

## AEGEAN AMMONOIDS FROM THE ANISIAN (MIDDLE TRIASSIC) GSSP CANDIDATE SECTION DEȘLI CAIRA (NORTHERN DOBROGEA, ROMANIA)

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**Abstract.** Deșli Caira in northern Dobrogea (Romania) is one of the key localities for the definition of the GSSP of the base of the Anisian stage. Eugen Grădinaru studied the Hallstatt limestone-facies of the Agighiol Limestone in this section for over 30 years, amassing a huge collection of ammonoids, and he also involved several specialists in the study of specific fossil groups. These ammonoids, which are the historical group for Triassic marine chronostratigraphy, have never been described until now. We present here the results of our ongoing study of the Grădinaru collection, including a new bed-by-bed sampling of the section and description of some Aegean taxa. The ammonoids consisting of 959 mostly juvenile specimens are not reelaborated, but are often preserved as hollow phragmocones filled by sediment or by sediment and cement. The ammonoid record of the section is dominated by leiostracan ammonoids, as is usual for the Ammonitico Rosso facies of the Agighiol Limestone. The Olenekian/Anisian Ammonoid Faunal Turnover (O/A AFT), the most significant turnover in the history of Triassic Ammonoidea, occurs within a 1.1 m-thick interval.

We provide descriptions of Aegean ammonoids, i.e., *Stenopopanoceras*, *Paracrochordiceras*, *Ageiceras*, *Leiophyllites*, as well as of *Grădinarites aegeicus* n. gen. n. sp, *Robinsonites simionescui* n. sp. and *Acrochordiceras* sp.

The ammonoid range chart, integrated with magnetostratigraphy and conodont chronostratigraphy, provides a new calibration of the GMPTS, and emphasizes the nearly coincident position of the O/A AFT with the base of magnetochron MT3.

We present the correlation of the Deșli Caira section with the Chios, Kçira and Wantou sections, based on ammonoids and integrated stratigraphy and an overview of ammonoid faunal comparison with the most important O/A successions. Deșli Caira provides the best record of the O/A AFT with rich Aegean ammonoid faunas, allowing for the best calibration of the magnetochrons MT1-MT3. Therefore, we propose the combination of the O/A AFT with the base of MT3 as a powerful solution for the definition of the GSSP of the Anisian.

## INTRODUCTION

The Deșli Caira section in northern Dobrogea (Romania) is one of the key sections for the definition of the Global boundary Stratotype Section and Point (GSSP) of the base of the Anisian stage of the Middle Triassic series (Fig. 1), which is one of the Triassic GSSPs that has yet to be defined. One of the main strong points of this section is in its rich ammonoid record, which spans from the late Olenekian to the Early Anisian.

Deșli Caira has been under study for more than 30 years by one of us (EG), who devoted most of his life collecting ammonoids from the site. EG organized an international field workshop in June 2000 to present the Deșli Caira section, and involved several specialists in the study of this locality, resulting in a preliminary proposal of Deșli Caira as candidate for the GSSP of the Anisian base (Grădinaru et al. 2007). Much paleontologic and stratigraphic data have been published thus far, but the taxonomic description of the ammonoid faunas was delayed by EG, who was always looking for new and better-preserved specimens. A sudden worsening of his health in 2022 necessitated his hospitalization for medical treatment, which prevented him from completing the study of his very rich ammonoid collection.

The huge work carried out by EG would have likely been a loss to science if Spencer Lucas, chairman of the Olenekian/Anisian boundary Working Group (Subcommission on Triassic Stratigraphy) had not intervened in the Spring of 2023 and invited two of us (IL and MB) to resume EG's work and assess the suitability of the ammonoid record of the Deșli Caira section to support a formal proposal for the GSSP of the Anisian.

This contribution, which provides results from the first year of work, funded by the Research Institute of the University of Bucharest (ICUB), was devoted to the evaluation and initial study of the Grădinaru collection, and two field trips to the Deșli Caira section (June and September 2023).

The structure of this paper is threefold. The first part is devoted to the recovery of Grădinaru's data, with a detailed analysis of the available ammonoid collection from Deșli Caira. The accuracy of this part is necessary because the conservation of fossil collections is one of the requirements for the presentation of GSSP proposals (e.g., Remane et al. 1996; Page 2004). In the second part of the paper

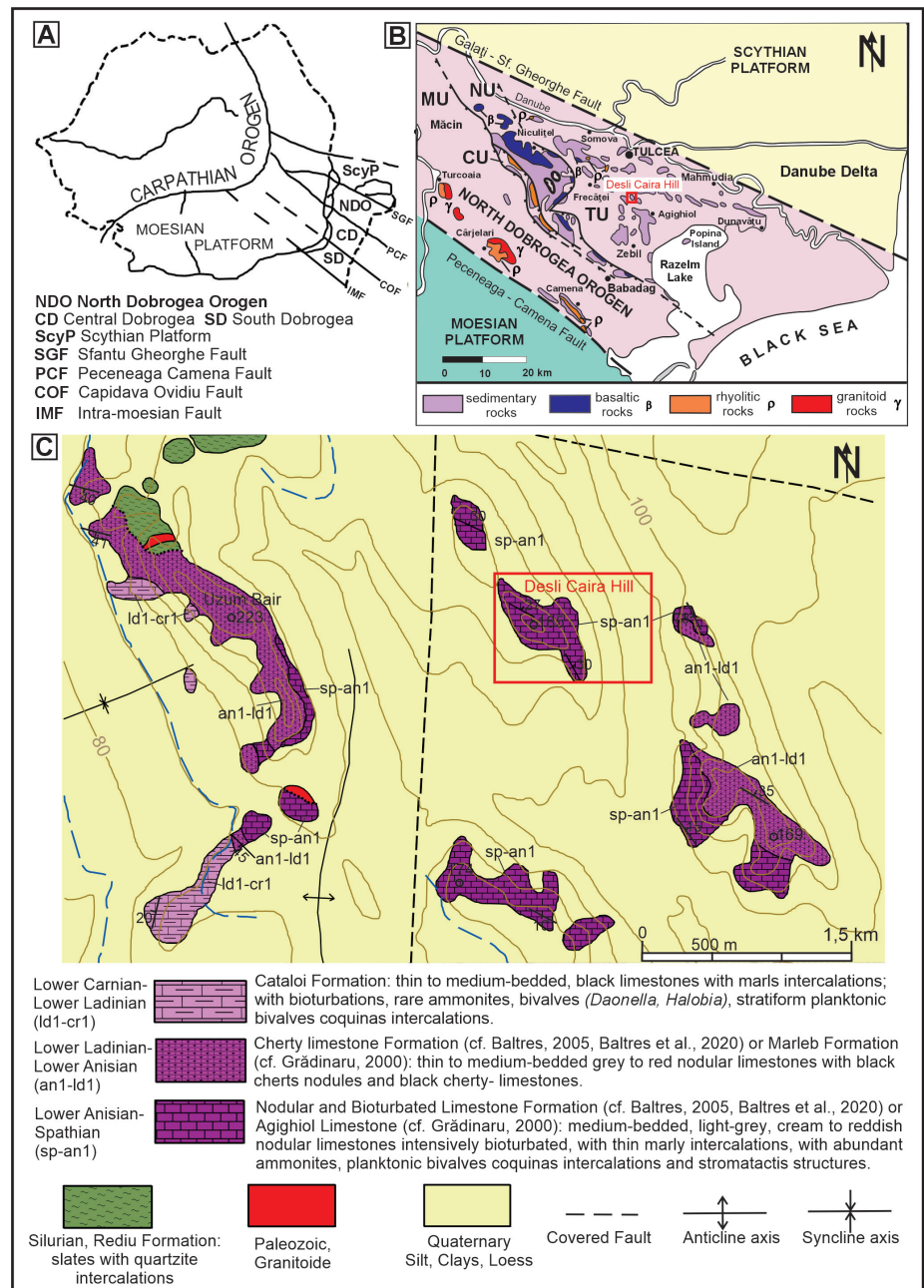
North America Nevada			Western Tethys			type locality
Stage	Substage	Zone	Stage	Substage	Zone	
ANISIAN	Middle	Shoshonensis	ANISIAN	Pelsonian	Zoldianus	Southern Alps (Italy)
		Taylori			Balatonicus	
		Hyatti			Ottonis	
	Lower	Americanum		Bithy- nian	Ismidicus	Gebze (Turkey)
		Caurus	Osmani			
		Mulleri	Aegean	Paracrochord.- Japonites beds	Chios (Greece)	
		Guexi				
		Welteri				
		Haugi				
		Subcolumbites				
Columbites						
OLENEK.	Spathian	OLENEK.	Spathian	Prohungarites- Subcolumbites	Chios (Greece)	

