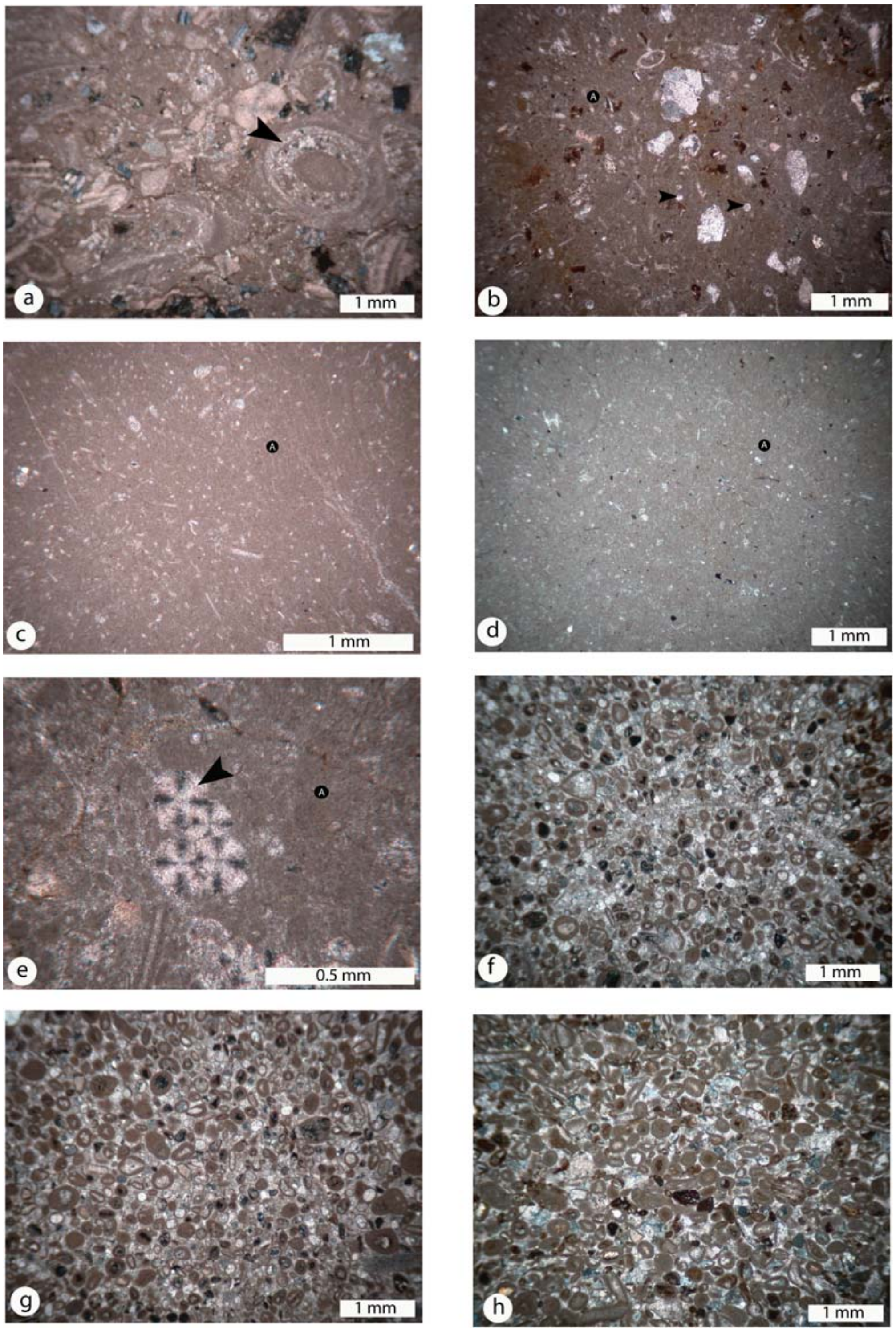


Figure 7.5. Microphotography from thin sections of the lithologies and fragmentary fossils of Baños del Flaco Formations. **a:** Wackestone. Ooids (black arrow). **b:** wackestone. A. biomicrite. calcispheres (black arrow). **c:**calci-mudstone. **A**. biomicrite. **d:** calci-mudstone. **A.** biomicrite. **e:** calcimudstone. **A.** biomicrite. Ooids (black arrow). **f-g-h:** Grainstone.

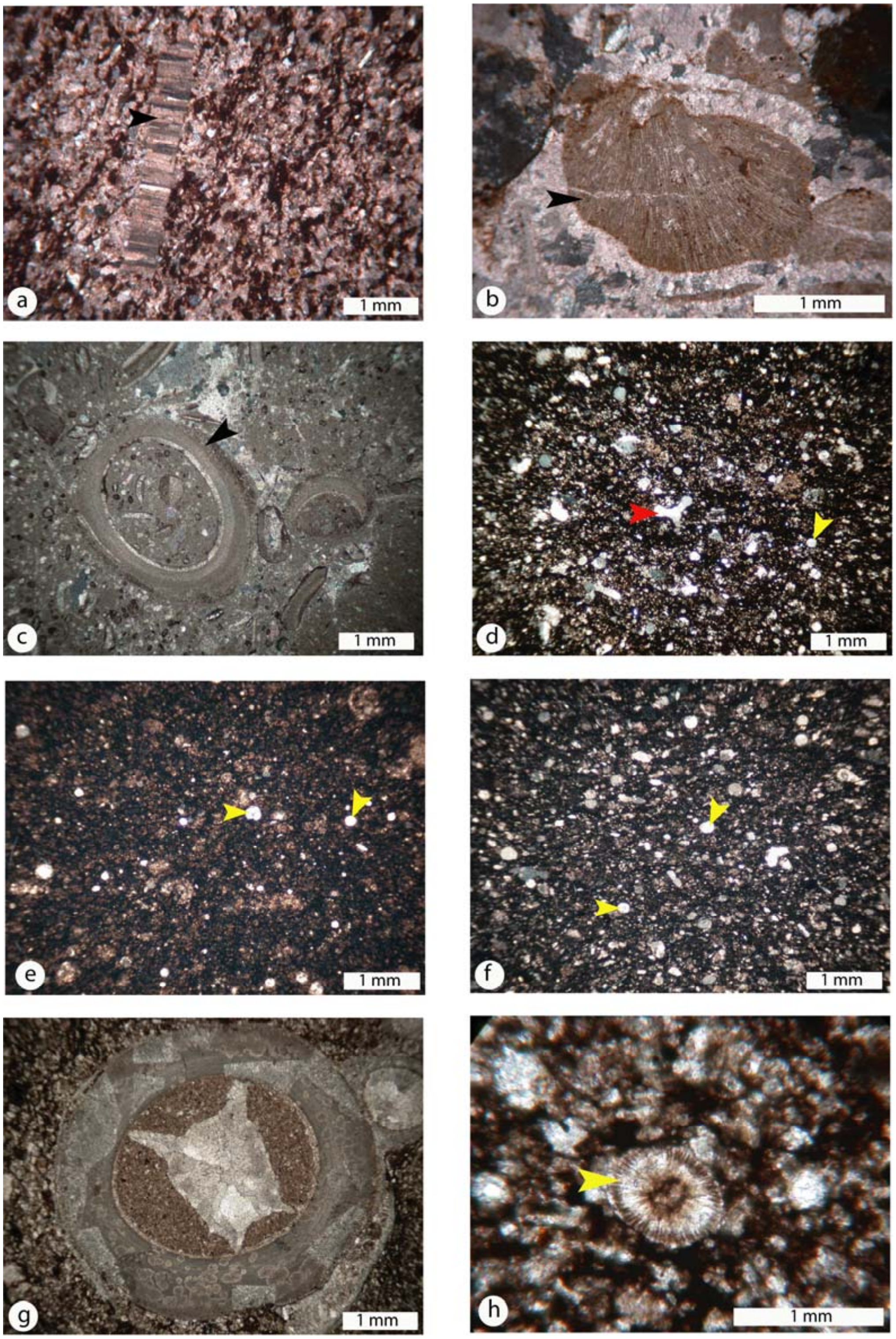


Figure 7.6. Microphotography from thin sections of the lithologies and fragmentary fossils of Lo Valdés and Baños del Flaco formations. **a:** fined-grained calcareous sandstone. Inoceramus fragment (black arrow). **b:** algae (black arrow). **c:** wackestone. serpulids (black arrow). **d:** calcareous siltstone. calcispheres (yellow arrow), spicules (red arrow). **e:** siltstone. calcispheres (yellow arrow). **f:** calcareous siltstone. calcispheres (yellow arrow). **g:** serpulid. **h:** calcareous siltstone. green Algae (yellow arrow).

7.2 Offshore transition facies (Mid-ramp)

Offshore transition facies are represented predominately by siltstone, calcareous siltstone and silty limestone. As compared to shoreface environments, conglomerate and sandstone are characteristically absent and faunal diversity is significantly higher. Offshore transition facies are extendedly represented in the Lo Valdés Formation.

Siltstone and calcareous siltstone are composed by silt-sized siliciclastic, carbonate, abundant organic matter and disseminated pyrite (figure 7.6 d, e, f). Horizontal lamination is widely distributed. Fossil assemblage is dominated by ammonoids and calcispheres (figure 7.6 d, e); serpulids (figure 7.6 g), sparse fragments of algae (figure 7.6h), sponge spicules (figure 7.6 d, 7.7 a), echinoderms (figure 7.7 b), rare foraminifers (figure 7.7 c, e, f, g), radiolarians and possible calpionellids (figure 7.7 d); inoceramids, other bivalves and gastropods are scare.

Silty limestone representing offshore transition environments correspond to calci-mudstone (figure 7.7 h), wackestone (figure 7.8 a) and packstone (figure 7.8 b, c), with planar lamination and also containing disseminated pyrite. The fauna encompasses mainly ammonoids and calcispheres (figure 7.8 c); bivalves and gastropods are scare, fragments of echinoderms (figure 7.8 d), algae, radiolarians (figure 7.8 e) serpulids (figure 7.8 f) and benthic foraminifers? are rare. In the Cajón del Morado and Lo Valdés sections, some layers with high oyster concentrations also exist (see chapter 3.1.3 and 3.2.3).

In the Baños del Flaco and Rio Maitenes sections of the Baños del Flaco Formation, the offshore transition consists of planar laminated siltstone and also contains carbonate, organic matter and disseminated pyrite. The faunal diversity is low, but scare ammonoids, bivalves and calcispheres are present.

7.3 Offshore facies (Outer ramp)

The offshore facies is characteristically present in the Cajón del Morado and Lo Valdés sections of the Lo Valdés Formation. The offshore facies consists of silty limestone, sandy limestone, limestone and occasional layers of calcareous siltstone; sandstone is characteristically absent. The silty-limestone shows planar lamination and corresponds to either calci-mudstone (figure 7.8 g, h) or wackestone (figure 7.9 a, b), other lithologies consist in wackestone (figure 7.9 c, d), bio-intrasparite, biosparite, biomicrite and bio-intramicrite. In the calcareous siltstone (figure 7.9 e) organic matter and disseminated pyrite are common.

The faunal diversity is lower than in offshore transition facies and includes occasional oysters-rich layers, scare ammonoids, bivalves (figure 7.9 b), annelids (figure 7.9 f), sponges, bryozoans (figure 7.9 c, d), undetermined echinoderms (figure 7.9 c), echinoids (figure 7.9 g, h), pentacrinoids (figure 7.9 h), corals, algae, radiolarians (figure 7.9 i), calcispheres and possible calpionellids (figure 7.9 j).

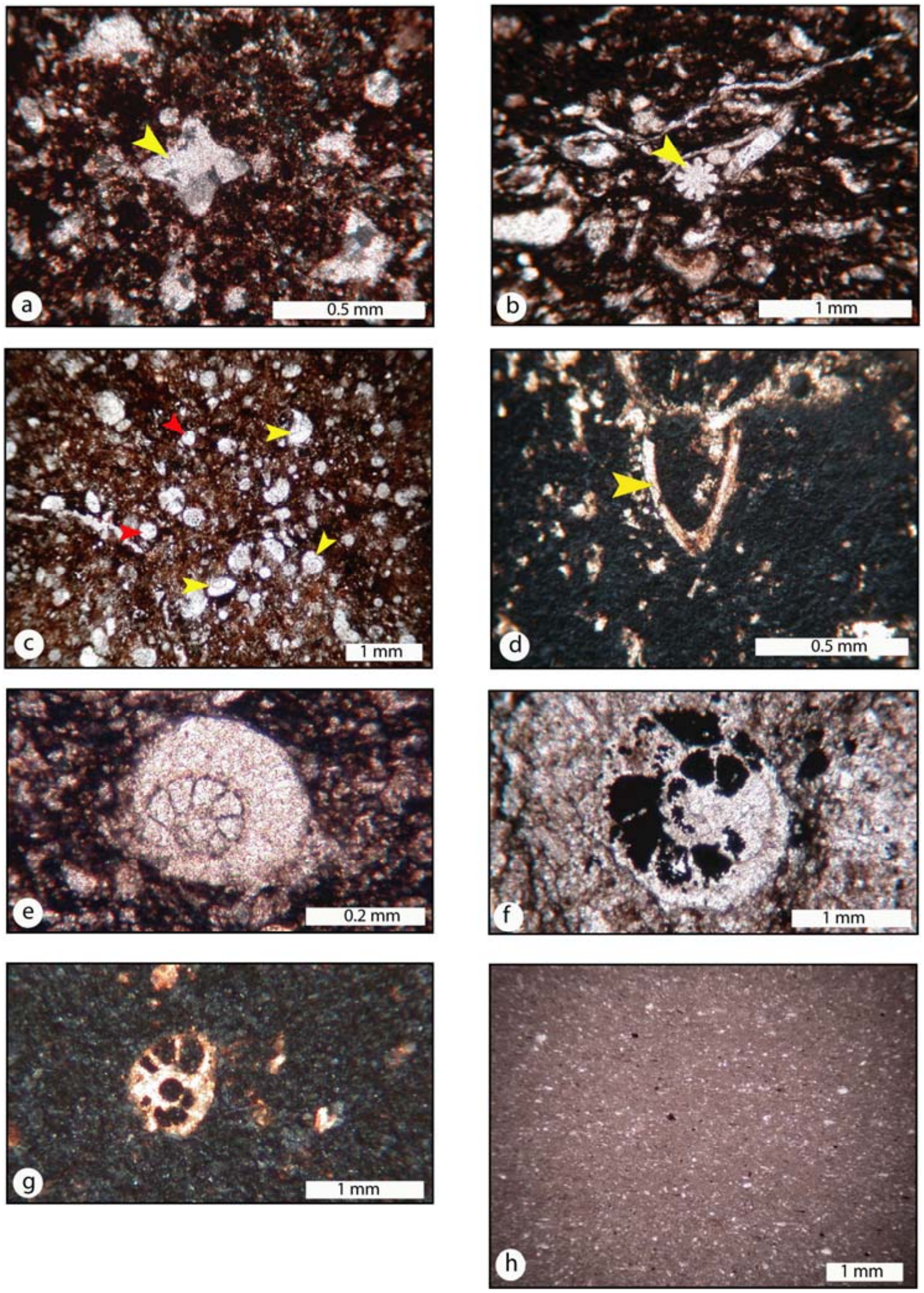


Figure 7.7. Microphotography from thin sections of the lithologies and fragmentary fossils of Lo Valdés Formation. **a:** Calcareous siltstone. sponge spicules (yellow arrow). **b:** Calcareous Siltstone. echinoderm spine (yellow arrow). **c:** Calcareous Siltstone. Benthic Foraminifera (yellow arrow). Calcispheres (red arrow). **d:** possible Calpionella (yellow arrow). **e-f-g:** Benthic foraminifera. **h:** Calci-mudstone.