Fig. 1 - Chronostratigraphic subdivisions of the upper Olenekian to Middle Anisian in North America (Nevada) and western Tethys (modified from Jenks et al. 2015). Vertical bar for poorly constrained correlations. The Anisian stage is divided into Lower, Middle and Upper substages in the North American scale, while the Tethyan scale by tradition the subdivision is in four substages: Aegean, Bithynian, Pelsonian and Illyrian. All these substages were defined in pre-Hedberg (1976) and pre-GSSP times (i.e., Pia 1930; Tozer 1967; Assereto 1974). They have always been treated as formal units in Triassic chronostratigraphic scales. In this paper we use the Aegean substage for the Tethyan localities, while for all other areas we use Lower Anisian. Color codes for the stages follow the standard of ICS Chronostratigraphic scale.

we present our data, namely a new high resolution stratigraphic log of the section, systematic descriptions of selected Aegean taxa and a new range chart. In the third and last part of the paper we analyze the ammonoid record of the three most important sections for the GSSP definition and compare them with the Deșli Caira section by using magnetostratigraphy as an independent tool for chronostratigraphic calibration, and conodonts for the intervals lacking age diagnostic ammonoids. We also discuss the options thus far proposed as potential marker events for the GSSP and we compare them to the Olenekian/Anisian Ammonoid Faunal Turnover (O/A AFT), one of the major turnover events in the Triassic history of Ammonoidea.

This paper is a tribute to the work of Eugen Grădinaru, but we feel morally obligated to include him as co-author, even though his health issues prevent him from taking an active part in writing this paper.

Fig. 2 - A) Simplified geotectonic map of Romania with location of the North Dobrogea Orogen (NDO); B) Tectonostratigraphic map of the North Dobrogea Orogen showing the main tectonic units and the distribution of Triassic deposits: MU Măcin Unit, CU Consul Unit, NU Niculițel Unit, TU Tulcea Unit, red box indicates location of the Deșli Caira section (modified from Grădinaru 2005); C) Location of the Deșli Caira section on the geological map of the area (based on Baltres et al. 2020).



## GEOLOGICAL AND STRATIGRAPHIC SETTING

### Geological background

The North Dobrogea Orogen (NDO) crops out in the Dobrogea region of Romania, between the Danube River and the Black Sea (Fig. 2). The orogen is bounded by two major transcrustal faults, i.e., the Sfantu Gheorghe Fault on the north and the Peceneaga - Camena Fault on the south (Săndulescu 1984; Săndulescu & Visarion 2000). These faults separate the orogen from the Scythian Platform to the north and the Moesia Platform to the south. The NDO is a Cimmerian (Early Alpine) fold-and-thrust belt representing the western part

of the Cimmerian fold belt prolonged to the east with Crimea, Great Caucasus and extending to the Asian Cimmerides (Murgoci 1914; Săndulescu 1984; 1994; Sengör 1984; Nikishin et al. 2001; Seghedi 2001). The NDO is built up of high-angle overthrusts (with north-east vergence) represented by adjacent tectonic units, i.e., Măcin and Consul (the uppermost units), Niculițel (the median unit) and Tulcea (the lowermost unit). The Măcin, Consul and Tulcea units are units with the continental basement that contain relics of a Varsican Orogen, and the Niculițel unit is interpreted as a suture zone, considering the extensive development of Middle Triassic basaltic rocks in this unit (Săndulescu 1995;



Visarion et al. 1990). The Triassic deposits from the NDO have the largest development in the Tulcea Unit. The Triassic sedimentary series of the Tulcea unit unconformably overlie the Variscan continental basement and reveal a complicated facies distribution from basin facies in the western part towards carbonate platform facies in the middle and eastern part of the Tulcea unit. The complex facies distribution of different lithostratigraphic units in the territory of the Tulcea unit during the Triassic was influenced by both tectonics and eustasy (Grădinaru 1995; 2000). Moreover, the authors that described these lithostratigraphic units (e.g., Grădinaru 1995; 2000; Baltres 2005; Grădinaru et al. 2007; Baltres et al. 2020) have different opinions regarding the thickness, stratigraphic extension and terminology of these units. However, during the Triassic (early Spathian to Norian) an extensive carbonate platform occupied large areas of the Tulcea unit. Several studies concerning the lithofacies, microfacies and sedimentology of the Triassic deposits were performed by Baltres (1976), Atudorei et al. (1997), Grădinaru (2000), Baltres (2005), Popa et al. (2014), and Baltres et al. (2020).

These studies indicate deposition of the Triassic sequences on a westward deepening carbonate platform with E-W facies zonation, from shallow-water carbonates in the east towards deep water basinal facies to the west.

### Lithostratigraphy and facies

The studied section is located on Deșli Caira Hill, in the central part of the Tulcea Unit, in the Agighiol area (Fig. 2). In this area the Triassic sedimentary succession unconformably overlies the Variscan basement, represented by granitoids (Grădinaru 2000; Seghedi 2001; Baltres et al. 2020). The carbonate succession at Deșli Caira Hill is approximately 60 meters thick and can be followed in two complementary, partially overlapping sections (Fig. 3), i.e., the first 20-25 meters are observed on the southeastern slope of the hill (section A of Grădinaru et al. 2007) and the next 27-30 meters are exposed on the southern slope of the hill (section B, of Grădinaru et al. 2007). Section A consists of lower Spathian “dolomitic cupolas”, represented by pinkish to white dolostones and dolomitized limestones that grade laterally or are interbedded with bio-micritic and oncoidal limestones (Grădinaru 2000; Grădinaru et al. 2007; Baltres

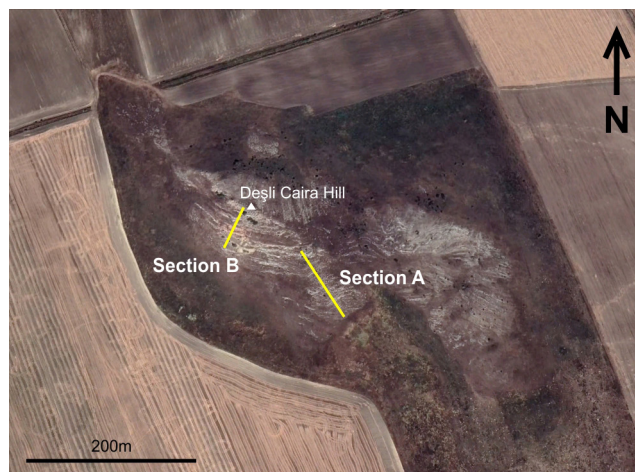


Fig. 3 - Deșli Caira hill, showing positions of the two partly overlapping sections studied in the past 30 years. Section A (Grădinaru et al. 2007) was cited as section 100/500 by Horacek & Grădinaru (2023, fig 2 and text). Section B of Grădinaru et al. (2007) was reported by Horacek & Grădinaru (2023) as section 810, nearby section 820. The top of the hill is marked with a white triangle. Satellite image from Google Earth.

et al. 2020). The dolostones are overlain by Hallstatt-type limestones containing poorly preserved ammonites of middle Spathian age (section A of Grădinaru et al. 2007). The next overlying deposits (section B of Grădinaru et al. 2007), which correspond to the Spathian/Aegean interval, are almost 38 meters thick and composed of thick to medium-bedded, light-grey or cream to reddish nodular limestones (~5 meters thick), which grade upwards into brick-red coloured Hallstatt-type limestones, locally interbedded with bioclastic limestones (“*Posidonia*”-bearing, pale coquinoïd limestones cf. Grădinaru 2000). The Hallstatt-type limestones are intensively bioturbated locally and the first 5 meters of the succession are affected by numerous fractures filled with radiaxial cements. Stromatolite-type structures have been also observed.

From a lithostratigraphic perspective, the carbonate succession from the Deșli Caira section, which corresponds to the stratigraphic interval from the upper Spathian to the lower Carnian, was included by Grădinaru (in Atudorei et al. 1997), Grădinaru (2000) and Grădinaru et al. (2007) as a part (member) of the Agighiol Limestone. Baltres (2005) and Baltres et al. (2020) included the same succession in the Nodular and Bioturbated Limestone Formation (upper Spathian – lower Anisian). However, all authors referring to the Deșli Caira section report that it is composed of



thick pelagic microbial carbonates accumulated on deep submerged plateau or pelagic swells (Atudorei et al. 1997; Forel & Grădinaru 2021). We follow the lithostratigraphic nomenclature of Grădinaru (2000), which is commonly used in the literature (e.g., Grădinaru et al. 2007; Forel & Grădinaru 2021; Horacek & Grădinaru 2023).

### Literature on Deşli Caira

The Deşli Caira fossil locality was discovered in the early 20th century (Kittl 1908; Simionescu 1910, 1911) and later studied in the 1970s by Mirăuță (1974) and Mirăuță & Gheorghian (1978). Then, over 30 years ago Prof. Eugen Grădinaru (University of Bucharest) began an extensive sampling program for ammonoids at the locality, the most important fossils for Triassic high-resolution chronostratigraphy of marine successions. Over the years Grădinaru assembled a large collection of ammonoids that were housed in the Laboratory of Paleontology Collections of the University of Bucharest, and he guided several specialists in the field that were studying different fossil groups as well as the magnetostratigraphy and chemostratigraphy of the section. This collaboration led to the publication of several papers on different fossil groups as follows:

- ammonoids and nautiloids (Grădinaru 2000; Grădinaru & Sobolev 2006; Grădinaru 2022; Balini et al. 2023);
- conodonts and foraminifera (Mirăuță 2000; Grădinaru & Ivanova 2002; Grădinaru et al. 2006; Orchard et al. 2007a; Golding 2021, 2023);
- brachiopods (Grădinaru & Gaetani 2019);
- ostracods (Mirăuță et al. 1993; Crasquin-Soleau & Grădinaru 1996; Sebe et al. 2013; Forel & Grădinaru 2021).

### MATERIAL AND METHODS

The first part of our work was dedicated to the recovery and analysis of available data. First, we assessed the quality of the ammonoid collection made by EG in the Laboratory of Paleontology of the University of Bucharest, and then we examined the available data on the stratigraphic section. Our field work carried out in June and September 2023 proved to be crucial for testing the reliability of the faunal succession restored from the Grădinaru collection, as well as evaluating the potential for further sampling.

**The nomenclatural acts in this article are registered in Zoobank under:** urn:lsid:zoobank.org:pub:75D94F63-6904-40C4-B548-D34880407E0F.

### Grădinaru collection

Over a more than 30 year period, EG collected thousands of ammonoids from the Deşli Caira section. The precise number is hard to establish because only a portion of the ammonoids stored in drawers, boxes and sample bags in Grădinaru's room was labelled with the sample number or bed number. None of them (numbered and unnumbered) were registered in the collection of the Laboratory of Paleontology of the University of Bucharest. Moreover, nearly all of them lack labels reporting the classification of the specimen.

After more than three months of work by IL and AL, 959 specimens with reference to bed/sample number have been found. These include: 1) specimens with bed number, 2) specimens stored in plastic boxes with a lid, with bed number recorded on the lid, and 3) specimens from sample trays with bed number reported on labels. Specimens from sample trays with no reference to the Deşli Caira beds/samples have not been taken into account, even if the trays were stored in drawers reporting bed/sample number of the Deşli Caira section (e.g., GR7). The quality and preservation of these unnumbered specimens sometimes is very good, and some of them even exhibit the suture line.

All ammonoids figured in plate 1 of Grădinaru et al. (2007) have been found; these specimens are extremely important, because they are the only specimens that can be tied to a classification by Grădinaru. Most of these figured ammonoids were found in the disordered sample trays without bed or sample numbers, so this discovery demonstrates that those specimens with numbers by far under-represent the original collection from Deşli Caira.

Ammonoids with reference to bed number (from here onward referred to as ammonoids with number) cover the entire section. We grouped together the specimens with the same bed/sample number, and these groups exhibit a taxonomic composition that is consistent both, within each group and with respect to the stratigraphic position in the section.

### Information on the stratigraphic section

Two sections have been studied at Deşli Caira hill (Grădinaru et al. 2007): section A, in a lower stratigraphic position, and section B, which straddles the Olenekian/Anisian boundary.

Section B is the GSSP candidate section (Grădinaru et al. 2007) that has been sampled bed-by-bed over a period of several decades. This section was reported as equivalent to section 810 by Horacek & Grădinaru (2023). The logs thus far published (e.g., Grădinaru et al. 2007, fig. 3; Horacek & Grădinaru 2023, fig. 4) are synthetic and do not show the true bedding to scale. Instead, they show only the relative position of the samples and the synthetic lithology. Obviously, these simplified logs cannot be used to support a GSSP proposal.

The only log reporting the individual beds thus far published is the specific detail of the Olenekian/Anisian boundary shown in figure 5 by Grădinaru et al. (2007), and in fig. 4 by Orchard et al. (2007a). In this log, however, there are some inconsistencies between the thickness of some beds (e.g., bed 821A), reported in cm, and the thickness of these beds in the drawing. In some papers, Grădinaru illustrated the position of the ammonoids faunas on a geological cross section (e.g., Grădinaru et al. 2007 fig. 2C; Horacek & Grădinaru 2023, fig. 3C), but even in this case, the published geological cross section does not report the bedding to scale.

Very few data are available for section A, which was referred to as section 100/500 by Horacek & Grădinaru (2023, fig. 2). Grădinaru et al. (2007, fig. 7) presents the magnetostratigraphy without a lithologic log and sample numbers. The succession exposed at section A records a change in the magnetic polarity, with the lower part of the section showing normal magnetization while the polarity n

of the upper part is reversed. This change in polarity is Olenekian age, but it has never been biostratigraphically calibrated. Some data/samples from section A (e.g., sample numbers 5xx) were included with data from section B in a composite log and range chart, such as figure 3 of Grădinaru et al. (2007).

Sampling of the Deșli Caira section was carried out by Grădinaru over several decades, and during this long period, different sets of samples were taken. At least seven sets of samples are referred to in the log of Section B, i.e., 20x, 5xx, 6xx, 810-835, 9xxx, GRx, and Gx. However, no explanation concerning location of the samples, year of collection and purpose of sampling has been provided. Apparently, samples 9xxx were taken as conodont samples (e.g., Orchard et al 2007a), but some conodont samples were labelled with other numbers (Orchard et al. 2007a).

Given this complex variety of data, our field work was dedicated to taking new bed-by-bed measurements, re-describing section B, and searching for bed numbers in the field. We also identified the exact places in the field where the few published field photos with bed numbers were taken (e.g., figure 2B of Grădinaru et al. 2007).

### Test sampling

The Deșli Caira beds from which the specimens with bed numbers were supposedly collected were resampled in June and September 2023. Ammonoids collected from these samplings are basically consistent with those from the Grădinaru collection.

## DEȘLI CAIRA SECTION

The slopes of the Deșli Caira Hill are very gentle, but the sedimentary succession is quite well exposed on its southern slope, where the beds dip against the slope (Fig. 3).

Sections A and B are easy to recognize in the field, because several of the bed numbers are still preserved.

### Section A

Section A can be recognized by the numbers 5xx painted in red on the outcrop. Magnetostratigraphic cores are still visible, even though their identifying numbers have been erased by weathering. As reported in the previous chapter, this section was never studied in detail. Field pictures and range charts were never included in the several papers and reports published thus far on Deșli Caira. Data from this segment were included in composite sections, such as figure 3 of Grădinaru et al. (2007).

### Section B

The best exposure of uppermost Olenekian to lower Anisian outcrops is S-SW of the top of Deșli Caira hill, about 150 m west of section A (Fig. 4). The lower part of section B (beds 812 to 820) is well exposed in a small abandoned quarry, and even though the upper part of the section is more grass-covered

than the lower part, its key parts were trenched by Grădinaru during the past years.