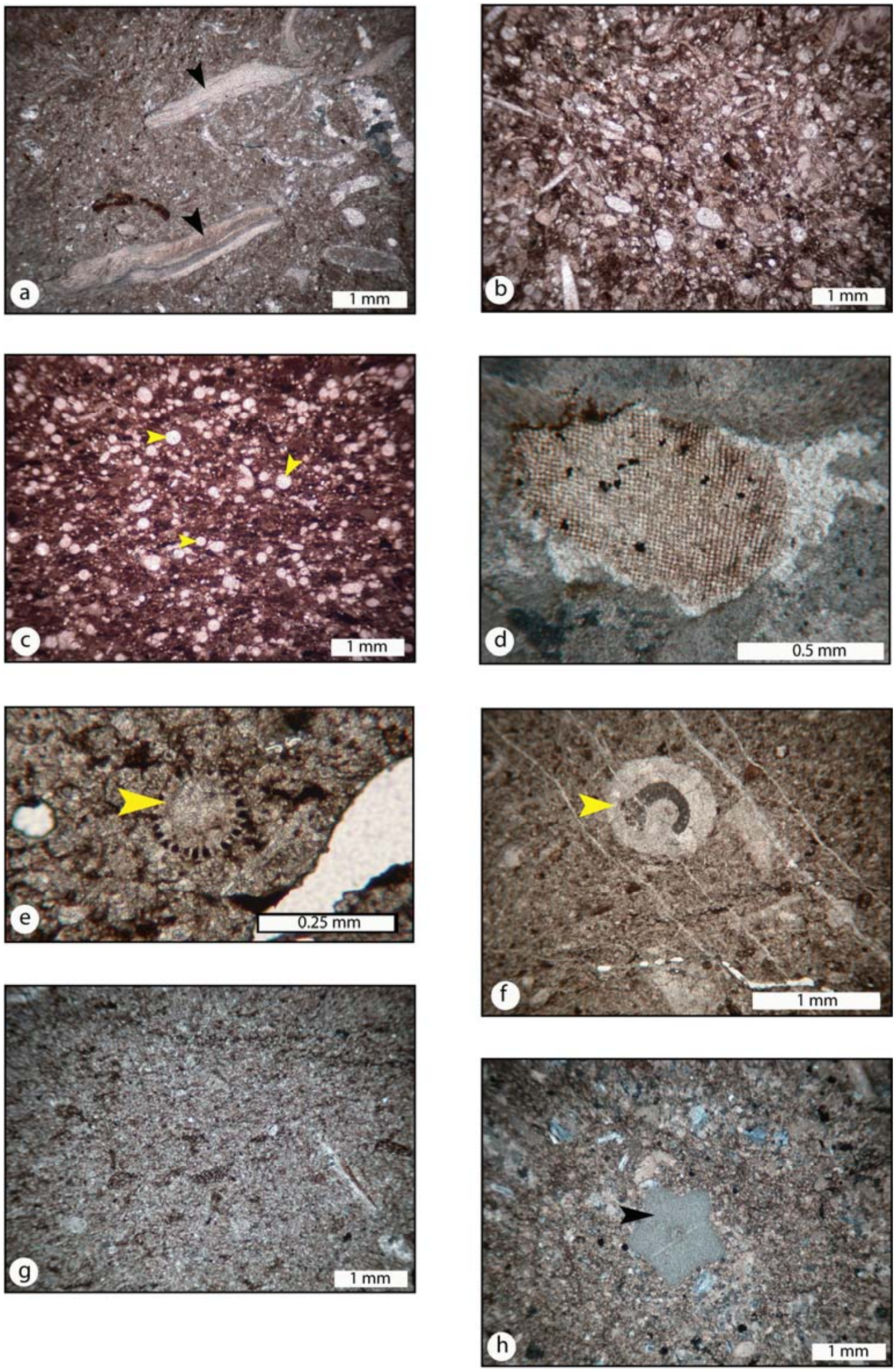


Figure 7.8. Microphotography from thin sections of the lithologies and fragmentary fossils of Lo Valdés Formation. **a:** Silty wackestone. Oysters fragments (black arrow). **b:** Silty packstone. **c:** Silty packstone. calcispheres (yellow arrow). **d:** Echinoderm fragment. **e:** radiolarids (yellow arrow). **f:** annelid (yellow arrow). **g:** calcimudstone. **h:** calci-mudstone. Pentacrinoid (black arrow).

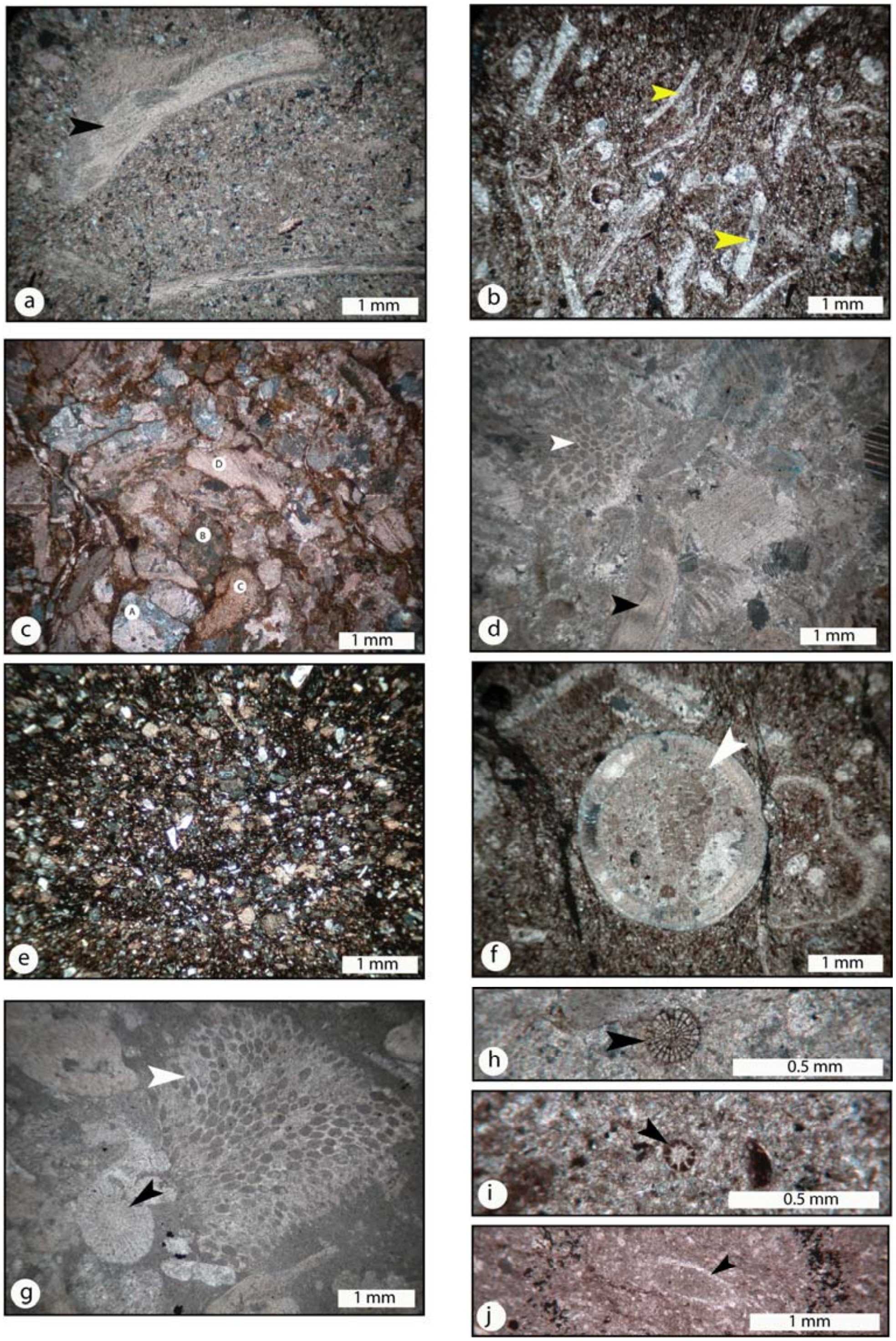


Figure 7.9. Microphotography from thin sections of the lithologies and fragmentary fossils of Lo Valdés Formation. **a:** Silty-wackestone. Oyster fragment (black arrow). **b:** Silty-wackestone. bivalve fragments (yellow arrow). **c:** Sandy wackestone. **A.** plagioclase. **B.** volcanic fragment rock. **C.** echinoderm fragment. **D.** oyster fragment. **d:** Wackestone, Oyster fragment (black arrow). Bryozoan fragment (white arrow). **e:** calcareous siltstone. **f:** serpulids (white arrow). **g:** spine echinoids (black arrow), bryozoan (white arrow). **h:** spine echinoids (black arrow). **i:** radiolarids (black arrow). **j:** possible calpionellid (black arrow).

7.4 Depositional setting

Lithologies of the Lo Valdés Formation are dominated by andesite and fine-to middle-grained siliciclastic sediments such as sandstone and siltstone. Carbonate is also constantly present and its amount increases upsection. In consequence, the upper part of the formation is composed mainly by limestone with varying degree in siliciclastic input.

The Baños del Flaco Formation is predominated by siliciclastic sediments and carbonate is only a minor component. Conglomeratic layers are present in the basal Baños del Flaco Formation and are interpreted to correspond to an upper shoreface facies (Figure 7.1), with a major input of proximal continental sediment. Conglomeratic lasts were redistributed by transgressive lags to form coarse sediment deposited on the shelf. During periods of low sea level these layer were reworked by wave action. During sea level rise the gravel is transported by waves in a landward direction, resulting in thin, usually only a few tens of centimetres thick, conglomerate beds (Plint 1988, Hart & Plint 1995, Nichols 2009).

In the Lo Valdés Formation the transsgresive conglomerate is absent, but in Catedral Formation, transgressive sequences are characterised by layers of calcareous siltstone and silty limestone (Figure 3.1, 3.3). These shoreface facies environments are occasionally altered by submarine andesite lava (Figure 3.1, 3.3). A restricted coastal shallow marine environment is present, with micro-conglomerate and sandstone as well as sandy-limestone with few ooids and scare trigoniids indicating an upper shoreface facies.

In the *Sandstone Member* of the Lo Valdés Formation, transgressive intervals are represented by calcareous sandstone and sandy-limestone of lower shoreface origin (Figure 3.9, 3.14). In the Baños del Flaco Formation, similar lithologies and facies are widely distributed in the Lower and Upper Member (Figure 3.20, 3.24).

The calcareous sandstone contains principally lithic fragments, volcanics rocks, feldspar and shell fragments. The texture is well sorted and clasts are subangular to rounded. Some layers present cross lamination, horizontal lamination and few ooids, which is characteristic for deposits of shallow sandy seas and shoreface facies distributed across a storm-dominated shelf (Nichols 2009). Authigenic glauconite is a frequent component and was considered by numerous authors as an indicator of shallow marine conditions (Nichols 2009). It is commonly present in sandstone formed on the shelf and epicontinental seas.

Under these shallow marine conditions, an association of wackestone/calci-mudstone, grainstone, packstone/wackestone is frequently present and was associated with “inner ramp” carbonate environments (Wright 1986).

Ammonoids and bivalves such as trigonoiids, oysters and inoceramids, are dominant faunal elements in the inner ramp-shoreface facies of Lo Valdés and Baños del Flaco formations and a single unit rich in corals is present in the Lo Valdés and Cajón del Morado sections (see chapter 3.2.1 and 3.2.2). Shoreface facies are commonly characterised by abundant bivalves and the vast majority of bivalves are know to exist in shallow-marine settings, where a general correlation exists between shell thickness (e.g. trigonids) and higher energy levels (Scholler and Ulmer-Scholler 2003). The abundance of trigoniids occupied shallow-water habitats (no deeper than 10-15 m) in coarse-grained sediments (Stanley 1977) and in transgressive environments such as shallow water and moderate-energy environments of less 30 m depth (Francis & Hallam 2003).

The offshore transition in Baños del Flaco Formation is restricted to the Siltstone Member (Figure 3.20-3.24) and is frequently characterised by horizontal lamination and scare fragments of ammonoids and bivalves. In the Lo Valdés Formation, the transition between shoreface and offshore transition is marked by an abrupt change from fine-grained calcareous sandstone to calcareous siltstone.

The offshore transition facies in the Lo Valdés Formation is determined by rhythmically-bedded siltstone, calcareous siltstone, wackestone and packstone with horizontal lamination, abundant organic matter and disseminated pyrite. Carbonate content increases upsection.

Mud-rich deposits of the inner shelf are frequently intensively bioturbated, except for cases where the rates of mud deposition out-paces the rate at which organisms can rework the sediment. In these cases, organic matter is often concentrated and resulting shelf mud sediments are very dark grey or black in colour (Nichols 2009). The presence of disseminated pyrite and high concentration of organic matter in the Chilean deposits indicates low oxygen and low energy environments.

The silty-limestone layers contain abundant bioclasts (wackestone and packstone) which are transported in a sea-ward direction of the shelf by storm processes (Nichols 2009, Wright 1986).

In the transition between shoreface and offshore transition, trigoniids, inoceramids and gastropods decrease in abundance and my even be absent (e.g. trigoniids), whereas ammonoids increase in abundance. Serpulids are common in the siltstone and calcareous siltstone. The presence o serpulids normally represent a period of transition between open marine conditions and a hyposaline lagoon environment (Guerard et al 2004).

The contact towards from proximal to distal offshore conditions is gradual and frequently characterised by a decreasing content in fine-grained siliciclastic input from the continent and increase in carbonate. In consequence, offshore facies are here characterized by limestone and silty-limestone (calci-mudstone and wackestone), whereas calcareous siltstone and sandy-limestone is restricted to a few isolated beds. In general, layers are commonly grey-dark from abundant organic matter and disseminated pyrite. This suggest that the sea floor was poorly oxygenated (Nichols 2009).

In the offshore (outer-ramp) are common the silty wackestone and calci-mudstone, which are redeposited from the deeper water, bellow storm wave base outer ramp deposit (Nichols 2009).

Faunal diversity decreases and is scare, the assemblages are dominated by oysters, others bivalves, scare ammonoids and echinoderms. These organisms are known to exist under stenohaline conditions, tolerating only low salinity changes (Scholler and Ulmer-Scholler 2003).

Oysters-rich-layers are present in the Cajón del Morado and Lo Valdés sections. These isolated patch “reefs” may occur in the more proximal parts of a ramp or on mud mounds (Nichols 2009).

7.5 Summary Table

Depositional facies of the Lo Valdés and Baños del Flaco Formations

Depositional Environment		Lithology	Description	Characteristic Fossils
Offshore (Outer ramp)		limestone	wackestone, bio-intrasparite, biosparite, biomicrite, bio-intramicrite	echinoderms, echinoids, sponge
		sandy limestone	wackestone, biomicrite	ammonoids, echinoderms
		silty limestone	calci-mudstone, wackestone, biomicrite, bio-intramicrite, bio-intrasparite	sponges annelids, echinoderms, calcispheres, pentacrinoids
Offshore transition (Mid-ramp)		silty limestone	calci-mudstone, wackestone, packstone, biomicrite. sediment structures: planar lamination disseminated pyrite	echinoderms, algae, calcispheres, rare radiolarians, benthic foraminifers?, calpionellids?,
		calcareous siltstone	C-org-rich siltstone sediment structures: planar lamination disseminated pyrite	annelids, algae, sponges, foraminifers, calpionellids?, echinoderms, rare annelids, bryozoans
		siltstone	C-org-rich siltstone sediment structures: planar lamination disseminated pyrite	echinoderms, annelids, calcispheres
		limestone	biomicrite, calci-mudstone	bivalves
Shoreface (Inner ramp)	Lower Shoreface	sandy limestone	sandy packstone biomicrite, oomicrite few ooids	oysters, inoceramids, trigoniids.
			sandy wackestone wackestone-biomicrite, shell fragments few ooids	inoceramids, oysters
		limestone	grainstone, calci-mudstone	trigoniids, oysters
		calcareous sandstone	clasts: volcanic rocks, fossils, plagioclase, , subangular to subrounded, well sorted; matrix: fine-grained, carbonate sediment structures: cross-lamination, planar lamination, few ooids	oysters, inoceramids, trigoniids, corals
	Upper Shoreface	conglomerate	clasts: quartz, volcanic rocks, plagioclase, fine-grained, subangular to subrounded, well sorted; matrix: carbonate, mud	unfossiliferous
Volcanic basement		Andesite	andesite porphyry with large phenocrystals	

8. Sequence Stratigraphy

Correlation between sections of the Lo Valdés Formation and the Baños del Flaco Formation is possible by sequence stratigraphic analysis. This method allows us to recognize sea level changes and reconstruct the geological evolution of marine sediments in the Central Chilean part of the Andean basin.