The outcrop is wide, and the beds can be followed along strike for some tens of meters. The sedimentary succession is locally slightly displaced by two faults (Fig. 4, 5B). One is not clearly visible and bounds the outcrop to the east (dashed line in Fig. 4), while the second fault (red line in Fig. 4, 5B), with a displacement of about 80 cm, is located in the middle part of the outcrop. This fault was detected by Grădinaru in his early days, as reported in one of his field notebooks from the late 1970s. However, he apparently did not realize that in addition to the displacement of beds 821A to 822A2, the fault also affects the overlying beds, from 825 to 829, and above. As a result, some beds displaced by the fault were numbered in stratigraphic succession, such as 826, which is actually the lateral equivalent of 825, and 830 that is the lateral equivalent of 829 (Fig. 4). The occurrence of this fault was reported only in the magnetostratigraphy by Grădinaru et al. (2007, fig. 7), without any further explanation.

Most of the beds in the section are very well numbered with red paint. All 8xx beds can be easily identified, and the position of some GRx and 20x samples is also painted on the outcrop. The boundary interval 820-822A2 is very well exposed, and has been trenched by Grădinaru at three sites (Fig. 4, 5), i.e., here referred to as the western, central and eastern trenches. Bed 821A, has been exposed by removing debris for more than 20 meters, between the central and eastern trenches and the potential for further sampling of the boundary interval is excellent.

A comparison of outcrop pictures and logs reported in the various publications with the the present numbering of the beds, and the numbering of the ammonoids in the Grădinaru collection, leads to the conclusion that over the years, Grădinaru changed his method of numbering certain key beds across the Olenekian-Anisian boundary. This issue affects only a specific portion of the section, namely the beds between 821 and 822A2 (Fig. 7). Most likely in the early days Grădinaru did not sample all the beds, but rather only the most fossiliferous (e.g., 821 and 822). Then, during further sampling of the boundary interval, he found fossils in the intermediate beds that he labelled with letters. It is now impossible to reconstruct the precise evolution of bed numbering over the years, because Grădinaru in his latest papers was very conservative and always used the same field picture (e.g.,





Fig. 4 - General view, taken by drone, of the Olenekian/Anisian boundary succession exposed at Deşli Caira section B with the position of the uppermost Olenekian ammonoid level (long dashed light blue line) and of the first Anisian ammonoid level (short dashed light blue line). The Olenekian/Anisian AFT is located in-between. The FO of the conodont *Chiosella timeorensis* (from Golding 2021) is marked with a purple star. The boundary beds were trenched by Grădinaru at three sites over the years, here designated as west, central and east trench. White dotted line shows the trace of the section (see Fig. 6 and 10). Fossil-bearing bed numbers are shown in black, with white background. The red line shows the N-S trending normal fault with a displacement of about 80 cm. Dashed red line is for the fault that bounds the studied outcrop to the East. For further explanations see text. Yellow arrow marks a block slid down from higher part of the section that has been removed during field works.

Grădinaru & Gaetani 2019; Forel & Grădinaru 2021; Grădinaru 2022). On the other hand, the year of collection of most of his specimens is unknown; therefore, with the exception of two specimens (see next chapter), it is impossible to refer the ammonoids from level “822” to one of its several subdivisions, i.e., 822A1, 822A2 Lower, 822A2 Middle and 822A2 Upper.

## AMMONOID COLLECTION

The ammonoid collection currently consists of 959 specimens, i.e. (Tab. 1) 833 specimens from the Grădinaru collection with bed numbers and 126

specimens collected by us in 2023. These specimens come from beds of section B, from the lower part (beds 812-813) to the uppermost level of the section (bed 835).

The number of specimens per bed often consists of some tens of specimens (Tab. 1). There is, however, a weak point in the available dataset; the stratigraphic position of the lowermost Anisian ammonoids is unprecise. The 254 ammonoids reported from samples 822 and 822A (about 26% of the whole collection) cannot be precisely traced to their level of collection, because over the years Grădinaru changed his numbering system for these beds (see previous subchapter). Only 11 specimens and 20 fragmentary specimens, all col-





Fig. 5 - Olenekian/Anisian boundary beds at Deșli Caira section B. A) General view of the middle part of the section taken from the eastern trench looking to the West; B) The interval 821A to 824 in the central trench, also shows the 80 cm displacement by the normal fault (see Fig. 4). Bed 821A is the last bed yielding Olenekian ammonoids. The first Aegean ammonoid has been found in the Lower part of bed 822A2. The O/A AFT is in between these two levels.

lected by us in 2023 from beds 822A1 to 822A2 Middle, are precisely located.

### AMMONOID TAPHONOMY

The Ammonitico Rosso facies, which includes the Triassic Hallstatt and Han Bulog limestones, are well known for their abundance of cephalopods and for the variety of their complex taphonomic histories (e.g., Jenkins 1971; Wendt 1973; Neumann & Schumann 1974; Martire et al. 2000). These histories document a slow burial due to low sedimentation rates, but sometimes they represent a complex interplay of dissolution, cementation and infilling processes and even exhumation after bur-

ial, displacement and second burial (reelaboration sensu Fernández López 1991, 1995, 2007, a definition that is more specific than reworking, which has been used for fossils displaced before burial, or exhumed after burial, but without any evidence of fossilization).

A study of the taphonomy of ammonoids from the Agighiol Limestone of Deșli Caira, which undoubtedly comprises Hallstatt-type red limestones, would be of great interest, but it is beyond the scope of the present work. However, in order to properly address taxonomic and chronostratigraphic analyses of Deșli Caira ammonoids, a brief outline of the most significant taphonomic features of the ammonoids from this site is necessary.

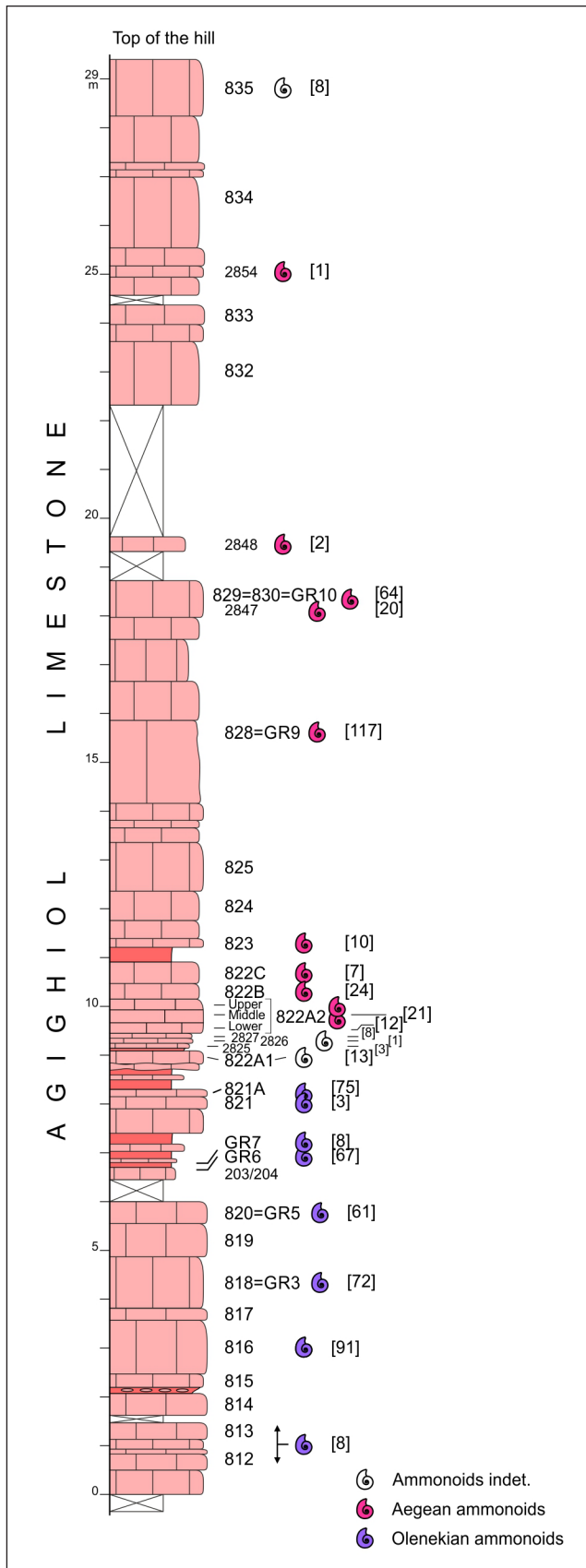


Fig. 6 - Detailed log of Deşli Caira middle-upper part of section B with the stratigraphic position of the most important fossil-bearing beds. The bedding is drawn to scale. Numbers in bracket indicate the number of specimens, but only the specimens with accurate stratigraphic position are shown, Tab. 1 includes all the specimens available.