Depositional facies in their genetical context are explained here in chapter 4 are summarized in elementary (Strasser et al. 1999) or parasequences (Coe & Church 2003 and Nichols 2009), they form groups of sequences or depositional sequences (Strasser et al. 1999; Coe & Church 2003 and Nichols 2009).

Depositional sequence changes depend on the rate of sediment supply and accommodation space, their delimitations are expressed by sequence boundaries (SB), falling stage systems tracts (FSST), lowstand systems tracts (LST), transgressive surfaces (TS), transgressive systems tracts (TST) and (HST) highstand systems tracts (Coe & Church 2003, Nichols 2009). The maximum flooding surface (mfs) represents the moment in time when accommodation is balanced by sediment supply and the rate of sea level rise slows down the depositional system. It does not necessarily represent the highest sea level in the cycle, which occurs later in the HST (Nichols 2009). The falling stage systems tract (FSST) commonly occurs during forced regression (Coe & Church 2003), but due to the following emersion of the depositional area, it is frequently eroded (Schafhauser 2006). The FSST were not identified in the Lo Valdés and Baños del Flaco formations.

8.1 Parasequence

In the sections analyzed, 21 parasequences are recognized by a retrogradational and progradational pattern of depositional facies. Their thickness reaches from 12 to 153 m (figure 8.1). Parasequences 1 to 11 were determined in the Baños del Flaco Formation, whereas parasequences 12 to 21 were identified in the Lo Valdés Formation. In the Baños del Flaco Formation the composition of parasequences is quite uniform. Parasequence 1 is developed in upper shoreface facies, parasequences 2 to 6 show lower shoreface facies, whereas parasequence 7 consists in offshore transition, and parasequences 8 to 11 only contain lower shoreface facies.

The parasequences 12 to 21 belong to Lo Valdés Formation and the composition of these parasequences is quite uniform. Lower shoreface facies pass into offshore transition facies and on to offshore facies. Parasequences 12 to 16 encompass lower shoreface facies, while parasequence

17 represents the offshore transition facies. Parasequences 17, 18, 19, 20 and 21 are composed by offshore facies, whereas parasequence 19 in the upper part of the Cajón del Morado section consists only of offshore transition.

Boundaries of parasequences are marked by a facies shift from shallow to deeper, or deep to shallower water deposition (e.g. from foreshore to offshore transition), suggesting a rapid increase in relative sea level; they are separated by a layer of “flooding surface”, which should not be confused with *mfs* (Nichols 2009).

8.2 Depositional sequences

Two depositional sequences (figure 8.1) are recognized in the Baños del Flaco Formation and an additional two in the Lo Valdés Formation. These sequences are based on the vertical stacking pattern of the 21 parasequences described above.

Depositional sequence 1 is between 191 m and 344 m thick and consists of a TST followed by a HST. The TST is characterized by a retrogradational stacking pattern of parasequences 1 to 3, which include high shoreface (parasequence 1) and lower shoreface (parasequense 2 and 3) facies. Parasequence 3 contains the mfs. The HST is formed by the retrogradational stacking pattern of parasequences 4 to 7. Parasequences 4 to 6 correspond to lower shoreface and parasequence 7 to offshore transition facies, representing maximum water depths in the depositional area.

Depositional sequence 2 is between 178 m to192 m thick and consists of a TST and HST. Parasequence 8 is developed by lower shoreface facies. A retrogradational stacking pattern of the lower part of parasequence 8 characterizes the TST. The HST is characterized in the parasequences 9 to 11. A retrogradational stacking pattern of the upper part of parasequence 8 indicates the HST. In addition, parasequence 9 is aggradational to progradational and represents a lower shoreface facies. In the lower part of this parasequence 9 at Baños del Flaco, offshore transition facies is recorded in a restricted level. Maximum water depths are indicated near the base of parasequence 9. The upper part of the sequence contains a progradational stacking pattern of parasequences 10 and 11 characterizing the HST.

In consequence, the sequence 1, represent transgressive facies during the lowermost Middle Tithonian with a maximum depth during the uppermost Middle Tithonian; the sequence 2 represent in the lower part transgressive facies during the Upper Tithonian and a regression in the Lower Berriasian (figure 8.1).

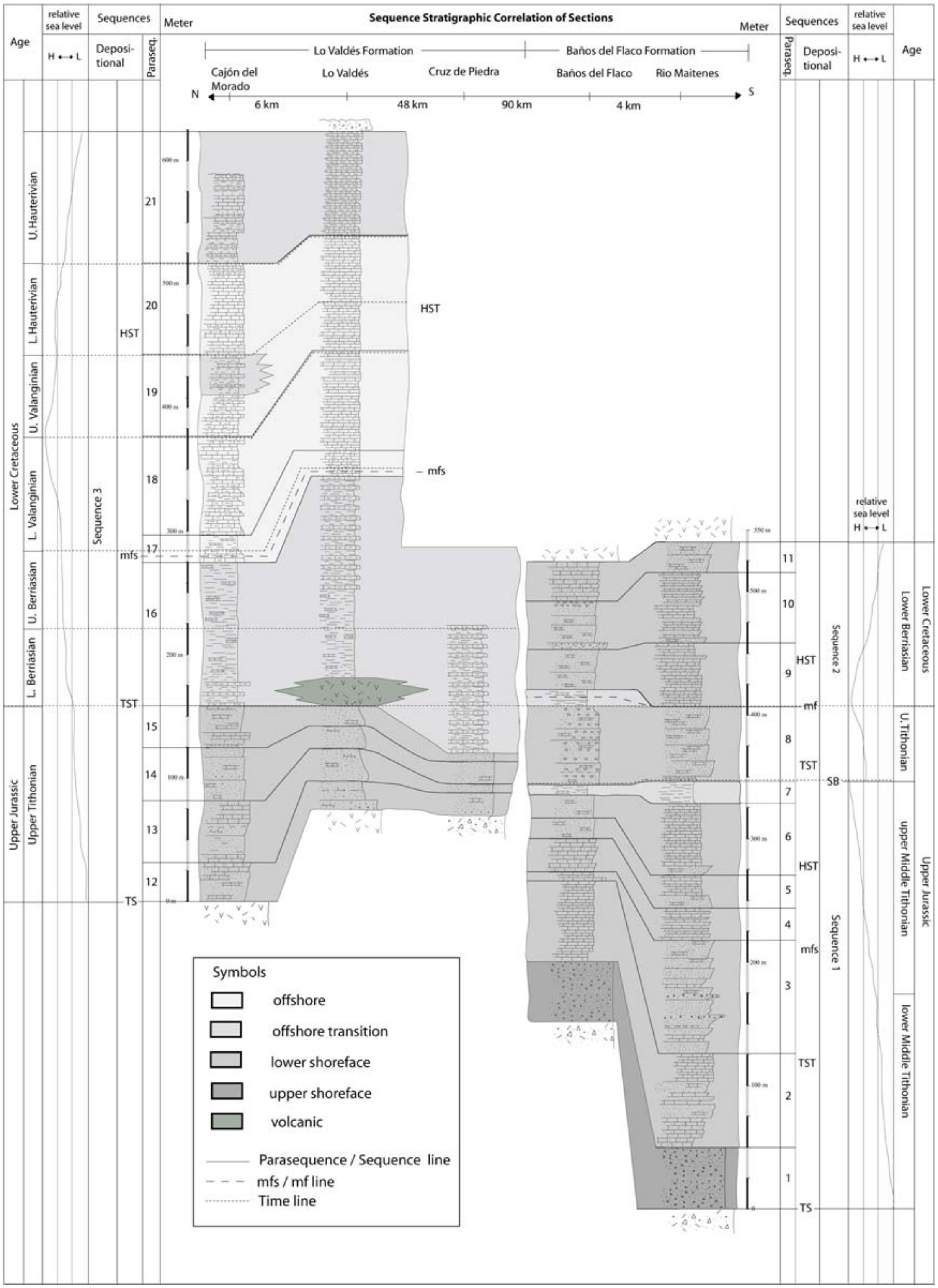


Figure 8.1. Sequence stratigraphic correlation of sections in Baños del Flaco and Lo Valdés formations. The stages boundary is based on the biozonations form the chapter 5.5.

Depositional sequence 3 is developed in sections of the Lo Valdés Formation; the tickness is between 539 m (Lo Valdés section) and 582 m (Cajón del Morado section) and consists of a TST and HST. The TST is characterized by a retrogradational stacking pattern of parasequences 12 to 18. They consist of lower shoreface facies in the parasequences 12 to 15 and offshore transition facies in parasequence 16. The HST is characterized by a retrogradational and progradational stacking pattern in the parasequences 17 to 21. Parasequences 17 to 18 are characterized by a retrogradational stacking pattern and consist in offshore facies. Parasequence 17 contains the mfs. Parasequences 19 and 20 consist in offshore and parasequence 21 in offshore transition facies.

In consequence, sequence 3 presents a retrogradational and progradational pattern, which result in transgression during the Upper Tithonian to Lower Valanginian; and regression during the Upper Valanginian to Upper Hauterivian (figure 8.1).

9. Discussion and Conclusions

9.1. Discussion and Conclusions

The Baños del Flaco and Lo Valdés formations in Central Chile contain sediments of Tithonian-Hauterivian age (figure 1.1 and 1.2). They were deposited in a back-arc basin related to a subduction system extending eastward into Argentina and show a general southeastward bend (Charrier *et al.* 2007).

The Baños del Flaco Formation was defined by Klohn (1960) on the south side of the Rio Tinguiririca valley (figure 1.1). Another good section crops out along Rio Maitenes (figure 1.1). Both sections were analyzed for this research; fossil content is scare in the type locality. The analysis of the Rio Maitenes section is partly based on Lajos Biro's field book descriptions and fossil collection; we remeasured the section. The Baños del Flaco section (BF) is 369 m thick in the type locality and 536 m thick at Rio Maitenes (RM). The Formation was divided in a Lower Member (BF: 191 m thick; RM: 344 m thick) and an Upper Member (BF: 178 m thick; RM: 192 m thick) and consists of calcareous and siliciclastic sediment (figures 3.20 and 3.24).

The Lo Valdés Formation was defined by González (1963) on the south side of the Rio Volcán valley (figure 1.1). González measured a thickness of 1635 m at the type locality, while Biro (1964) considered this section to be 1456 m thick. The latter author also distinguished three members (from bottom to top): "Spilítas" or Spilite member, "Arenáceo" or Sandstone member and "Calcáreo" or Calcareous member. The Spitite member is restricted locally and according to the original description of the member is composed of >90% of volcanic rocks and restricted sedimentary layers. Elsewhere this member differs compositionally from other members of the Lo Valdés Formation. We therefore propose to separate this unit from the Lo Valdes Formation and suggest the formation of a new unit, denominated "Catedral" Formation (Salazar & Stinnesbeck, submitted). The type locality of the newly-defined Catedral Formation is at Catedral hill, on the south side of the Rio Volcán valley, (figure 1.1). The unit is 760 m thick and composed by andesite porphyry with long phenocrystals of plagioclase and a chloritized matrix. Restricted levels of calcareous and clastics rocks also exist and contain ammonites, which indicate that this formation is Lower-Middle Tithonian in age (figure 3.1 and 3.3).

The Lo Valdés Formation was restricted to the sediment-dominated units (Salazar & Stinnesbeck, submitted). The unit is divided into three members, from base to top a Sandstone, Siltstone and

Limestone member. In this study three section of the Lo Valdés Formation were measured and sampled. The Lo Valdés section (LV) represents the type locality; sediment are 539 m thick. Thickness at Cajón del Morado (CM) is 582 m and 150 m at Cruz de Piedra (CP). The Sandstone member is 73 m thick at LV, 160 m thick at CM and 50 m thick at CP. This member is composed by fine sandstone, calcareous sandstone and sandy limestone. The Siltstone member is composed by calcareous siltstone and silty limestone; it is 214 m thick at LV, 217 m thick at CM and 100 m thick at CP. The Limestone member consists of limestone, sandy limestone, silty limestone and calcareous siltstone; it is 252 m thick at LV and 206 m thick at CM (see figures 3.9, 3.14 and 3.16).

The Baños del Flaco Formation was studied at Rio Maitenes section. For the first time ammonite assemblages are described and discussed here and include 12 species referred to 10 genera. *Windhauseniceras internispinosum*, *Corongoceras alternans* and *Substeueroceras koeneni* were informally recorded previously. New records are registered here for this formation include *Aulacosphinctes proximus*, *Micracanthoceras spinulosum* and *Corongoceras evolutum*. *Pseudolissoceras* cf. *zitteli*, *Euvirgalithacoceras malarguense*, *Choicensisphinctes windhauseni*, *Catutosphinctes* cf. *americanensis*, *Virgatosphinctes scythicus* and *Micracanthoceras microcanthum* are first records for Chile. Strong ontogenetic changes not recorded previously are noted in *Micracanthoceras spinulosum*. *Virgatosphinctes scythicus* is here considered a morphologically variable species and considered synonymous with classical South American taxa such as *Virgatosphinctes andesensis*, *V. mendozanus*, *V. mexicanus* and *V. leñaensis*. *Windhauseniceras internispinosum* is a rare taxon elsewhere but relatively abundant at Rio Maitenes; its morphology varies considerably during ontogeny. *Virgatosphinctes* aff. *pseudolictor* and *V.* cf. *raja*, both described by Indans 1954, and *V. guadalupensis*, are considered synonymous with *E. malarguense*, while *V. tenuilineatus* is synonymous with *C. windhauseni* and *Aulacosphinctes chilensis* with *A. proximus*. Other synonymies include *Micracanthoceras lamberti* and *M. tapiai*, with *M. microcanthum*, and *Corongoceras rigali* with *C. alternans*.

Fossil content is abundant and well preserved in the Lo Valdés Formation. In the type locality at Lo Valdés, at Cajón del Morado and at Cruz de Piedra, were identified 39 species of ammonoids referred to 22 genera. The assemblage is here described and discussed for the first time. *Aulacosphinctes proximus*, *Micracanthoceras spinulosum*, *Corongoceras* cf. *koellikeri*, *Substeueroceras koeneni*, *Argentiniceras fasciculatum*, *Pseudofavrella angulatiformis*, *Crioceratites andinum* and *Crioceratites diamantense* were informally recorded previously from the Lo Valdés Formation. *Frenguelliceras magister* is a new record for central Chile. *Pterolytoceras exoticum*, *Aspidoceras rogoznicense*, *Micracanthoceras microcanthum*, *Micracanthoceras vetustum*, *Corongoceras lotenoense*, *Corongoceras mendozanum*, *Spiticeras acutum*, *Spiticeras pricei*, *Spiticeras spitiense*, *Groebericeras rocardi*, *Berriasella* (*Berriasella*) *jacobi*, *Malbosiceras malbosi*, *Chigaroceras bardensis*, *Tirnovella kayseri*, *Thurmaniceras thurmanni*, *Crioceratites perditum* and *Bochianites* sp. are first registers for Chile. *Lytohoplites paredesi* n. sp., *Lytohoplites zambranoi* n. sp., *Lytohoplites varelae* n. sp. and *Lytohoplites rauloi* n. sp. are new species. The neotype of *Substeueroceras* is designated here and corresponds to the lectotype of *Substeueroceras koeneni*. *Parodontoceras* is here considered a junior synonym of *Substeueroceras*. The lectotypes of *Micracanthoceras spinulosum*, *Micracanthoceras vetustum*, *Spiticeras acutum*, *Substeueroceras calistoide*, *Argentiniceras fasciculatum*, *Tirnovella kayseri*, *Crioceratites andinum*, *Crioceratites diamantense* and *Crioceratites perditum* are designated here. *Spiticeras acutum* is a morphologically variable species. *Berriasella fraudans* is considered a senior synonym of *B. jacobi*, but the latter is a well accepted index fossil for the Lower Berriasian used in biozanations worldwide. We suggest that the name should be kept but this issue must be solved by a discussion in the Bulletin of Zoological Nomenclature.