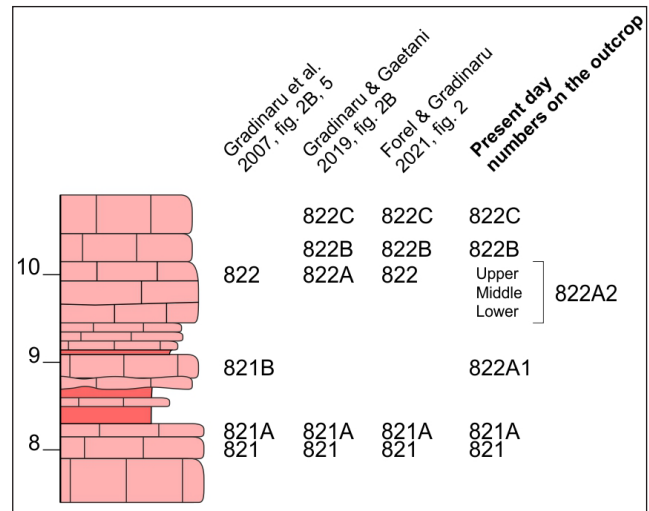


Fig. 7 - Changes in numbering of the key Olenekian/Anisian boundary beds at the Deşli Caira section B over the years. For further explanation see text.

The Deşli Caira ammonoids are not reelaborated sensu Fernández López. They do not exhibit even one of the eight criteria for reelaboration described for ammonoids by Fernández López (1984). They often exhibit geopetal fillings of the phragmocones/shells, but field observations demonstrate that specimens from the same bed all exhibit consistent geopetal filling, which is also consistent with the polarity of the bed, unlike the reelaborated ammonoids from the Hallstatt facies of Epidaurus (Greece) described by Wendt (1973).

Ammonoids are usually preserved with a recrystallized test, but the type of preservation of the phragmocones can vary widely (Fig. 8). Several ammonoids are preserved as infilled hollow phragmocones sensu Seilacher et al. (1976), Maeda & Seilacher (1996) and Fernández López (2000), and not sensu Landmann et al. (2007), Doguzaheva et al. (2014), Hoffmann et al. (2018) and Ryan et al. (2020), who consider hollow phragmocones as those with the original septal architecture preserved without any kind of infilling. This type of preservation, i.e., infilled hollow phragmocones has never been described from the Ammonitico Rosso facies, and it differs from the seilacheran hollow phragmocones in terms of taphonomic history and final preservation.

Hollow phragmocones at Deşli Caira were formed by very early dissolution of septa, but with preservation of the test, followed by complete infilling by sediment of the resulting open space, or by incomplete infilling by sediment and subsequent precipitation of cement.



Level	Specimens
835 (GR11)	8
2854	1
2850	1
2848	2
830 (GR10)	64
2847	20
828 (GR9)	117
206?	17
823	10
822-823	14
822 C (top B)	7
822B	24
822A-B	15
822A (A2?) superior part	83
822A2 Middle	21
822A2 Lower	12
2827	8
2826	1
2825	3
822A1-A2	1
822A1	13
2823	1
822A right fallen part	11
822A	9
822A inf	18
below the level 822 A	15
822-822A	4
822	52
1 meter below level 822	7
821A-821A1	3
821A (top)	3
821A	75
below the level 821 A	5
821	2
821 base (nodular)	1
GR7	8
GR6	67
820A	4
820	13
GR5=820	48
GR3=818	57
818	15
816	91
812-813	8
Total	959

Tab. 1 - Ammonoid collection from Deșli Caira section B.

Seilacher's hollow phragmocones were described from the "Laibstein-Bank" of the bituminous limestones of the Jurassic Posidonia Shale (Seilacher et al. 1976). These ammonoids, which retain the siphuncle (phosphatized), were not filled by sediment/cement, except for a thin internal coating of drusy calcite that also covers the siphuncle (Seilacher et al. 1976, fig. 18A).

Figure 8 shows some examples of deșlicairan hollow phragmocones from Deșli Caira. Dissolution of the septa does not seem to be species specific, but is common in several taxonomic groups. Some specimens are not at all affected by septal dissolution (Fig. 8A), or the hollow phragmocones may differ in the portion of the phragmocone that have been affected by septal dissolution. In several specimens all septa have been dissolved, but quite often the dissolution did not affect the innermost whorls of the phragmocone, which are still chambered (Fig. 8B, 8C). In other specimens, some septa of the last of last but one whorl survived the dissolution, at least in part (Fig. 8C, 8D). Some specimens seem to have experienced a final dissolution event that affects the test (e.g., Fig. 8B).

The available data do not allow us to quantify the frequency of deșlicairan hollow phragmocones in the ammonoid faunas from Deșli Caira. This type of preservation can be easily recognized in the field when the specimens are exposed in cross section (e.g., Fig. 8B) or when they are exposed on top of the beds and weathered (e.g., Fig. 8A, 8C, 8D). It is more difficult to recognize this preservation in 3-dimensional specimens with preserved test from Grădinaru's collection. These specimens are undergoing taxonomic study and cannot be sectioned to verify the type of preservation of the phragmocone. It is worth noting, however, that suture lines are rarely visible on Grădinaru's specimens, even on those that are broken. This fact may be additional evidence for the common occurrence of septal dissolution during the taphonomic history of these specimens.

## AMMONOID TAXONOMY

Specimens from the Grădinaru collection are preserved in 3-dimensions and their size ranges from a few millimeters to 8-10 cm in diameter. Most specimens have been removed from the rock



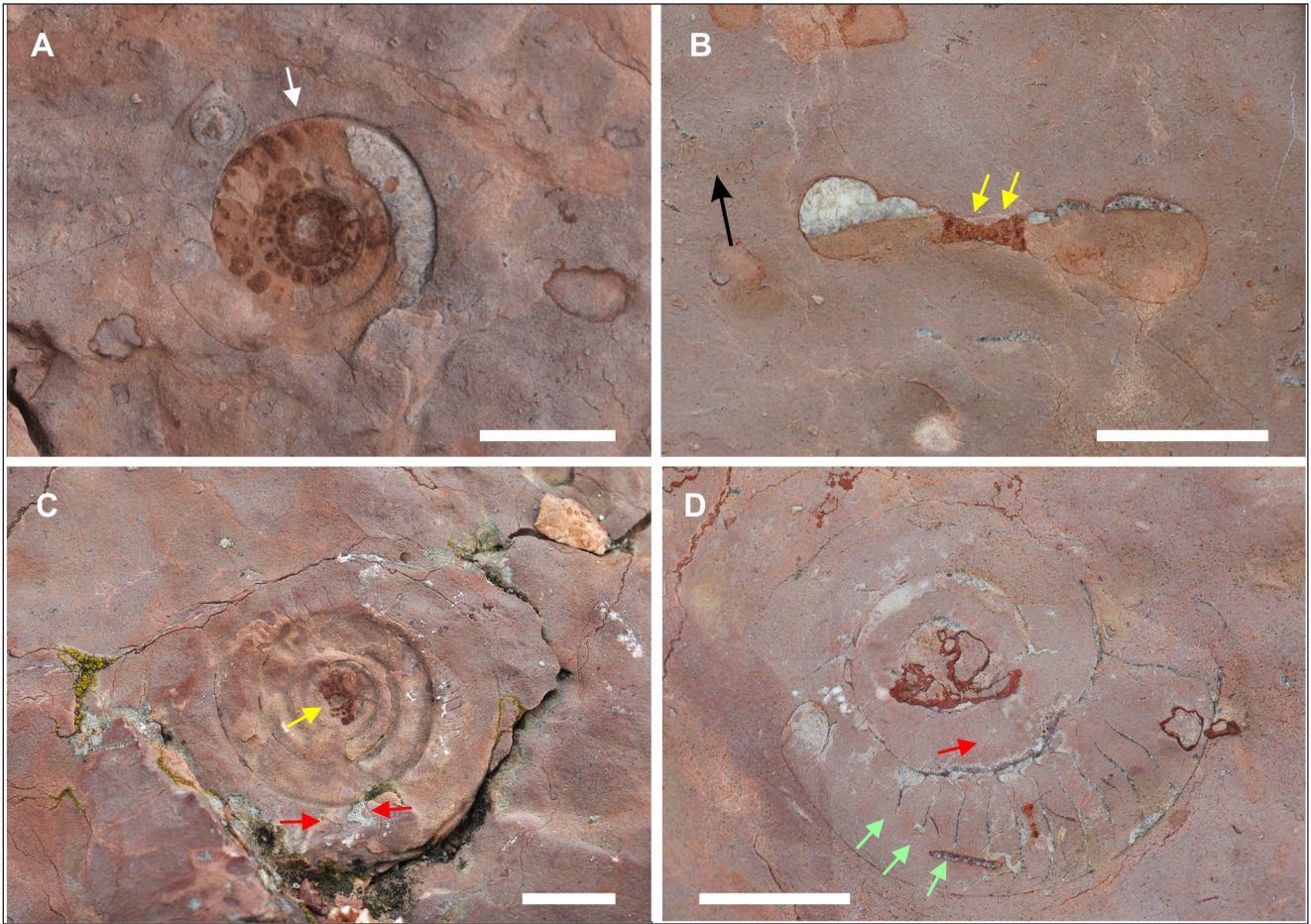


Fig. 8 – Most common taphonomic features of Deşli Caira ammonoids: A: chambered phragmocone; B-D: hollow phragmocones. A) Upper view of a specimen (?*Leiophyllites*) on top of bed 821A: chambers of the phragmocone are preserved and infilled by sediment; body chamber shows geopetal filling with sediment (below) and a thin layer of cement. B) Cross section of *Leiophyllites* from bed 821, whose last three whorls are preserved as hollow phragmocone with geopetal filling, while the innermost whorls are still chambered. The continuous layer of sediment filling the last three whorls suggests that septa were dissolved before the sediment infilling of the shell. C) Upper view of a specimen on the top of bed 821A. The septa of the very inner whorls and of a small part of the phragmocone survived dissolution. D) Upper view of a deeply weathered specimen from the bed 821 showing incomplete dissolution of the septa. In this specimen some septa are preserved while others are half dissolved. Color explanation for the arrows: white arrow is for last septum of the phragmocone; yellow arrow is for chambered portion of the phragmocone not affected by dissolution; red arrow is for septa that survived dissolution; light green arrows indicate partially dissolved septa; black arrow is for the polarity of the bed. Bar scales are 1 cm.

matrix and have been well prepared by Grădinaru. The proportion of juveniles may change from bed to bed, but on average it is high. i.e., sometimes they account for more than 50% of the specimens.

The abundance of juveniles combined with the rare preservation of the suture lines (see previous chapter) makes the classification of ammonoids much more complex than usual, and this probably is the reason Grădinaru delayed for years the publication of taxonomic descriptions of his collection from Deşli Caira. Here, we present a preliminary description of the faunas and the systematic descriptions of some Anisian taxa, i.e., *Stenopopanoceras transiens* Tozer, 1972, *Paracrochordiceras denseplicatum*

Fantini Sestini, 1981, *Aegeiceras ugra* (Diener, 1895), *Leiophyllites pradyumna* (Diener, 1895) and *L. pseudo-pradyumna* (Welter, 1915). We also describe a new genus and species, i.e., *Gradinaruites aegeicus* n. gen. n. sp., from the lower and middle part of the Aegean (see subchapter New taxa), a new species of *Robinsonites* Shevyrev, 1995, *R. simionescui* n. sp., and *Acrochordiceras* sp. ind. from the upper part of the section.

Faunal composition and diversity are more complex than may seem apparent from this work, mainly because several taxa are still under study. For instance, there are at least four taxa within interval 822A1-A2 in addition to those here described.

These include two *Grambergia*-like taxa, represented by small specimens, and an Acrochordiceratidae. Japonitidae occurs in the middle-upper part of the section, but are still under study.

### Faunal composition

Ammonoid faunas of the Agighiol Limestone at Deșli Caira are dominated by long ranging leiostracan genera, as is usual in Hallstatt and Han Bulog red limestones (Balini et al. 2010; Vidakovic et al. 2023). At Deșli Caira the most common leiostracan are *Leiophyllites* and *Ziyunites*, while *Psilosturia*, *Psilocladiscites*, and *Sturia* are slightly less common. Most of these taxa occur in both the Olenekian and Anisian part of the section (see Ammonoid biochronostratigraphy chapter). Acrochordiceratidae and Japonitidae are not very common, at least in the available collection of numbered specimens. *Paracrochordicerias*, for instance is represented by only two specimens.

### Update of previous classifications

Grădinaru usually cited a few ammonoid taxa in every paper, sometimes with very slight correction of classification. The only exception is the significant change of taxonomy of ammonoids from levels G7A=GR7 to 821. Grădinaru (in Grădinaru et al. 2007) identified a few Anisian taxa from these levels, i.e., *Japonites* sp. from level 821, and *Paracrochordicerias* sp. and ? *Karangatites* sp. from level G7A. Fortunately, these taxa were figured in plate 1, which is pivotal for the revision of Grădinaru's taxonomy, given the lack of collection labels accompanying the specimens and published systematic descriptions.

Identification of taxa from G7A and 821 in 2007 was probably one of the most important reasons for placing the Olenekian/Anisian boundary below these beds, namely between the bed 203/204 and G7A (Grădinaru et al. 2007, fig. 2; see Ammonoid biochronostratigraphy chapter). However more recent publications (e.g., Grădinaru & Gaetani 2019 and Forel & Grădinaru 2021) provide different stratigraphic positions for key Anisian taxa, as well as a different position for the suggested Olenekian/Anisian boundary. *Paracrochordicerias* and *Japonites* were reported from beds (822A) slightly higher than G7A, together with other Anisian taxa such as *Aegeiceras* and *Grambergia*, while taxa preported from beds 821 and 821A

are Olenekian. This change is not due to changes in the stratigraphic position of key ammonoids, but instead, is due to changes in their classification.

After our examination of Grădinaru's ammonoids from beds G7A, 821 and 821A, we confirm the occurrence of Olenekian taxa in these beds. Description of the Olenekian faunas will be accomplished in a future paper, but here we present some notes on the classification of specimens figured in 2007.

*Specimen LPB III cph 11902.* Previously attributed to *Japonites* sp. in Grădinaru et al. (2007) (pl. 1, fig. 1), it was probably reassigned to *Eogymnites arthaberi* (Diener, 1915), an Olenekian genus and species, by Grădinaru (in Grădinaru & Gaetani 2019 and Forel & Grădinaru 2021). We confirm this specimen does not belong to *Japonites*. Its coiling is much more evolute and its whorl section is not as high as in typical *Japonites* (e.g., *J. planiplicatus* Mojsisovics, 1888). This specimen lacks ribs, but more importantly, its ammonitic suture line is characterized by a second lateral lobe that is almost as wide as the second lateral saddle, rather than much narrower as in typical *Japonites*, i.e., *J. planiplicatus* (Mojsisovics, 1888) (type), *J. sugriva* (Diener, 1895), and *J. chandra* (Diener, 1895). In this feature specimen LPB III cph 11902 is much closer to *Eogymnites* Spath, 1951, a Spathian genus that exhibits a wide second lateral lobe.

*Specimen LPB III cph 11898.* This small sized specimen (D<20mm) was assigned to *Paracrochordicerias* sp. by Grădinaru (in Grădinaru et al. 2007, pl. 1, fig. 3a-b). It exhibits notably rursiradiate and closely spaced ribs, with deep inter-rib furrows, as well as a marked weakening of the ribs between the shoulder and the venter. These features do not occur in *Paracrochordicerias*. Some early Paracrochordiceratids like *P. americanum* (McLearn, 1946), exhibit weakened ribs in the middle of the venter, but this is not the case with LPB III cph 11898, whose ribs fade at the shoulder, not in the median part of the venter. Therefore, we do not confirm the identification made in 2007. The specimen could be an early juvenile of Danubitidae.