In South America, transitions of Jurassic-Cretaceous boundary (Tithonian-Hauterivian) are well known from Colombia, Peru, Argentina and Chile (Leanza H. 1981a). Argentinean localities have been studied best (e.g. Steuer 1897-1921, Gerth 1921-1925, Leanza A. 1945, Leanza H. 1980, Parent et al. 2011a and 2011b).

In Central Chile, sediments of this age are known as the Baños del Flaco and Lo Valdés formations (e.g. Biro 1964, Covacevich et al. 1976, Biro 1980a, Hallam et al. 1986). For the Baños del Flaco Formation, Hallam et al. (1986) assigned a Lower-Middle Tithonian to Lower Berriasian age. For the Lo Valdés Formation, a biozonation was proposed by Biro (1964, 1980a) and Hallam et al. (1986) These authors divided the unit into eight biozones and assigned a Lower-Middle Tithonian to Hauterivian age for the formation.

Here we present a detailed biozonation for the Baños del Flaco Formation which is based on first and last appearances of ammonites and ammonite assemblages (from bottom to top): *Virgatosphinctes scythicus* / *Pseudolissoceras zitteli* zone, *Windhauseniceras internispinosum* zone, *Micracanthoceras microcanthum* / *Corongoceras alternans* zone and *Substeueroceras koeneni* zone (figure 5.4 and 5.10). We suggest that the Baños del Flaco Formation reaches from the lower part of the Middle Tithonian to the lowermost part of the Lower Berriasian (figure 5.10).

Six biozones are identified for the Lo Valdés Formation (from bottom to top): Zone 1 *Micracanthoceras microcanthum* / *Corongoceras alternans*, Zone 2 *Substeueroceras koeneni* (*Berriasella jacobi* sub-zone and *Groebericeras rocardi* sub-zone), Zone 3 *Thurmanniceras thurmanni* / *Argentiniceras fasciculatum*, Zone 4, Zone 5 and Zone 6 *Crioceratites diamantense* (figure 5.11). Ammonite assemblages indicate that the Lo Valdés Formation reaches from the upper part of the Upper Tithonian to the Upper Hauterivian (figure 5.11).

Biozonations of the Baños del Flaco and Lo Valdés formations combined correspond to 9 biozones (figure 5.16). Relative richness and abundance as well as diversity allow for the identification of Tithonian to Hauterivian bioevents. The ecological indices, such as “relative abundance”, “relative richness”, “Evenness” and “Shannon” diversity index indicate that a major bioevent occured in the Upper Tithonian, as indicated by the highest relative abundance and diversity for Central Chile and also a high richness. The ecological index remains high in the Lower Berriasian (e.g. the highest richness), but the turn-over analysis indicate low Jaccard index similarity between the Upper Tithonian and Lower Berriasian (figure 5.16).
In perceptual terms, age by age, the relative Richness is the same, 41%, in both the Tithonian and Berriasian; during the Valanginian richness decreases considerably to 13% and even to 6% in the Hauterivian. Values of the relative Abundance reach 43% during the Tithonian and 42% in the Berriasian; in the Valanginian values drop abruptly to 13% and even to 2% in the Hauterivian (figure 5.17).

Ammonites from the Middle Tithonian to Lower Valanginian of Central Chile show a high degree of endemism, but Indo-Pacific, Caribbean, Tethyan and Boreal influences are also notable. Endemic and Indo-Pacific taxa dominate during the Tithonian, but connections with the Indo-Austral province, the Tethyan and Boreal region are also noted (figure 6.3). In the Berriasian Endemic taxa decrease and Cosmopolitan taxa dominate, but an Indo-Pacific influence remains important (figure 6.5). The Valanginian is characterised by a decrease in Cosmopolitan ammonites, but increase in Tethyan taxa. Endemic, Indo-Pacific and Boreal influences are still present (figure 6.7). The Hauterivian is not well represented; only three species are recorded with low abundances (figure 6.8).

The Middle Tithonian to Lower Valanginian is dominated by Endemic species (33% Richness and 31% Abundance), followed by an Indo-Pacific influence (21% Richness and 25% Abundance), and Tethyan affinities (14% Richness and 16% Abundance). A Boreal influence is less evident but is still represented by 9% species Richness and 13% Abundance (figure 6.10).

Taxa endemic to Central Chile and Argentina as well as Tethyan species are the dominant ammonites during the Tithonian (figure 6.2-6.3). This pattern changes abruptly during the Berriasian with an increase in Cosmopolitan and Indo-Pacific taxa (figure 6.4-6.5). These taxa are dominant in the Berriasian, whereas Tethyan and Endemic ammonites are dominant in the Valanginian (figure 6.6-6.7). The abundance of endemic taxa suggests that during the Tithonian Central Chile may not have been well connected with the Tethyan region (figure 6.2-6.3) and that the Hispanic Corridor was not open yet (figure 6.13). Indo-Pacific affinities, on the other hand, are notable and may result from an open Indo-Austral seaway (figure 6.13). During the Berriasian, the dominance of Cosmopolitan and abundance of Indo-Pacific taxa suggests (figure 6.4-6.5) that new pathways opened between Antarctica and South America – Africa. These connections were likely established via the Indo-Austral seaway and a new connection through the Hispanic Corridor (figure 6.13). Subsequently during the Lower Valanginian (figure 6.6-6.7) Tethyan, Indo-Pacific (Indo-Austral) and Boreal taxa are present in the Central Chilean fauna and Endemic ammonites are equally abundant (figure 6.10). This may correspond to a similar grade of influence from the Hispanic Corridor and the Indo-Austral seaway (figure 6.13).

Sediment of the Baños del Flaco and Lo Valdés Formations represent a mix of clastic and carbonate environments. We identified shoreface (inner ramp), offshore transition (middle ramp) and offshore (outer ramp) facies (see chapter 7.5. The shoreface (inner ramp) environment is divided in an upper and a lower shoreface. The upper shoreface facies is characterized by unfossiliferous conglomerates that were redistributed by transgressive lags to form coarse sediment units on the shelf. The lower shoreface facies is characterized by calcareous sandstone and sandy limestone (grainstone), with the characteristic presence of trigonoiids, oysters, inoceramids, and restricted levels of corals. Some layers present cross-lamination. The offshore transition facies (middle ramp) is represented by siltstone, calcareous siltstone, silty limestone and calci-mudstone. This facies is rich in organic carbon and disseminated pyrite, while sediment structures are dominated by planar-lamination. The offshore facies (outer ramp) is represented by silty limestone, sandy limestone and limestone (wackestone); clastic input is low.

21 parasequences are recognized in the Lo Valdés and Baños del Flaco formations by a retrogradational and progradational pattern of depositional facies. Two depositional sequences are identified in the Baños del Flaco Formation and a third in the Lo Valdés Formation (figure 8.1). In the Baños del Flaco Formation the depositional sequence 1 consists of a TST followed by a HST. The TST is characterized by a retrogradational stacking pattern, and contains the mfs. The HST is formed by the retrogradational stacking pattern. Depositional sequence 2 consists of a TST and HST. A retrogradational stacking pattern characterizes the TST. The HST is characterized by a retrogradational, as well as by aggradational to progradational stacking patterns. The upper part of the sequence contains a progradational stacking pattern characterizing a HST.

In consequence, sequence 1 represents transgressive facies during the lowermost Middle Tithonian, with a maximum depth during the uppermost Middle Tithonian; sequence 2 represents transgressive facies during the Upper Tithonian and a regression in the Lower Berriasian (figure 8.1).

In the Lo Valdés Formation, depositional sequence 3 consists of a TST and a HST. The TST is characterized by a retrogradational stacking pattern and also contains the mfs. The HST is characterized by a retrogradational and progradational stacking pattern. Sequence 3 presents a retrogradational and progradational pattern, which results in transgression during the Upper Tithonian to Lower Valanginian; a sealevel regression occured during the Upper Valanginian to Upper Hauterivian interval (figure 8.1).

9.2. Recommendations

For future studies in the region the following recommendations are given:

- The high number of ammonite specimens of most taxa discussed here allows for an evaluation of possible sexual dimorphisms. Numerous taxa show similar morphological characters and a wide range of intraspecific variability.

- An analysis of the stable isotopic composition (C, O) appears to be promising for future palaeoclimatological and oceanographic interpretations. Thin section work indicates that oyster shell fragments are well preserved. They occur throughout the sediment sequence, from the Tithonian to Hauterivian. In addition, the content of organic carbon is high in the Lo Valdés Formation, mainly in the Siltstone and Limestone members (Berriasian-Valanginian).

- The analysis of palynological remains is also recommended for an evaluation of palaeoenvironmental conditions, such as changes in temperature and in vegetation along the ancient coast line.

- An extension of the research area is suggested to evaluate other parts of the Central Andean back-arc basin. For instance, sections between Lo Valdés and Cruz de Piedra (figure 1.1) and to the north of Cajón del Morado are known as the San José Formation. Is also recommended to expand the study area to the fore-arc basin, to sections of the Lo Prado Formation. This extension of the study area would lead to a more detailed and broader sequence stratigraphic and biofacies interpretation.

- It is recommended to extend the analyses to basins located to the north and south, to the Chañarcillo and Austral areas. These regions have never been studied in detail. Research in these regions will allow for a comparison of the faunal content, for instance regarding the distributional changes of cold and warm water and continental taxa along the North-South directed late Jurassic to early Cretaceous coast line of Chile.

10. Acknowledgements

This thesis was prepared at the Institute of Earth Sciences at Heidelberg University and supervised by Prof. Dr. Wolfgang Stinnesbeck. I am very much indebted to him, for continuous support with his experience and knowledge, but also for his friendship that we developed over the years; he also improved my English writing.

I am grateful to Prof. Dr. Luis Arturo Quinzio Sinn, Prof. Abraham González Martínez and Gerardo Flores Miranda (Curator), from the Department of Earth Science of the University of Concepción (Chile), for their logistical and administrative support in the development of this thesis.
Pablo Bernabé, Loreto Donoso, Thomas Eggers, Danilo González, Jorge Knabe, Luis Rivas, Gerd Sielfeld, Natalia Varela, Marko Yurak and Patricio Zambrano from the University of Concepción, Chile, assisted me during field work in the high Andes. I am grateful for their friendship and the hard work during these field campaigns.

Joachim Fillauer (Heidelberg University) assisted in the preparation of thin sections and fossils, Klaus Will (Heidelberg University) provided assistance in photography and photo edition, and Tobias Gerwig, Bolko Janssen, Martin Metloufi and Andreas Kraft helped with the fossils preparation and catalogue.

I am grateful to the late Lajos Biro who in the 1960ies collected fossil material discussed here from the Rio Maitenes section. Mr. Guillermo Cabrera (Geologist) from "Cementos Bio Bio Company" gave us access to the "El Fierro" Mine and introduced us to the geology of the Rio Maitenes area. Ms. Claudia Piccoli and Hernán Espinosa assisted us in the field work in Cajón del Morado locality and at "Fundo Cruz de Piedra" (Gasco Company, Chile) gave as permission to work on this latter property. We are grateful to "Carabineros de Chile", especially the endowment January 2008-2009 of "Avanzada Cruz de Piedra", for their great help and cooperation during field work in this area.

Dr. Hannes Löser (Universidad Nacional Autónoma de México at Hermosillo) is gratefully acknowledged for the determination of corals, bryozoans and algae. Dr. Miguel Álvarez (Universität Bonn, Germany) for his acknowledged and support in the statistical analysis. Dr. Georg Heumann (STIPB, Bonn, Germany) and Dr. Mike Reich (GZG, Göttingen, Germany) kindly provided access to fossil collections in their care. Dr. Ernesto Pérez D`Angelo (SNGM, Chile), Dr. Alfonso Rubilar (SNGM, Chile), Dr. Amaro Mourgues (SNGM, Chile), Dr. István Főzy (Hungarian Natural History Museum, Budapest), Dr. Horacio Parent (Universidad Nacional de Rosario, Argentina) and Dr. Mikhail Rogov (Geological Institute of RAS Moscow, Russia) kindly supplied information and commented on aspects of this thesis.

I am grateful to Dr. Christina Ifrim (Heidelberg University) and Dr. Hartmut Jäger, for helpful comments and their experience in geology and palaeontology. Ms. Francisco Cueto (Heidelberg University) is acknowledged for his comment and support in geology and informatics. Dr. Jorham Contreras, Dr. Sonja Pabst, Dr. (c) Markus Karl, Dr.(c) Natalia Muñoz, Dr.(c) Judith Pardo, Dr.(c) Enric Pascual and Dr.(c) Dominik Hennhöfer (Heidelberg University) constantly helped me with simple but important comments during my time in Heidelberg. I am happy for their friendship. I am grateful to the staff working at the Institute of Earth Sciences, Heidelberg University, and thank you very much for the help of everyday. Also for my friends in Heidelberg, for them constant and nice friendship.

Financial support to this thesis was given by a scholarship “President of the Republic of Chile”, but also by the Deutsche Forschungsgemeinschaft (STI 128/15) and the BMBF (CHL10/A09) and is gratefully acknowledged.

Last but not least, special thanks go to Isaias Salazar, Monica Soto and Pia Salazar (my family), for their constant support and love.

11. References

Adatte, T., Stinnesbeck, W., & Remane, J. 1994. The Jurassic-Cretaceous boundary in Northeastern Mexico. Confrontation and Correlation by microfacies, clay mineral mineralogy, calpionellids and ammonites. *Geobios*, 17: 37-56.

Adatte, T.; Stinnesbeck, W., Remane, J. & Hubberten, H. 1996. Paleooceanographic change at the Jurassic-Cretaceous boundary in the western Tethys, northeastern Mexico. *Cretaceous Research*, 17: 671-689.

Aguirre, L., 1960. Geología de los Andes de Chile central (provincia de Aconcagua). *Instituto de Investigaciones Geológicas Chile*, Boletín 9: 70 p.

Aguirre, R. 2001. Paleontología y bioestratigrafía de las facies calcáreas marinas del Grupo Chañarcillo, Cretácico Inferior, en Quebrada Las Breas (29°07´30´´S, 70°46´W). Sureste de Domeyko, límite III y IV Regiones, Chile. *Memoria de Título, Universidad de Chile*. http://www.fosil.cl/lasbreasportada.html

Aguirre-Urreta, M. 1993. Neocomian Ammonite Bioestratigraphy of the Andean Basin of Argentina and Chile. *Revista Española de Paleontología*, 8 (1): 57-74.

Aguirre-Urreta, M. 2002. Bioestratigrafía del Cretácico Inferior de la Cuenca Austral Argentin0-Chilena. *Actas del XV Congreso Geológico Argentino*. Comunicación.

Aguirre-Urreta, M. & Charrier, R. 1990. Estratigrafía y amonites del Tithoniano-Berriasiano en las nacientes del Río Maipo, Cordillera Principal de Chile Central. *Ameghiniana* **27** (3-4): 263-271.