*Specimen LPB III cph 11897.* This specimen was referred with doubt to the genus *Karangatites* by Grădinaru in Grădinaru et al. (2007, pl. 1, fig. 2a-b), a genus that is common in the Lower Anisian of the Arctic paleobioprovince (Dagys et al. 1979; Tozer 1981a; Shevyrev 1986, 1990; Kon-



stantinov 2008). This identification was apparently discarded by Grădinaru, because the genus was not cited in his more recent papers (Grădinaru & Gateani 2019, Forel & Grădinaru 2021; Grădinaru 2022). The specimen is not well preserved, but it exhibits a notably subrectangular whorl section, with the periumbilical margin separating the flanks from the umbilical wall. In *Karangatites* there is no distinct periumbilical margin and its flanks are convex (e.g., Dagys et al. 1996) rather than flat as in the specimen LPB III cph 11897; therefore, we agree with Grădinaru and do not confirm the occurrence of *Karangatites* at Deşli Caira.

### New taxa

We have examined two taxonomic problems in Deşli Caira ammonoid literature. The first is the status of ‘*Romanites*’ cf. *simionescui* Kittl, 1908, which we have solved. The second is the validity of the genus *Deslicairites*, a *nomen nudum* cited in literature since 2003. This problem is complex and requires additional work.

‘*Romanites*’ cf. *simionescui* is cited in nearly all papers and abstracts regarding Deşli Caira from 2003 (Grădinaru 2003) without any description or reference to features. The main problem with this taxon is not only its open nomenclature status, but also in the inconsistency of its chronostratigraphic position with respect to the chronostratigraphic record of *Romanites* Kittl, 1908. This genus is known from the Ladinian to Lower Carnian; thus, its occurrence in an Olenekian/Anisian boundary section would be very unusual.

This twofold taxonomic and chronostratigraphic problem has been solved because one specimen of ‘*Romanites*’ cf. *simionescui* was figured in Grădinaru et al. (2007, pl. 1, fig. 4a-b). This specimen is of large size, with a thick subtrapezoidal whorl section and flat venter, features that are not consistent with *Romanites* Kittl, 1908. *Romanites* is of large size, but with a compressed whorl section, flat and parallel flanks and a rounded venter. More convincing differences exist in the suture line, which fortunately is preserved in the specimen figured by Grădinaru. This specimen exhibits a typical cladiscitid suture, while the suture line of *Romanites* (e.g., Kittl 1908, text-fig. 7) is typical of the family Joannitidae, which is very highly and deeply indented, notably curved between the venter and the umbilical margin, and with the top of the sad-

dles divided into two parts by a median deep indentation. The identification of four specimens in the Grădinaru collection conspecific with the one figured provides support for the description of the new genus *Gradinaruites* (type species *G. aegeicus* n. sp.), for the former ‘*Romanites*’ cf. *simionescui* (for more details see the Systematic descriptions).

*Deslicairites* is a *nomen nudum* first cited by Grădinaru in 2003, from the Olenakian part of Deşli Caira section B. This name was used in all subsequent publications, without a formal definition. He cited no features that were characteristic of the genus, but he did state that *Deslicairites* is an “olenikid-like ammonoid species group” (Grădinaru et al. 2007: 58). He attributed two new species to *Deslicairites*, i.e., *D. simionescui* and *D. kittli*. Two specimens representing each species were figured in Grădinaru et al. (2007, pl. 1), but these species have never been formally described, and thus are considered as *nomina nuda*.

We have examined these figured specimens and concluded that more work is necessary to determine whether they really represent a new genus and two new species. The main problem is their very small size (diameter ~ 10 mm) and their very involute coiling, which makes it difficult to reconstruct its ontogeny and compare it with the ontogeny of similar taxa.

## SYSTEMATIC DESCRIPTIONS

(by Marco Balini and Alexandra Lăcătuş)

Family group taxonomy is basically that given by Tozer (1981a), with the integration of Gamsjäger (1982) for the subdivision of the family Cladiscitidae Zittel, 1884.

**Dimensions.** *Acronyms:* D=diameter (mm), H=whorl height measured along D (mm), U=umbilical diameter in D (mm); W=whorl width in H (mm).

**Repository of the collection.** All specimens collected by Grădinaru and those collected by us are deposited in the Collection of the Laboratory of Palaeontology at the University of Bucharest, cephalopod collection, Department of Geology, Mineralogy and Paleontology, Faculty of Geology and Geophysics, University of Bucharest, 1 N. Bălcescu Bd, 010041 Bucharest, Romania. The registration number is LPB III cph xxxxx.

Our study of the Deşli Caira ammonoids has required their direct comparison with collections from Chios (Greece), type locality of the Aegean substage, and with collections from Gebze (Turkey), type locality of the Bithynian substage. These collections, studied by Fantini Sestini (1981, 1988) and Fantini Sestini in Gae-



tani et al. (1992), are housed in the Museo di Paleontologia, Dipartimento di Scienze della Terra "Ardito Desio", Università degli Studi di Milano, Via Mangiagalli 34, 20133 Milano, Italy. The acronym for the registration number of these specimens is MPUM. The registration reported here updates that cited in paper (Gc 1xxx), which refers to an old inventory.

### Order **Ceratitida** Hyatt, 1884

Superfamily Megaphyllitoidea Mojisovics, 1896

Family Popanoceratidae Tozer, 1971

Genus *Stenopopanoceras* Popov, 1961

Type species: *Stenopopanoceras mirabilis* Popov, 1961

### *Stenopopanoceras transiens* Tozer, 1972

Pl. 1, fig. 1a-b, 2, 3a-e

1972 *Stenopopanoceras transiens* Tozer, p. 36, pl. 10, fig. 4a-b, 5a-c; text-fig. 4D

1995 *Stenopopanoceras transiens* – Shevyrev, p. 55, pl. 6, fig. 5, 6; text-fig. 27a-b

non 2011 *Stenopopanoceras transiens* – Vaziri, pl. 4, fig. 5a-b

**Material:** Eleven specimens. One specimen, LPB III cph 12468, from 822A2 Lower. One specimen, LPB III cph 12295, from level 822A2 Middle. Nine specimens from 822A2 Upper: LPB III cph 11993; LPB III cph 12309; LPB III cph 12328; LPB III cph 12325; LPB III cph 12344; LPB III cph 12327; LPB III cph 12310; LPB III cph 11990; LPB III cph 11994. Specimen LPB III cph 12468 is from our 2023 sampling, all other specimens are from the Grădinaru collection.

**Description.** The 11 specimens are of very similar size, ranging from 21.9 to about 28 mm of D (Tab. 2).

The coiling is involute and concentric, with a distinct umbilical egggression taking place at about 24-26 mm of D (LPB III cph 12295). The U/D increases with the size, from 0.23 (D about 22 mm) to 0.27-0.29 (D about 26.9-27.5) to about 0.32 in the largest specimen available (D about 28 mm).

The whorl section of the very inner whorls (D about 10 mm), visible on the broken part of LPB III cph 12309 (Pl. 1, fig. 3d-e), is rounded and the shell is globose, probably depressed. During

ontogeny the whorl section become semioval compressed, but with some variability from specimen to specimen. In the specimen LPB III cph 12325 the H/W is about 0.8 at about H of 7.5, while at about H of 10.6 H/W is about 1.2. The larger specimens available exhibits H/W slightly higher than 1.2.

The venter is usually rounded, but in the largest specimen LPB III cph 12295 (Pl. 1, fig. 1b) the venter becomes subacute starting from about 9 mm of H. The flanks directly overlap the last but one whorl without any umbilical wall and shoulder.

The specimens are smooth, except for LPB III cph 12468 (Pl. 1, fig. 2), which exhibits very weak, wavy-like ribbing on the outer part of the flank.

None of the specimens exhibit the suture line.

### **Dimensions:** (see Tab. 2)

**Discussion.** Assignment of the specimens to *Stenopopanoceras* Popov, 1961 is based on their concentric coiling with umbilical egggression, depressed inner whorls becoming compressed during ontogeny, and the ventral side, which is rounded on the inner whorls, but subacute on larger specimens.