Aguirre-Urreta, M & Rawson, P. 1997 The ammonite sequence in the Agrio Formation (Lower Cretaceous), Neuquén Basin, Argentina. *Geological Magazine*, 134 (4): 449-458.

Aguirre-Urreta, M. & Alvarez, P. 1999. The Berriasian genus *Groebericeras* in Argentina and the problem of its age. *Scripta Geologica*, Special Issue 3: 15-29.

Aguirre-Urreta, M., Rawson, P., Concheyro, G., Bown, P., Ottone, E. 2005. Lower Cretaceous (Berriasian-Aptian) Biostratigraphy of the Neuque´n Basin. In: Veiga, G., et al. (Eds.), The Neuquén Basin: A case study in sequence stratigraphy and basin dynamics. *The Geological Society*, Special Publication, 252 p.

Aguirre-Urreta, M., Mourgues, F., Rawson, P., Bulot, L. & Jaillard, E. 2007a. The Lower Cretaceous Chañarcillo and Neuquén Andean basins: ammonoids biostratigraphy and correlations. *Geological Journal*, 42: 143-173.

Aguirre-Urreta, M., Suárez, M., de la Cruz, R. & ramos, V. 2007b. Ammonoids (Crioceratitinae, Hauterivian) from the Austral basin, Chile. *Ameghiniana*, 44: 387-397.

Aguirre-Urreta, M. & Rawson, P. 2010. Lower Cretaceous ammonites from the Neuquén Basin, Argentina: the neocomitids of the *Pseudofavrella angulatiformis* zone (upper Valanginian). *Cretaceous Research*, 31: 321-343

Aguirre-Urreta, M., Mourgues, F., Rawson, P., Bulot, L. & Jaillard, E., 2007. The Lower Cretaceous Chañarcillo and Neuquén Andean basins: ammonoids biostratigraphy and correlations. *Geological Journal* 42, 143–173.

Aguirre-Urreta, M. & Vennari, V. 2009. On Darwin's footsteps across the Andes: Tithonian-Neocomian fossil invertebrates from the Piuquenes pass. *Revista de la Asociación Geológica Argentina*, 64(1): 32-43.

Álvarez, P., Aguirre-Urreta, M., Godoy, E. & Ramos, V., 1997. Estratigrafía del Jurásico de la Cordillera Principal de Argentina y Chile (33º 45’ – 34º 00’ LS). *VIII Congreso Geológico Chileno*, 1: 425-429.

Anderson F. 1945. Knoxville Series in California Mesozoic. *Geological Society of America*, Bulletin, 56 (10): 909-1014.

Arcos, R. 1987. Geología del Cuadrángulo Termas del Flaco, provincia de Colchagua, VI Región, Chile. Memoria de Título, *Departamento de Geología, Universidad de Chile*, 279 p.

Arkell, W. 1956. Jurassic geology of the World. Oliver & Boyd (edinburg & London) xv + 804.

Arkell, W. 1957. Introduction to Mesozoic Ammonoidea, in: Treatise on Invertebrate Paleontology, Part L, Mollusca 4, Cephalopoda-Ammonoidea, Edited by R. C. Moore, *Geological Society of America and University of Kansas* Press, L 490 p.

Arnould-Saget, S. 1953. Les ammonites pyriteuses du Tithonique supérieur et du Berriasiaen de Tunisie centrale. *Annales des Mines et de la Géologie*, Tunis 10. 133 p.

Bartolini A., Baumgartner P. & Guex J. 1999. Middle and Late Jurassic radiolarian palaeoecology versus carbon-isotope stratigraphy. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 145:43–60.

Baumberg, E. 1906. Fauna der untern Kreide im westschweizerischen Jura II. Teil. Die Ammonitiden der unteren Kreide im westschweizerischen Jura. *Abhandlungen der Schweizerischen Paläontologischen Gesellschaft* 32 (3). 1905: 1-80.

Behrendsen O. 1891-1892. Zur Geologie des Ostabhanges der argentinischen Cordillere. *Zeitschrift der Deutschen Geologischen Gesellschaft 1891*, 43: 369-420; 1892, 44: 1-42.

Behrendsen O. 1922. Contribución a la geología de la pendiente oriental de la Cordillera Argentina. *Actas de la Academia Nacional de Ciencias en Córdoba (República de Argentina)*, 7: 155-227.

Benzaggagh, M. & Atrops, F. 1997. Stratigraphie et associations de faude d'ammonites des zones du Kimméridgien, Tithonien et Berriasien basal dans le Prérif interne (Rif, Maroc). *Newsletter Stratigraphy*, 35 (3): 127-163.

Biro, L., 1964. Estudio sobre el límite entre el Titoniano y el Neocomiano en la Formación Lo Valdés, Provincia de Santiago, principalmente en base a Ammonoideos. *Memoria de Título, Universidad de Chile, Escuela de Geología*, 118 p.

Biro, L. 1980a. Estudio sobre el limite entre el Titoniano y el Neocomiano en la Formación Lo valdés, Provincia de Santiago (33° 50`lat. Sur.), Chile; principalmente sobre la base de ammonoideos. *Actas II Congreso Argentino Paleontología Bioestratigrafía I Congreso Lationoamericano Paleontología*, Buenos Aires 1978, 1, 137-152.

Biro, L. 1980b. Algunos ammonites nuevos en la Formación Lo Valdés, Titoniano-Neocomiano, Provincia de Santiago (33° 50`lat. Sur.), Chile. *Actas II Congreso Argentino Paleontología Bioestratigrafía I Congreso Lationoamericano Paleontología*, Buenos Aires 1978, 1, 223-242.

Blanford, H. 1864. On Dr. Gerard`s collection of fossils from Spiti valley, in the Asiatic Society`s Museum. *Journal of the Asiatic Society of Bengal*, Calcutta 32 (1863): 124-138.

Bodenbender, G. 1892. Sobre el terreno Jurásico y Cretácico en los Andes argentinos entre el río Diamante y el río Limay. *Boletín de la Academia Nacional de Ciencias*, 13: 5-44.

Burckhardt, C. 1900a. Profils géologiques transversaux de la Cordillere Argentino-Chilenne. *Anales Museo La Plata, Sección Mineralogía & Geolología*, 2 : 1-136.

Burckhardt, C. 1900b. Coupe géologiques de la Cordillere entre Las Lajas et Curacautín. *Anales Museo La Plata, Sección Mineralogía & Geolología*, 3: 1-102.

Burckhardt, C. 1903. Beiträge zur Kenntnis der Jura und Kreide Formation der Cordillere.- *Palaeontographica*, 50: 1 -145.

Burckhardt, C. 1906. La faune Jurassique de Mazapil, avec un appendice sur les fossiles du Crétacé inférieur. *Boletín del Instituto Geológico de México*, 23, 1-216.

Burckhardt C. 1911. Schlusswort zu der Diskussion über die russisch-borealen Typen im Oberjura Mexikos und Südamerikas. *Centralblatt Mineralogie Geologie Palaontologi,e* 24: 771-773.

Burckhardt, C. 1912. Faunes Jurassiques et Cretaciques de San Pedro del Gallo. *Boletín del Instituto Geológico de México*, 39: 1–260.

Burckhardt, C. 1919–1921. Faunas Jurásicas de Symón (Zacatecas). *Boletín del Instituto Geológico de México,* 33, 1–135.

Burckhardt, C. 1930. Étude synthétique sur le Mésozoique Mexicain. *Mémoires de la Societé Paléontologique Suisse*, 49-50: 280 p.

Buckman, S. 1921. Yorkshire type ammonites. Vol 3: 5-64. Wesley & Son edit., London.

Bürgl, H. 1958. Bioestratigrafía de la Sabana de Bogotá y sus alrededores. *Boletín Geológico*, 5 (2): 113-185.

Bürgl, H. 1960. El Jurásico e Infracretácico del Rio Batá, Boyaca. *Boletín Geológico,* 6 (1-3): 169-211.

Callomon, J. 1993. In: von Hillebrandt, A., Smith, P., Westermann, G.E.G., Callomon, J.H. (Eds.), Upper Jurassic, especially of Mexico. Part 4: Biochronology. 12. Ammonite Zones of the Circum-Pacific Region. *The Jurassic of the Circum-Pacific*, pp. 247–272.

Cantú-Chapa A. 1967. El límite Jurásico-Cretácico en Mazatepec, Puebla (Mexico). *Instituto Mexicano del Petróleo, Sección Geología*, Monografía 1: 3-24.

Cantú-Chapa, A. 1976. El contacto Jurásico-Cretácico, la estratigrafía del Neocomiano, el hiato Hauteriviano Superior-Eoceno Inferior y las ammonites del Pozo Bejuco 6 (centro-Este de México). *Boletín de la Sociedad Mexicana*, 37: 60-83.

Cantú-Chapa, A. 1989. Precisiones sobre el límite Jurásico -Cretácico en el subsuelo del Este de México. *Revista de la Sociedad Mexicana de Paleontología*, 2: 26-69.

Cantú-Chapa, A. 1999. Confrontation of stratigraphic methods to define the Jurassic-Cretaceous boundary in eastern Mexico subsurface. *Geological Society of America Special Paper*, 340: 93-103.

Cantú-Chapa, A. 2006. New Upper Tithonian (Jurassic) ammonites from the Chinameca Formation in southern Veracruz, eastern Mexico. *Journal of Paleontology*, 80: 294-308.

Charrier, R. 1981a. Geologie der chilenischen Hauptkordillere zwischen 34° und 34°30' südlicher Breite und ihre tektonische, magmatische und paläogeographische Entwicklung. *Berliner Geowissenschaftliche Abhandlungen*, A, 36: 270 p.

Charrier, R., 1981b. Mesozoic and Cenozoic stratigraphy of the Central Argentinian-Chilean Andes (32°-35°S) and chronology of their tectonic evolution. *Zentralblatt* für *Geologie* und Paläontologie, I, 3: 344-355.

Charrier, R., 1982. La Formación Leñas-Espinoza: Redefinición, petrografía y ambiente de sedimentación. *Revista Geológica de Chile*, 17: 71-82.

Charrier, R., Wyss, A., Flynn, J., Swisher, C., Norell, M., Zapatta, F., McKenna, M., Novaceck, M. 1996. New evidence for late Mesozoic - early Cenozoic evolution of the Chilean Andes in the upper Tinguiririca valley (35º S), Central Chile. *Journal of South American Earth Sciences*, 9: 1-30.

Charrier, R., Pinto, L. & Rodríguez, M. 2007. Tectonostratigraphic evolution of the Andean Orogen in Chile. In: The Geology of Chile. Moreno T. & Gibbons, W. (eds). *The Geological Society of London*: 21-114.

Chao, K. 1976. Jurassic and Cretaceous ammonites from Mount Jolmo Lungma Region. In: A report of the scientific expedition in the Mount Jolmo Lungma Region. III. Palaeontology Academia Sinica, Tibetan Scientific Expedition Team. *Science Press*. Beijing: 504-545.

Coe, A. 2003. The Sedimentary Record of Sea-Level Change. *Cambridge University Press*, Cambridge, p. 286.

Coe, A. & Church, K. 2003. Sequence stratigraphy and sea-level change. In: A. Coe (Editor), The Sedimentary Record of Sea-Level Change. *Cambridge University Press*, Cambridge, 57–98.

Collignon, M. 1960. Atlas des fossils charactérisques de Madagascar. Fascicule 6 (Tithonique) *Service Geologique de Madagascar*, Tananarive. Plates 134-175.

Company, M. 1987. Los Ammonites del Valanginiense del sector oriental de las Cordilleras Béticas (SE de España). *Tesis Doctoral Universidad de Granada*: 294 p.

Corvalán, J. 1956. Über marine Sedimente des Tithon und Neocom der gegend von Santiago. *Geologischen Rundschau*, Vol. 43, No. 3, p. 919-926.

Corvalán, J. 1959. El Titoniano de Rio Leñas. Provincia de O'Higgins. *Instituto de Investigaciones Geológicas Chile*. Boletín N° 3. 59 p.

Corvalán, J. 1974. Estratigrafía del Neocomiano marino de la región al sur de Copiapó, Provincia de Atacama. *Revista Geológica de Chile*, 1: 13 -36.

Corvalán, J. & Pérez, E. 1958. Fósiles Guías Chilenos. *Instituto de Investigaciones Geológicas*. Manual 1: 1-48, pl. 1-16.

Covacevich, V., Varela, J. & Vergara, M., 1976. Estratigrafía y Sedimentación de la Formación Baños del Flaco al sur del Río Tinguiririca, Cordillera de los Andes. Provincia de Curico, Chile. *Actas I Congreso Geológico Chileno*, p. 191-211.

Covacevich, V., de la Cruz, R.& Suarez, M. 1994. Primer hallazgo de fauna del Berriasiano inferior (Neocomiano) en la Formación Ibanez, Region XI, Aisén. *Actas 7 Congreso Geológico Chileno*, I: 425-429.

Dembowska, J. 1973. Portland na Nizu Polskim (Portlandian in the Polish Lowlands). *Prace Inst. Geol*., 70. Warszawa.

Djanélidzé, A. 1922. Les Spiticeras du sud-est de la France. *Mémories pour Servir a l`Éxplication de la Carte géologique Détailée de la France*. 255 p.

Dietrich, W. 1925. Über eine, den mittleren Sauriermergel am Tendaguru äquivalente, rein marine Kimmeridgebildung in Mahokondo Deutsch-Ostafrika. *Palaeontographica*, Stuttgart Suppl. 7: (1) 23 pp.

Douvillé, R. 1910a. Céphalopodes argentins. *Mémoires de la Société Géologique de France*, 43, 24 p.

Douvillé, R. 1910b. Un *Virgatites* du Caucase occidental; origene méditerranéenne de ce genre; *Ataxioceras, Pseudovirgatites, Virgatosphinctes*. *Bulletin Société Géologique France*, Paris **4** (10), 730–739.

Dunham, R., 1962. Classification of carbonate rocks according to depositional texture. In: Ham, W. E. (ed.), Classification of carbonate rocks: *American Association of Petroleum Geologists* Memoir, 108-121.

Embry, A. & Klovan, J. 1971. A late Devonian reef tract on northeastern Banks Island, NW Territories. *Bulletin of Canadian* Petroleum Geology, 19: 730-781.

Enay, R. 1964. L'étage Tithonique, *Institut grand-ducal de Luxembourg*, Section des sciences naturelles, physiques et mathématiques. 355–379.

Enay, R. & Geyssant, J. 1975. Faunes tithoniques des chaines bétiques (Espagne meridionale) . In Colloque sur la limite Jurassique-Crétacé, Lyon – Neuchatel, septembre 1973. *Mémoires du BRGM*, 86, 39-55.

Enay, R. Barale, G, Jacay, J & Jaillard, E. 1996. Upper Tithonian Ammonites and Floras from the Chicama Basin, Northern Peruvian Andes. *GeoResearch Forum*. 1-2, 221-234.

Enay, R. & Cariou, E. 1997. Ammonite fauna and palaeobiogeography of the Himalayan belt during the Jurassic: Initiation of a Late Jurassic austral ammonite fauna. *Palaeogeography Palaeoclimatology Palaeoecology*, 134:1-38.

Fatmi, A. 1968. The palaeontology and stratigraphy of the Mespzoic rocks of Western Kohat, Kala Chitta, Hazara and the Trans Indus Salt Range, West Pakistan. *Thesis University of Wales* (manuscript), 409 p.

Fatmi, A. 1972. Stratigraphy of the Jurassic and Lower Cretaceous rocks and Jurassic ammonites from northern areas of West Pakistan. *Bulletin Museum (Natural History), Geology*, 20 (7): 299-380.

Fatmi, A. & Zeiss, A. 1999 First Upper Jurassic and Lower Cretaceous (Berriasian) ammonites from the Senbar Formation (Belemnite Schales), Windar Nai Lasbela – Balochistan, Pakistan. *Geological Survey of Pakistan*. Memoir 19. 114 p.

Feruglio, E. 1937. Palaeontographia patagonica. Parte I. *Memorie dell'Istituto Geologico della Reale Universitá di Padova*..XI. 192 p.

Folk, R. 1968, Petrology of Sedimentary Rocks: Austin, *University of Texas* Publication, 170 p.

Fözy, I. 1990. Ammonite succession from three Upper Jurassic sections in the Bakony Mts. (Hungary). *Atti del secondo convengno internazionale Fossili, Evoluzione, Ambiente, Pergola*, 1987: 323-329.

Fözy, I. 1995. Upper Jurassic ammonites from Seno di Guidaloca (Western Sicily). *Hantkeniana Géczy Jubilee*. 1: 131-143.

Francis, A. & Hallam, A. 2003. Ecology and evolution of Jurassic trigoniid bivalves in Europe. *Lethaia*, 36(4): 287-304.

Fuenzalida, R. 1966. Reconocimiento geológico de Alto Palena (Chiloe Continental.) *Anales de la facultad de Ciencias Físicas y Matemáticas*, 22-23 (año 1965-1966): 95-158.

Furrazola-Bermúdez, G., Gutierrez-Domech, R., Torres-Silva, A. & Pantaleón, G. 1998. Ammonites y Aptychus del Mesozoico de Cuba. Actualización. *Geomin*, 98: 1-29.

Gasparini, Z. & Fernández, M. 1997. Tithonian marine reptiles of the Eastern Pacific. En: J.M. Callaway y E.L. Nicholls (eds.), Ancient marine reptiles, *Academic Press, San Diego*. 435-440.

Gerth, E. 1921. Fauna und Gliederung des Neokoms in der argentinischen Kordillere. *Zentralblatt für Mineralogie, Geologie und Paläontologie*, 112-119; 140-148.

Gerth H. 1925. Contribuciones a la estratigrafía y paleontología de los Andes Argentinos I: Estratigrafía y distribución de los sedimentos mesozoicos en los Andes Argentinos. *Actas de la Academia Nacional de Ciencias de la República Argentina*, 9(1-2): 7-55.

Gerth, H., 1928. Die Fauna des Neokom in der argentinischen Cordillere. In: E. Jaworski, F. Krantz & H. Gerth: Beiträge zur Paläontologie und Stratigraphie des Lias, Doggers, Tithons und der Unterkreide in der Kordillere im Süden der provinz Mendoza (Argentinien). *Geologische Rundschau*, 17a (1926) : 463-494.

Geyer, O. 1973. Das präkretazische Mezoicum von Kolumbien. *Geologisches Jahrbuch*, Reihe B 5: 156 p.

Geyer, O. 1983. Obertithonische Ammoniten-Fauna von Peru. *Zentralblatt für Geologie und Paläontologie*. Teil I (3/4): 335-350.

Gill, T. 1871. Arrangement of the families of mollusk. *Smithsonian Miscellaneous Collections* 227. xvi + 49 p.

Giovine, A. 1950. Algunos cefalópodos del Hauteriviense de Neuquén. *Revista de la Asociación Geológica Argentina,* 5: 35-76.

González, O., 1963. Observaciones geológicas en el valle del río Volcán. *Revista Minerales*, 81: 20-54.

González, O. & Vergara, M., 1962. Reconocimiento Geológico de la Cordillera de los Andes entre los paralelos 35° y 38° Latitud Sur. *Publicaciones*, N° 24, Departamento de Geología, Universidad de Chile, 121 p.

González-Arreola, C., Óloriz, F. & Villaseñor, A. 1995. Nuevos datos sobre el Valanginiano en el nor-noreste de México. *Géologie Alpine*, Mémorie Hors Serie 20 (1994): 191-203.

Gradstein, G., Ogg, J. & Smith, A. 2004. A geological Time Scale 2004. *Cambridge University* Press. 589 p.

Grigorieva, O. 1938. A Lower Valanginian ammonite fauna from the basin of the Belaya River on the northern slope of the Caucasus (Maikop area). *Azovo-Chernomorsku geotogtcfieskii Trest. Materialv po geologii i poleznym iskopaemvtn*, 1: 83-122.

Gröcke, D., Price, G., Baraboshkin, E., Mutterlose, J. & Ruffell, A. 2003. The Valanginian terrestrial carbon-isotope record. *Geophysical Research*, Abstracts, 5.

Guerard, G.M., Greer, L., and Curran, H.A., 2004, Environmental indicator proxies from a mid-Holocene coral reef, Enriquillo Valley, Dominican Republic, *in* Lewis, R.D., and Panuska, B.C., eds., Proceedings of the 11th Symposium on the Geology of the Bahamas and Other Carbonate Regions: San Salvador, *Gerace Research Center*, p. 35–48.

Hallam, A. 2001. A review of the broad pattern of Jurassic sea-level changes and their possible causes in the light of current knowledge. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 167: 23–37.

Hallam, A., Biro-Bagoczki, L. & Perez, E. 1986. Facies analysis of the Lo Valdés Formation (Tithonian-Hauterivian) of the High Cordillera of central Chile, and the palaeogeographic evolution of the Andean Basin. *Geological Magazine.* 123, N 4, p.425-435.

Haq, B. U., Hardenbol, J., and Vail, P. R. 1987 Chronology of fluctuating sea levels since the Triassic (250 million years ago to present). *Science*, 235: 1156-1167.

Haq, B.U., J. Hardenbol and P.R. Vail, 1988, Mesozoic and Cenozoic chrono-stratigraphy and cycles of sea-level change. - In: Sea-Level Changes. *SEPM*, Special Publication, 42: 26-108.

Hardenbol, J., Thierry, J., Farley, M. B., Jacquin, T., de Graciansky, P. C. and Vail, P. R., 1998, Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins, in Graciansky, P.-C. de, Hardenbol, J., Jacquin, T., and Vail, P. R., eds., Mesozoic and Cenozoic sequence stratigraphy of European basins. *SEPM*, Special Publication 60, 3-13, Charts 1-8.

Hart, B.S. & Plint, A.G. (1995) Gravelly shoreface and beach deposits. In: Sedimentary Facies Analysis: a Tribute to the Research and Teaching of Harold G. Reading (Ed. Plint, A.G.). Special Publication 22, International Association of Sedimentologists. *Blackwell Science*, Oxford; 75–90.

Hass, O. 1960. Lower Cretaceous ammonites from Colombia, South America. *American Museum Novitates*, 2005, 62 p.

Haupt, O. 1907. Beiträge zur Fauna des oberen Malm und der unteren Kreide in der argentinischen Cordillere. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie,* 23: 187-236.

Hégarat, G. & Remane, J. 1968. Tithonique supérieur et Berriasien de lÀrdeche et de l`Hérault. Corrélation des ammonites et des calpionelles. *Geobios* 1: 7-70.

Helmstaed, H. 1969. Eine Ammoniten-Fauna aus den Spiti-Schiefern von Muktinah in Nepal. *Zitteliana*, 1: 63-88.

Hoedemaeker, P., 1982. Ammonite biostratigraphy of the uppermost Tithonian, Berriasian and Lower Valanginian along the Rio Argos (Caravaca, SE Spain). *Scripta Geologica*, 65: 1-181.

Hoedemaker, P. 1987. Correlation possibilities around the Jurassic/Cretaceous boundary. *Scripta Geologica*, 84, 55 p.

Hoedemaker, P. 1991. Tethyan - Boreal Correlations and the Jurassic/Cretaceous boundary. *Newsletters on Strattigraphy*, 25: 37-60.

Hoedemaeker, P. 2003. Report on the 1st International Workshop of the IUGS Lower Cretaceous Ammonite Working Group, the “Kilian group” (Lyon, 11 July 2002). *Cretaceous Research*, 89-94.

Howarth, M. 1992. Tithonian and Berriasian ammonites from the Chia Gara Formation in Northern Iraq. *Palaeontology*, 35: 597655

Howarth, M. 1998. Ammonites and nautiloids from the Jurassic and Lower Cretaceous of Wadi Hajar, southern Yemen. *Bulletin of the Museum of Natural History (Geology)*, 54: 33–107.

Howarth, R. & McArthur, J. 1997. Statistics for strontium isotope stratigraphy: A robust LOWESS fit to the marine Sr-isotope curve for 0 to 206 Ma, with look-up table for derivation of numeric age. *Journal of Geology*. 105: 441 - 456.

Howlett, P. 1989. Late Jurassic-early Cretaceous cephalopods of eastern Alexander Island, Antarctica. *Special Papers in Palaeontology*. 41**,** p. 72.

Humphries, C. 2005. Cladistic Biogeography. eLS.

Hupé, L. 1854. Zoología. In: Gay, C. (Ed.): Historia física y política de Chile, 8: 499 p.

Hyatt, A. 1889 Genesis of the Arietidae. Smithsonian Contributions to Knowledge, **673**, xi + 238 pp.

Imlay, R. 1939. Upper Jurassic ammonites from Mexico. *Geological Society of America Bulletin*, 50, 1-68.

Imlay, R. 1942. Late Jurassic fossils from Cuba and their economic significance. *Geological Society of America Bulletin*, 53: 1417-1478.

Imlay, R., 1943 Upper Jurassic ammonites from the Placer de Guadalupe District, Chihuahua, Mexico. *Journal of Paleontology*, 17**:** 527–544.

Imlay R. & Jones D. Ammonites from the Buchia Zones in Northwestern California and Southwestern Oregon. *US Geological Survey, Professional Paper*, 647-B: 1-60.

Indans, J. 1954. Eine Ammoniten fauna aus dem Untertithon der argentinischen Kordillere in Süd-Mendoza. *Palaeontographica*, 105 A: 96-132.

Jeletzky, J. 1984. Jurassic - Cretaceous boundary beds of Western and Arctic Canada and the problem of the Tithonian-Berriasian stages in the Boreal Realm. *Geological Association of Canada*, Special Paper 27: 175-255.

Jones C. 1992. Strontium Isotopes in Jurassic and Early Cretaceous Seawater. *Ph.D. dissertation, University Oxford*.

Jurgan, H. 1977. Zur Gliederung der Unterkriede-Serien in der Provinz Atacama Chile. *Geologische Rundschau*, 66 (2): 405-434.

Kalacheva, E. & Sey, L. 2000. Ammonites. In: kolpenskaya, N., Nikiforova, E., Sochevanova, O., Sey, I. & Kalacheva, E. The Berriasian of the North Caucasus (Urukh section). *Biochronology and correlation of Phanerozoic of oil and gay basin of the Russia*, 2: 69-101.

Karakasch N.I. 1907. Le cretace inferieur de la Crimee et sa faune. *Travaux de la Societe Imperiale des Naturalistes de St.-Petersbourg, vol.XXXII, livr.5*, *Section de Geologie et de Mineralogie*, 482 p.

Khimshiashvili N. 1976 Tithonian and Berriassian ammonites of the Caucasus. *Tbilisi: Metsniereba*. 180 p.

Khimshiashvili N. 1989. Berriasellids of the Caucasus. Tithonian fauna of the Lakorizi-Tau Mt. (Bsyb basin). 86 p.

Koleff, P., Gaston, K. J., Lennon J. J. 2003. Measuring beta diversity for presence-absence data. *Journal of Animal Ecology,* 72, 367-382.

Klein, J., 2005. Lower Cretaceous Ammonites I, Perisphinctaceae 1: Himalayitidae, Olcostephanidae, Holcodiscidae, Neocomitidae, Oosterellidae. In: Riegraf, W. (Ed.), Fossilium Catalogus I: Animalia. *Backhuys Publishers*, Leiden, pars 139, 484 p.

Klein, J., Busnardo, R., Company, M., Delanoy, G., Kakabadze, M., Reboulet, S., Ropolo, P., Vašíček, Z. & Vermeulen, J. 2007. Cretaceous Ammonites III, Bochianitoidea, Protancyloceratoidea, Ancyloceratoidea, Ptychoceratoidea. In: Riegraf, W. (Ed.), Fossilium Catalogus I: Animalia. *Backhuys Publishers*, Leiden, pars 144, 381 p.

Kraemer, P. & Riccardi, A. 1997. Estratigrafía de la región comprendida entre los lagos Argentino y Viedma (49° 40' - 50°10' lat. S), Provincia de Santa Cruz. *Revista de la Asociación Geológica Argentina*, 52: 333-360.

Krantz, F., 1926. Die Ammoniten des Mittel-und oberTithons. In: E. Jaworski, F. Krantz & H. Gerth: Beiträge zur Paläontologie und Stratigraphie des Lias, Doggers, Tithons und der Unterkreide in der Kordillere im Süden der provinz Mendoza (Argentinien). *Geologische Rundschau*, 17: 428-462.

Krantz, F. 1928b. La fauna del Titono superior y medio en la parte meridional de la provincia de Mendoza. *Actas de la Academia Nacional de Ciencias de la República Argentina*. 10:9-**57**.

Klohn, G. 1960. Geología de Santiago, O'Higgins, Colchagua y Curicó. *Instituto de Investigaciones Geológicas Chile*. Boletín 8: 95 p.

Kutek, J. & Zeiss, A. 1974. Tithonian-Volgian ammonites from Brzostówka near Tomaszów Mazawiecki, Central Poland. *Acta Geologica Polonica*. 24: (3) 505-542.

Kutek, J. & Zeiss, A. 1994. Biostratigraphy of the Highest Kimmeridgian and Lower Volgian in Poland. *Geobios*. 17: 337-341.

Kvantaliani, I. 1999. Berriasian Cephalopods of the Crimea and the Caucasus. *Proceedings Georgian Academy of Sciences Geological Institute (new series)*, 112, 188 p.

Larraín, A. & Biró, L. 1985. New *Pygurus* (Echinodermata: Echinoidea) from the Tithonian of Central Chile: first record from the Jurassic of the Southern Hemisphere. *Journal of Paleontology* 59: 1409-1413.

Leanza, A. 1945. Ammonites del Jurásico superior y del Cretácico inferior de la Sierra Azul en la parte meridional de la provincia de Mendoza. *Anales del Museo de La Plata* NS 1:1-99.

Leanza, A. & Leanza, H. 1973. *Pseudofavrella* gen. Nov. (Ammonitina) del Hauteriviano de Neuquén, sus diferencias con Favrella R. Douvillé, 1909, del Altiplano de Patagonia austral y una comparación entre el geosinclinal andino y el geosinclinal magallánico. *Boletín de la Academia Nacional de Ciencias, Córdoba, Argentina*, 50 (1-4): 127-145.

Leanza, H. 1973. Estudio sobre los cambios faciales de los estratos limítrofes Jurásico-Cretácicos entre Loncopué y Picún Leufú, Prov. de Neuquén, República de Argentina. *Revista de la Asociación Geológica Argentina*, 28 (2): 97-132.

Leanza, H. 1980. The Lower and Middle Tithonian ammonite fauna from Cerro Lotena, Province of Neuquén, Argentina. *Zitteliana*, 5: 3-49.

Leanza, H. 1981a. Faunas de ammonites del Jurásico superior y del Cretácico inferior de América del Sur, con especial consideración de la Argentina. Comité Sudamericano del Jurásico y Cretácico: *Cuencas sedimentarias del Jurásico y Cretácico de América del Sur* 2: 559-597.

Leanza, H. 1981b. The Jurassic-Cretaceous boundary beds in West central Argentina and their ammonite zones. *Neues Jahrbuch für Geologie und Paläontologie, Abhlandungen*, 161 (1): 62-92.

Leanza, H. 1996a. Advances in the ammonite zonation around the Jurassic/Cretaceous boundary in the Andean Realm and correlation with Tethys. In: *Jost Wiedmann Symposium, Cretaceous Stratigraphy, Paleobiology and Paleobiogeography, Tübingen, Germany 1996*. Abstracts: 215–219.

Leanza, H. 1996b. The Tithonian ammonite genus *Chigaroceras* Howarth (1992) as a bioevent marker between Iraq and Argentina. *GeoResearch Forum* 1-2: 451-458.

Leanza, H. & Wiedmann, J. 1980. Ammoniten des Valangin und Hauterive (unterkreide) von Neuquén und Mendoza, Argentinien. *Eclogae Geologicae Helvetiae*, 73 (3): 941-982.

Leanza, H. & Zeiss, A. 1990. Upper Jurassic lithographic limestones from Argentina (Neuquén Basin): Stratigraphy and fossils. *Facies*. 22: 169-186.

Leanza, H. & Zeiss, A. 1992. On the ammonite fauna of the lithographic limestones from the Zapala region (Neuquén province, Argentina), with the description of a new genus. *Zentralblatt far Geologie und Palaontologie* (Tell 1) 6:1841- 1850.

Léveillé, C. 1837. description de quelques nouvelles coquilles fossils du départment des Basses-Alpes. *Mémoires de la Société géologique de France*, 10 (2): 313-315.

Lewinski, J. 1923. Monographie geologique et paleontologique du Bononien de la Pologne. *Mémoires de la Société géologique de France*, 56. Paris.

Lisson C. 1907. Contribución a la Geología de Lima y sus alrededores. *Gil*. Lima. 123 p.

Liu, G. 1988. Upper Jurassic and Lower Cretaceous ammonites from Yamzho Yumco area Xizang (Tibet). In: *Chinese Academy of geological sciences* (Ed.), Professional papers of Xizang (Tibet) Paleontology: 66-122.

Liu Guifang & Wang Sien. 1987. A new advance in study of the Upper Jurassic and Lower Cretaceous of the Himalyas, Xizang (Tibet). *Professional Papers of Stratigraphy and Palaeontology*, 17: 157-166.

Lory, P. 1898. Le Crétacé du devolvy et des regions voisines. *Bulletin de la Société Géologique de France (series 3)*, 26: 132-138.

Mazenot, G. 1939. Les Palaehoplitidae tithonique et berriasiens du sud-est de la France. *Mémoires de la Société Géologique de France (new series) 18*, Mémoire 41. 303 p.

Matsumoto, T. & Sakai, H. 1983. On Some Jurassic ammonites from Muktinath, Nepal. *Memoir Faculty of Sciences Kyushu University, Serie D, Geology*, 25 (1): 75-91.

Michalski, A. 1890. Ammonity nizhniavo volzhkavo jarusa (Die Ammoniten der unteren Wolga-Stufe). *Trudy Geol. Komit*., 8, 2. Petersburg.

Mitta, V., Starodubtseva, I., Soroka, I. & Kashleva, M. 1999. N. P. Vischniakoff and its work “Description des Planulati (*Perisphinctes*) Jurassiques de Moscou”. *VM-Novitates*, 3: 1-47

Mourgues, F. 2004. Advances in ammonite biostratigraphy of the marine Atacama basin (Lower Cretaceous), northern Chile, and its relationship with the Neuquén basin, Argentina. *Journal of South American Earth Sciences*, 17: 3-10.

Mourgues, F. 2007. Paléontologie stratigraphique (Ammonites) et évolution tectono-sédimentaire du bassin d'arrière arc de Chañarcillo (Berriasien-Albien, Nord du Chili). *Unpublished Ph. D. thesis, University of Toulouse III*, France.

Möseler, B. M., Sievers, R., Alvarez, M. 2009. Diversitätsanalyse unter der Verwendung des Programmes DiversityCalc am Beispiel eines Wald-Transektes vom Aremberg in der Osteifel. *Decheniana*, 162, 67-78.

Mpodozis, C. & Ramos, V. 1989. The Andes of Chile and Argentina. In Ericksen, G.E., Cañas, M.T. & Reinemund, J. (eds.) Geology of the Andes and its relation to hydrocarbon and mineral resources, Circum-Pacific Council for Energy and Mineral Resources, *Earth Sciences Series*, 11: 59-90.

Muñoz, M. 1964. Amonitas del Jurásico Superior y del Cretácico Inferior del Extremo Oriental del Estado de Durango, México. *Paleontología Mexicana*, 20: 1-33.

Mutterlose, J. 1996. The Hauterivian Stage. *Bulletin de l`Institut Royal des Sciences naturelles de Belgique*, Suplement 66: 19-24.

Myczynski R., 1989. Ammonite biostratigraphy of the Tithonian of Western Cuba. *Annales Societatis Geologorum Poloniae*, 59: 43-125.

Myczynski R., 1990. *Simocosmoceras* Spath (Perisphinctidae, Ammonitina) in the Lower Tithonian of Sierra del Rosario (Western Cuba).- In G. Pallini, F. Cecca, S. Cresta, M. Santantonio (eds.): *Atti del secondo convegno internazionales Fossili, Evoluzione, Ambiente, Pergola 1987*: 401-403.

Neuenschwander, C. & Tavera, J. 1942. Yacimientos de plomo y Neocomiano de 'Las Cañas' en el Departamento de Vallenar. *In Congreso Panamericano de Ingeniería de Minas y Geología, No. 1*, Anales, 3: 1094-1109.

Neumayr, M. 1875. Die Ammoniten der Kreide und die Systematik der Ammonitiden. *Zeitschrift der Deutsche Geologischen Gesellschaft*, 27: 854-942.

Nichols, G. 2009. Sedimentology and Stratigraphy, 2nd edition, *Wiley Blackwell*, 432 p.

Nikolov, T. 1960. La fauna d'ammonites dans le Valanginien du Prébalkan Oriental. *Trudove vurkhu Geologiyata na Bulgariya (Seriya Paleontologiya)*, 2: 143–206.

Nikolov, T. 1982. Les Ammonites de la Famille Berriasellidae Spath, 1922. Tithonique Superieure – Berriasien. *Editions académie bulgare des sciences*. Sofia. 251 p.

Ogg, J. 2004. The Jurassic Period. In Gradstein, G., Ogg, J. & Smith, A. 2004. A geological Time Scale 2004. *Cambridge University Press*. 344-383.

Ogg, J., Agterberg, F. & Grandstein, F. 2004. The Cretaceous Period. In Gradstein, G., Ogg, J. & Smith, A. 2004. A geological Time Scale 2004. *Cambridge University Press*. 307-343.

Ohmert, W. & Zeiss, A. 1980. Ammoniten aus den Hangenden Bankkalken (Unter–Tithon) der Schwäbischen Alb (Südwestdeutschland). *Abhandlungen des Geologischen Landesamtes Baden-Württemberg* 9, 5–50.

Oloriz, F. 1978. Kimmeridgiense-Tithónico inferior en el sector central de las cordilleras Béticas (Zona Subbética). Paleontología. Bioestratigrafía. *Tesis Doctoral Universidad de Granada*, 758 p.

Oppel, A. 1963. Über ostindische Fossilreste aus den secundären Ablagerungen von Spiti und Gnari-Korsum in Tibet. *Palaeontologische Mittheilungen aus dem Museum des Koeniglich-Bayerschen Staates* IV: 267-288.

Oppel, A. 1865. Die tithonische Etage. *Zeitschrift der Deutschen Geologischen Gesellschaft*. 17: 535-558.

Orbigny, A. D'. 1840-1842.Paléontologie française. Description zoologique et géologique de tous les animaux mollusques et rayonnés fossiles de France. *Terrains Crétacés. Vol. 1. Céphalopodes.Arthus-Bertrand*; Orbigny,Paris,662 pp. [1-120 (1840); 121-430 (1841); 431-662 (1842)], 148 pl.

Parent, H. 2001. The Middle Tithonian (Upper Jurassic) Ammonoid Fauna of Cañadón de los Alazanes, Southern Neuquén-Mendoza Basin, Argentina. *Boletín del Instituto de Fisiografía y Geología*, 71 (1-2): 19-38.

Parent, H. 2003a. The ataxioceratid ammonite fauna of the Tithonian (Upper Jurassic) of Casa Pincheira, Mendoza (Argentina). *Journal of South American Earth Sciences*. 16: 143-165.

Parent, H.2003b. Taxonomic and biostratigraphic reevaluation of *Perisphinctes internispinosus* Krantz, 1926 (Upper Jurassic, Ammonoidea). *Paläontologische Zeitschrift,* 77(2): 353-360.

Parent, H. & Capello, O. 1999. Amonites del Tithoniano Inferior de Casa Pincheira, Mendoza (Argentina). *Revue de Paleobiologie*, 18 (1), 347–353.

Parent, H., Scherzinger, A. & Schweigert, G., 2006. The earliest ammonite faunas from the Andean Tithonian of the Neuquén-Mendoza Basin. Argentina. Chile. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, 241, 253–267.

Parent, H., Scherzinger, A., Schweigert, G. & Capello, O. 2007. Ammonites of the Middle Tithonian Internispinosum Zone from Barda Negra, Southern Neuquén-Mendoza Basin, Argentina. *Boletín del Instituto de Fisiografía y Geología,* 77 (1-2): 11-24.

Parent, H., Garrido. A., Schweigert, G. & Scherzinger, A. 2011a. The Tithonian ammonite fauna and stratigraphy of Picún Leufú, southern Neuquén Basin, Argentina. *Revue de Paléobiologie*, 30 (1): 45-104.

Parent, H., Scherzinger, A. & Schweigert, G. 2011b. The Tithonian-Berriasian Ammonite Fauna and Stratigraphy of Arroyo Cieneguita, Neuquén-Mendoza Basin, Argentina. *Boletín del Instituto de Fisiografía y Geología,* 79-81: 21-94.

Pérez, E. & Reyes, R. 1994. Catálogo de ejemplares tipo, conservados en la colección paleontológica del Servicio Nacional de Geología y Minería, Chile, desde 1953 a 1993. *Boletín Servicio Nacional de Geología y Minería*, 46: 1-99.

Pictet, F. 1867. Etudes paléontologiques sur la fauna à *Terebratula diphyoides* de Berrias (Ardèche). *Mélanges Paléontologiques. Bale-Genève*, 1 (2)2. 44-130.

Pictet, F. & Campiche, G. 1860. Description des fossiles du terrain Crétacé des environs de Sainte-Croix, part 1. *Matériaux pour la Paléontologie Suisse* (série 2) : 209-380.

Plint, A. (1988) Sharp-based shoreface sequences and offshore bars of the Cardium Formation of Alberta: their relationship to relative changes in sea-level. In: Sea Level Changes: an Integrated Approach (Eds C.K. Wilgus, B.S. Hastings, C.G.St.C. Kendall, H.W. Posamentier, C.A. Ross and J.C. Van Wagoner). Special Publication 42, *Society of Economic Paleontologists and Mineralogists, Tulsa*, OK; 357–370.

Pomel, A., 1889. Les céphalopodes Néocomiens de Lamoricière. *Matériaux pour la Carte géologique de l`Algerie*, 2: 1-99.

Poulton, T., Zeiss, A. & Jeletzky, J. 1988. New Molluscan Faunas from the Late Jurassic (Kimmeridgian and Early Tithonian) of Western Canada. *Contributions to Canadian Paleontology. Geological Survey of Canada Bulletin*, 379, 103-115.

Price, G. 1999. The evidence and implications of polar-ice during the Mesozoic. *Earth Science Reviews*, 48: 183–210.

Rawson, P.F. 2007. Global relationships of Argentine (Neuquén Basin) Early Cretaceous ammonite faunas. *Geological Journal*, 42: 175-183.

Remane, J. 1991. The Jurassic-Cretaceous boundary: problems of definition and procedure. *Cretaceous Research*, 12: 447-453.

Rémond de Corbineau, A. 1867. *Paleontolojía de Chile*, 29 (3): 99-141.

Riccardi, A. 1970. *Favrella* R. Douvillé, 1909 (Ammonitina, cretacico Inferior): edad y distribución. *Ameghiniana*, 7 (2): 119-138.

Riccardi, A. 1971. Estratigrafía en el oriente de la Bahía de la Lancha, Lago San Matín, Santa Cruz, Argentina. *Revista del Museo de la Plata* (new series), Tomo VII, Geologia 61: 245-318.

Riccardi, A. 1988. The Cretaceous System of Southern South America. *The Geological Society of America Memoir*, 168: 161 p.

Riccardi, A. 1991. Jurassic and Cretaceous marine connections between the Southeast pacific and Tethys. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 87: 155-189.

Riccardi, A. 1992. Argentina, Tithonian. In: Westermann (Ed.). The Jurassic of the Circum-Pacific. *Cambridge University Pres*s: pl. 81-82.

Riley, T., Crame, J., Thomson, M. & Cantrill, D. 1997. Late Jurassic (kimmeridgian-Tithonian) macrofossil assemblage from Jason Peninsula, Graham Land: evidence for a significant northward extension of the Latady Formation. *Antarctic Science*, 9 (4): 434-442.

Rivera, R. 1951. La fauna de los Estratos Puente Inga, Lima. *Boletín de la Sociedad Geolgógica del Perú*, 22, 1-53.

Rogov, M. 2004. Ammonite-Based Correlation of the Lower and Middle (*Panderi* Zone) Volgian Substages with the Tithonian Stage. *Stratigraphy and Geological Correlation*, 12: (7), 35-57.

Rogov, M. 2010. New Data on Ammonites and Stratigraphy of the Volgian stage in Spitzbergen. *Stratigraphy and Geological Correlation*, 18: (5), 505-531.

Roman, F. 1936. Le Tithonique du Massif du Djurdjura (Province d`Alger). *Materiaux pour la Carte Géologique de Serie 1 (Paléontologie)*, 7: 1-43.

Roman, F. 1938. Les ammonites jurassiques et crétacées. *Essai de genera. Masson*. Paris. 554 p.

Rossi, F. (1984): Ammoniti del Kimmeridgiano superiore-Berrisiano inferiore del Passo del Furlo (Appennino Umbro-Marchigiano). *Memorie della Società Italiana di Scienze Naturali e del Museo Civico di Storia Naturale in Milano*, 23 (3): 73-136.

Royo y Gómez, J. 1945. Fósiles carboníferos e infracretácicos del oriente de Cundinamarca. Compilación de los estudios geológicos oficiales en Colombia. *Servicio Nacional*, Bogotá, 6: 193-246.

Ruffell, A., Price, G., Mutterlose, J., Kessels, K., Baraboshkin, E. & Gröcke, D. 2002. Palaeoclimate indicators (clay minerals, calcareous nannofossils, stable isotopes) compared from two successions in the late Jurassic of the Volga Basin (SE Russia). *Geological Journal*, 37: 17–33.

Salazar, C. & Stinnesbeck, W. (accepted). Ammonites from Baños del Flaco Formation (Tithonian-Berriasian?) in Central Chile. *Palaeontology*.

Salazar, C. & Stinnesbeck, W. (submitted). Lo valdés and Catedral formations (Central Chile): redefinition, Stratigraphy and Facies. *Andean Geology*.

Salfeld, H. 1921. Kiel-und Furehenbildung auf der Schalenaussenseite der Ammonoideen in ihrer Bedeutung für die Systematik und Festlegung von Biozonen. *Zentralbland für Mineralogie, Geologie und Palaontologie*, p. 343–347.

Sapunov, I. 1979. Les fossils de Bulgarie III. 3. Jurassique supérieur. *Ammonoidea*. 263 p.

Sayn, G. 1907. Les ammonites pyriteuses des Marnes valanginienses de sud-est de la France (part 2). *Mémoires de la Société Géologique de France (Sayn 1901-1907)*, Paléontologie 15, Mémoire 23: 29-68.

Schafhauser, A. 2006. The Cardenas Formation in East-Central Mexico (Maastrichtian): Stratigraphy, Depositional Environment and Rudist Decline. Ph. D. Dissertation. *Universität Fridericiana zu Karlsruhe*. Germany. 106 p.

Schneid, T., 1915. Die Ammonitenfauna der obertithonischen kalke von neuburg a.d. Donau. *Geol. Puläont. Abh*. N.F. 13(5), 303–416.

Scholle, P. & Ulmer-Scholle, D. 2003. A Color Guide to the Petrography of Carbonate Rocks: *The American Association of Petroleum Geologist, Tulsa, Oklahoma*, U.S.A. AAPG Memoir 77: 474 p.

Sey I., Repin S., Kalacheva E., Okuneva T., Paraketsov K. & Poluoitko I. 1992. Eastern Russia // in: Wetermann G.E.G. (Ed.). The Jurassic of the Circum-Pacific. *Cambrige University Press*. 225-245

Sey I. & Kalacheva E. 1990. Lower Berriasian deposits of South Primorye and the Jurassic-Cretaceous boundary in the Far East of the USSR. In: W. Menner (Ed.), Granista yury I mela (Jurassic/Cretaceous boundary). *Trudy Instituta Geologii I Geografii Akademii Nauk SSSR, Sibirskoe Otdelenie*, 699: 178-187.

Sey I. & Kalacheva E. 1996. Upper Jurassic-Lower Cretaceous Biostratigraphy and Fauna of South Primorie (Russian Far East). *Geology of Pacific Ocean*, 12: 293-312.

Sey I. & Kalacheva E. 1997. Ammonite complexes from the Middle Tithonian deposits of Southern Seaside, Far-East of Russia (Haploceratidae, Oppeliidae,Ataxioceratidae). *Regional Geology and Metallogeny*, 6: 90-102.

Sey I. & Kalacheva E. 1999. The Early Cretaceous Ammonoids of the Sikhote-Alin System: Biostratigraphic and Biogeographic Significance. *Tikhookeanskaia Geologiia*, 18: 83-92.

Sey I. & Kalacheva E. 2001. Early Cretaceous ammonites of the Sikhote-Alin and the biostratigrapic and biogeographic implications. *Geology of the Pacific Ocean*, 16: 1091-1106.

Shome, S., Soma, D., Pinaki, R. & Shiladri S. Das. 2004. Ammonites as biological stopwatch and biogeographical black box – a case study from the Jurassic - Cretaceous boundary (150 Ma) of Kutch, Gujarat. *Current Science*, 86 (1): 197-202.

Shome, S. & Bardhan, S. 2009. A new Tithonian Ammonite assemblage from Kutch, Western India. *Journal of the Palaeontological Society of India*. 54 (1), 1-18.

Simionescu, I., 1899 - Note sur quelques ammonites du Néocomien francais. *Annales de l`Universite de Grenoble*, 11(3). 1-16.

Siemiradzki, J. von. 1899. Monographische Beschreibung der Ammonitengattung *Perisphinctes*. *Palaeontographica*, 45, 297-352.

Sokolov D. 1946. Algunos fósiles suprajurásicos de la República Argentina. *Revista de la Asociación Geológica Argentina* 1(1): 7-16.

Sowerby, J. 1840. Mineral Conchol of Great Britain. 7 vols., London 1812-1846. In Spath 1924

Spath, L. 1922. On Cretaceous ammonites from Angola, collected by Prof. J. W. Gregory, D.Sc., FRS. *Transactions of the Royal Society of Edinburgh*, 53 (1): 91-160.

Spath, L. 1923a. On ammonites from New Zealand. In Trechmann, Ch.T. (ed.) The Jurassic Rocks of New Zealand. Geological Society of London, *Quarterly Journal*, 79, p. 246-312.

Spath, L. 1923b. A monograph of the Ammonoidea of the Gault, part 1: 1-72. *Monograph of the Palaeontological Society of London*.

Spath, L. 1924. On the Blake collection of ammonites from Kachh, India. *Palaeontologia Indica*, new ser. 9, mem. 1. 1-29.

Spath, L. 1925. Ammonites and Aptychi. In Wyllie, B.N.K and Smellie, W.E. (eds.) The collection of fossils and rocks from Somaliland. Hunterian Museum, *Glasgow University*, Monograph 7: 111-164.

Spath, L. 1927-33. Revision of the Jurassic Cephalopod Fauna of Kachh (Cutch). Geological Survey India, *Paleontologica Indica*, 9: 1-945 (6 parts)

Spath, L. 1939. The cephalopoda of the Neocomian Belemnite Beds of the Salt Range. *Palaeontologica Indica*, *Memoirs of the Geological Survey of India (new series)* 25, memoir 1: 154 p.

Spath L. 1950. A new Tithonian ammonite fauna from Kurdistan, northern Iraq. *Bulletin British Museum of Natural History*, 1: 95-137.

Stanley, S. M. 1977. Coadaptation in the Trigoniidae, a remarkable family of burrowing bivalves. *Palaeontology*. 20: 869-899

Stappenbeck, R. 1929. Geologie des Chicamatales in Nordperu und seiner Antrazit-lagerstätten. *Geologie Paläontologie Abh*., 16, 305-356.

Steiger, P. 1914. Additional notes on the Fauna of the spiti Shales. Himalayan fossils. *Palaeontologica Indica,* 4 (5): 457-511.

Steinmann, G. 1890. Cephalopoda. In G. Steinmann and L. Döderlein (eds.) Elemente der Paläontologie, 344-475, W. Engelmann, *Leipzig*.

Steinmann, G. 1929. Geologie von Perú. *Heidelberg*.

Steuer, A. 1897. Argentinische Jura-Ablagerungen. Beitäge zur Kenntnis der Geologie und Paläontologie der argentinischen Anden. *Palaeontologische Abhandlungen*, 7 (3): 127-222.

Steuer, A. 1921. Estratos Jurásicos Argentinos. Contribución al conocimiento de la Geología y Paleontología de los Andes Argentinos entre el río Grande y el río Atuel. *Actas de la Academia Nacional de Ciencias de la República Argentina*, 7 (2), 25–128.

Strasser, A., Pittet, B., Hillgärtner, H., Pasquier, J. 1999. Depositional sequences in shallow carbonate-dominated sedimentary systems: concepts for a high-resolution analysis. *Sedimentary Geology*, 128: 201–221.

Takei, M., Matsuoka, A., Yang, Q., Kobayashi, K. Nagahashi, T., Zeng, Q. Wang, Y. & He., G. 2004. late Jurassic and Early Cretaceous ammonites from the Weimei Formation in Gyangze, southern Tibet. *Rivista Italiana di paleontologia e Stratigrafia*, 110 (1): 269-272.

Tavera, 1956, J. fauna del Cretácico Inferior de Copiapó. *Universidad de Chile*. Facultad de Ciencias Físicas y matemáticas. Instituto de Geología, 9: 205-216.

Tavera, J. 1970. Fauna Titoniana – Neocomiana de Isla Livingston, Islas Shetland del Sur, Antártica. *Serie Científica INACH*. 1 (2): 175-186.

Tavera, J. M. 1985. Los ammonites del Tithonico Superior-Berriasense de la zona subbetica (Cordilleras Beticas). Tesis Doctoral. *Universidad de Granada*. 381 p.

Thiele, R. 1980. Carta Geológica de Chile N° 39, Hoja Santiago, Región Metropolitana. *Instituto de Investigaciones Geológicas Chile*. 51 p.

Thomson, M. 1971. Ammonite faunas of south-eastern Alexander Island and their stratigraphical significance. In: Adie, R (Ed.) Antarcttic geology and geophysics. *Universitetsforlage. Oslo*: 155-160.

Thomson, M. 1974. Ammonite faunas of the Lower Cretaceous of south-eastern Alexander Island. *British Antarctic Survey Scientific Reports*, 80: 1-44.

Thomson, M. 1979. Upper Jurassic and Lower Cretaceous ammonite faunas of the Ablation Point area, Alexander Island. *Brithish Arctic Survey Science Report*, 97: 1–37.

Toucas, A. 1890. Étude sur la fauna des couches tihoniques de l'Ardèche. *Bulletin de la Société Géologique de France (Serie 3)*, 18: 560-629.

Trautschold H. 1861. Recherches geologiques aux environs de Moscou. Couche jurassique de Mniovniki. *Bull. Soc. Nat. Moscou*, vol. 34. Moskva.

Uhlig, V. 1903-1910. The Fauna of the Spiti Shales. *Palaeontologia Indica*, 15: 133-395.

Verma, H. & Westerman, G. 1973. Tithonian (Jurassic) ammonite fauna and stratigraphy of Sierre catorce, San Luis Potosi, México. *Bulletins of American Paleontology,* 63 (277): 103-320.

Vermeulen, J. 2004. vers une nouvelles classification à fondement phylogénétique des ammonites hétéromorphes du Crétacé inférieur méditerranée. Le cas des crioceratitidae Gill, 1871, nom, correct. Wright, 1952, des Emericiceratidae fam. nov. et des Acrioceratidae fam. nov. (Ancyloceratacea Gill 1871). *Riviéra Scientifique*, 88: 69-92.

Vischniakoff, N. 1882. Description des Planulati (*Perisphinctes*) jurassiques de Moscou. Moskva.

Waagen, W. 1875. Jurassic fauna of Kutch. Palaeontologia Indica. *Geological Survey of Indi*a, Memoir 9(1):247.

Weaver, C. 1931. Paleontology of the Jurassic and Cretaceous of West Central Argentina. *Memoirs of the University of Washington*, 1: 496 p.

Wierzbowski A. & Remane J. 1992. The ammonite and calpionellid stratigraphy of the Berriasian and lowermost Valanginian in the Pieniny Klippen Belt (Carpathians, Poland). *Eclogae Geologicae Helvetiae*, 85, 3: 871-891.

Weissert H. &. Channell J. 1989. Tethyan carbonate isotope stratigraphy across the Jurassic-Cretaceous boundary: an indicator of decelerated global carbon cycling?. *Palaeoceanography*, 4: 483–494.

Weissert, H. & Mohr, H., 1996. Late Jurassic climate and its impact on carbon cycling. *Palaeogeograhpy, Palaeoclimatology, Palaeoecology*, 122: 27-43.

Welter, O. 1913. Beiträge zur Geologie und Paläontologie von Südamerika. XIX. Eine Tithonfauna aus Nord-Perú. *Neues Jahr Mineralogie, Geologie und Paläontologie,* 1, 28-42.

Wentworth, C. 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology*, 30: 377-392.

Wiedmann, J. 1966. Stammesgeschichte und System der posttriadischen Ammonoideen - Ein Überblick (1. Teil). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, 125: 49–79.

Windhausen, A. 1931. Geología Argentina. Segunda parte, Geología histórica y regional del territorio Argentino. 645 p.

Wippich, M. 2001. Die tiefe Unter-Kreide (Berrias bis Unter-Hauterive) im Südwestmarokkanischen Becken: Ammonitenfauna, Bio- und Sequenzstratigraphie. PhD Thesis, *Ruhr-University of Bochum*. 142 p.

Wippich, M. 2003. Valanginian (Early Cretaceous) ammonite faunas from the western High Atlas, Marocco, and the recognition of western Maditerranean “standard” zones. *Cretaceous Research*, 24: 357-374.

Wright, V. 1986. Facies sequences on a carbonate ramp: the Carboniferous Limestone of South Wales. *Sedimentology*, 33: 221-241.

Wright, V. 1992. A revised classification of limestones. *Sedimentary Geology*, 76: 177-185

Wright, C., Callomon, J. & Howarth, M. 1996. Cretaceous Ammonoidea - Treatise on Invertebrate Paleontology, Part L, Mollusca 4, xx + 362 pp. *Lawrence & Boulder*. (Geological Society of America, University of Kansas press).

Yin J. & Enay, R. 2004. Tithonian ammonoid biostratigraphy in eastern Himalaya Tibet. *Geobios*, 37: 667-686.

Zakharov, V, Bown, P. & Rawson, P. 1996. The Berriasian Stage and the Jurassic-Cretaceous boundary. *Bulletin de l`Institut Royal des Sciences Naturelle de Belgique, Sciences de la Terre*, Supplement 66: 7-10.

Zeuschner, L. 1846. Nowe lub niedoktadnie opisane gatunki skamieniasci Tatrowych, Warszawa, 32 p.

Zeiss, A. 1968. Untersuchungen zur Paläontologie der Cephalopoden des Unter-Tithon der Südlichen Frankenalb. *Abhandlungen der Bayerischen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche* Klasse N.F. 132, 1–190.

Zeiss, A. 1983. Zur Frage der Äquivalenz der Stufen Tithon/Berrias/Portland in Eurasien und Amerika. Ein Beitrag zur Klärung der weltweiten Korrelation der Jura/Kreide Grenzschichten im marinen Bereich. *Zitteliana*, 10: 427-438.

Zeiss, A. 1984. Comments by A. Zeiss (Erlangen, F.R.G.). - In: Jurassic-Cretaceous Biochronology and Paleogeography of North America (Ed. G.E.G. Westermann). *Geological Association of Canada*, Special Paper 27: 250-253.

Zeiss, A. 1986. Comments on a tentative correlation chart for the most important marine provinces at the Jurassic/Cretaceous boundary. *Acta Geologica Hungarica*, 29: 27-30.

Zeiss, A., Schweigert, G., Scherzinger, A. 1996. Hegovisphinctes n. geneine neue Ammonitengattung aus dem Unter-Tithonium des nördlichen Hegaus und einige Bemerkungen zur Taxonomie der Lithacoceratinae. *Geologische Blatter für NO-Bayern*, 46 (3–4), 127–144.

Zeiss, A. & Leanza, H. 2010. Upper Jurassic (Tithonian) ammonites from the lithographic limestone of the Zapala region, Neuquén Basin, Argentina. *Beringeria*, 41: 25-76.

Ziegler, P., 1990, Geological atlas of Western and Central Europe (2nd edition): Shell Internationale Petroleum Maatschappij B.V, Geological Society of London, *Elsevier*, Amsterdam. 239 p., 56 encl.

Zittel, K. A. Von. 1868. Palaeontologische studien über Grenzschichten der Jura- und Kreide-Formation im gebiete der Karpaten, Alpen und Apenninen. Abh. I. Die Cephalopoden der Strambergen Schichten. *Palaeontologie Mittheilungen*. Bd. II. Stuttgart. S. v-viii, 1-118

Zittel, K. A. Von. 1884. Cephalopoda. Handbuch der Paläontologie, 1 (Abteilung 2, Lieferung 3); R. Oldenburg, München, *Leipzig*: 329-522.

Zittel, K. A. Von. 1895. Grundzüge der Palaeontologie. Oldenbourg. *Munich & Leipzig*. Viii + 971 p.

Declaration

I hereby declare that I have written this thesis myself, telling me no other than by me specifically-designated sources and helps have served.

I further declare that I am in no other place or applied for a review process. Have the dissertation in one form or another already used elsewhere as an examination paper or other Faculty submitted as a Dissertation (Thesis).

Heidelberg, October 2012

Christian Andrés Salazar Soto

Additionally, I hereby declare that I have submitted and published part of this thesis. The references of the articles are:

Salazar, C. & Stinnesbeck, W. (submitted). Redefinition, Stratigraphy and Facies of the Lo Valdés and Catedral Formations (Upper Jurassic – Lower Cretaceous) in Central Chile. *Andean Geology*.

Salazar, C. & Stinnesbeck, W. (accepted). Stratigraphy and Ammonites from the Baños del Flaco Formation (Tithonian-Berriasian?) in Central Chile. *Palaeontology*.

Salazar, C. & Stinnesbeck, W. 2011. Tithonian Ammonoids from Alto Maipo, Central Chile. 22nd International Colloquium on Latin American Earth Sciences. *GAEA heidelbergensis* 18, 191.

Salazar, C. & Stinnesbeck, W. 2011. Facies and Stratigraphy of the Late Jurassic to Early Cretaceous Sediment Sequence of the Andean Basin in Central Chile. 22nd International Colloquium on Latin American Earth Sciences. *GAEA heidelbergensis* 18, 190.