At the species level, the specimens are referred to *S. transiens* Tozer, 1972, because they exhibit two of the typical features of this species. Its coiling is more involute in this species than in other species of *Stenopopanoceras*, and the ventral side is not as acute as in other species of the genus, especially on the inner whorls. Specimens from Deşli Caira are slightly smaller than the type specimens from Iran (diameter between 21.9 and about 28 mm vs. between 31 and 38 mm for the type specimens), but in regard to the subacute venter, the larger specimen (LPB III cph 12295) exhibits the transition from a rounded to subacute venter (Pl. 1, fig. 1b) and is consistent with the description of the type specimens given by Tozer (1972).

Specimen	D	U	H	W	U/H	U/D	H/D	h	H/W	SGR
LPB III cph 12468		6.65	9.4		0.7					
LPB III cph 12295	27.95	9.1	10.3	8.3	0.88	0.32	0.36	8.55	1.24	20.46
LPB III cph 11993	27.45	8.1	11.55	9.45	0.70	0.29	0.42	7.8	1.22	48.07
LPB III cph 12309	23.1	5.7	9.65	8.5	0.59	0.24	0.41	7.75	1.13	24.51
LPB III cph 12325	24.95	6.8	10.65	8.9	0.63	0.27	0.42	7.5	1.19	42
same specimen			7.5	9.45					0.79	
LPB III cph 12310	21.9	5.05	9.2	8.2	0.54	0.23	0.42	7.65	1.12	20.26
LPB III cph 11990	26.9	7.35	10.3		0.71	0.27	0.38	9.25		11.35
LPB III cph 11994	26.3	8.45	9.35		0.93	0.32	0.35	8.5		10
Holotype	31	8.99	12.09		0.74	0.29	0.39	9.92		21.87
Paratype	38	12.54	14.82		0.84	0.33	0.39	10.64		39.28

Tab. 2 - Measurements of *Stenopopanoceras transiens* Tozer, 1972 from Deşli Caira and of the type specimens from Iran (from Tozer 1972).

Specimens from Deşli Caira are generally smooth, but one (Pl. 1, fig. 2) exhibits weak wavy ribs. Ribbing is not usually reported in text descriptions of species of *Stenopopanoceras* (e.g., Tozer 1994), but the genus cannot be considered as smooth. Growth striae resembling closely spaced weak ribs are typical of *S. falcatum* Tozer, 1994 (Lower Anisian of North America, Mulleri Zone). Weak ribs are occasionally visible on figured specimens, although their occurrence is not mentioned in text descriptions. This is the case for instance of the paratype of *S. transiens* illustrated by Tozer (1972, pl. 10, fig. 4).

**Remarks on synonymy.** The specimen from the type locality of Nakhlak (central Iran) classified as *S. transiens* by Vaziri (2011, pl. 4, fig. 5a-b) does not belong to *Stenopopanoceras*, because of the closed umbilicus and the thick whorl section with a wide rounded venter. None of the large set of ammonoids figured by Vaziri can be referred to *Stenopopanoceras*.

**Occurrence and age.** *Stenopopanoceras* is Lower–Middle Anisian in age, and is known to occur in the Arctic (e.g., Popov 1961; Dagys & Ermakova 1981; Dagys et al. 1996), western North America (Bucher 1989; Tozer 1994; Bucher 2002); New Zealand and the Tethys (Tozer 1971, 1972; Shevyrev 1995).

The only species of *Stenopopanoceras* thus far recognized in the Tethys Realm is *S. transiens*, first described from Nakhlak, Central Iran, by Tozer (1972). At the type locality this species is documented in the *Ussurites* beds (samples 118–119) in association with *Procladiscites* sp. ind. and *Ussurites arthaberi*, which Tozer assigned to the upper part of the Lower Anisian and very lowermost part of the Middle Anisian (1972: tab. 1). This fauna has not been identified in more recent investigations from Nakhlak (Balini et al. 2009; Vaziri 2011: see Remarks on synonymy).

A more precise position for this species was reported by Shevyrev (1995) from Mount Yatyrgvarta (Caucasus), where *S. transiens* typically occurs in the *Stenopopanoceras* beds, representing the lowermost part of the Anisian, Ugra Zone (Shevyrev 1995: fig. 2).

Superfamily Ceratitoidea Mojsisovics, 1879

Incertae familiae

Genus *Robinsonites* Shevyrev, 1995

Type species: *Robinsonites caucasicus* Shevyrev, 1995

**Preliminary remarks.** The family assignment of *Robinsonites* Shevyrev, 1995 is uncertain, mostly because of the limited knowledge of Early Anisian Ceratitoidea and their phylogenetic relationships with latest Olenekian families. Shevyrev included his new genus within the family Balatonitidae, without any discussion. He described the venter of the genus as flat, with a median keel; however, from pl. 12, fig. 6 and 7b, the venter appears carinate–slightly bisulcate (fig. 7b: holotype), to tricarinate bisulcate (fig. 6: paratype). This type of venter does not occur in the Balatonitidae, and moreover, Balatonitidae have never been reported from the Lower Anisian.

The Early Anisian genera *Pseudokeyserlingites* Bucher, 1989 (Family Siberitidae Mojsisovics, 1896, subfamily Keyserlingitinae Zakharov, 1970) and *Silberlingites* Bucher 1989 (subfamily Silberlingitinae Bucher, 1989), exhibit a carinate venter similar to that of *Robinsonites*, but their inner whorls are evolute and distinctly coronate.

### *Robinsonites simionescui* n. sp.

Pl. 1, fig. 4a–d, 5a–d

**Derivatio nominis:** The new species is dedicated to Ion Th. Simionescu (1873–1944), master of geology and paleontology of Romania (Brânzila 2023), who was the first paleontologist to study the Deşli Caira locality (Simionescu 1910), shortly after its discovery by Kittl (1908).

**Material:** Two specimens from the Grădinaru collection, LPB III cph 12060 (holotype) and LPB III cph 12483 (paratype).

**Stratum typicum:** The type specimens were collected by Grădinaru and stored in a box with number “822”. The stratum typicum could be bed 822A2.

**Diagnosis:** *Robinsonites* with involute coiling, carinate bisulcate venter, three rows of nodes, with lateral nodes close to the shoulder, at 2/3 of flank height.

**Description.** The two specimens are of very small size: the diameter of the larger specimen (LPB III cph 12060: Pl. 1, fig. 4a–d) is about 14.5 mm, while the smaller specimen (LPB III cph 12483: Pl. 1, fig. 5a–d) is about 8.3 mm. The coiling is involute (U between 28 and 32% of D) and the whorl section is compressed. The venter is distinctly keeled in both specimens, the keel is higher than the shoulders and is bordered by two deep furrows.

The ornamentation consists of ribs and three rows of nodes. Nodes are located at the umbilical margin, at 2/3 or more of the flank height, and at the shoulder, in ventrolateral position. The umbilical nodes, about 5–6 per half whorl, are strong and sub-

spiny on the holotype, while they are weaker on the paratype. The lateral nodes are rounded, and more sculptured on the paratype than on the holotype.

The ribs are rectiradiate, nearly straight until the lateral nodes, then they slightly bend forward. The holotype is more densely ribbed than the paratype, with 17 ribs counted at the shoulder in 180° (Pl. 1, fig. 4d), while in the paratype they are 12-13 (Pl. 1, fig. 5d). In both specimens the primary ribs start at the umbilical node, sometimes with a subdivision, and the intercalatory ribs start low on the flank. On the holotype, some ribs bifurcate at 2/3 of the flank height. Lateral nodes are located on the primary ribs, more rarely on intercalatory ribs. All ribs bear ventrolateral nodes, but they do not end there. They continue on the shoulder, but stop at the furrow.

#### Dimensions:

Specimen	D	H	U	U/D	U/H
LPB III cph 12060 Holotype	14.5	6.18	4.06	0.28	0.65
LPB III cph 12483 paratype	8.34	3.68	2.52	0.32	0.68

**Discussion.** The genus *Robinsonites* Shevyrev, 1995 is of small size, as documented by the 28 mm size of the holotype of the type species *R. caucasiensis* Shevyrev, 1995 (Shevyrev 1995: 89). The two specimens under study are of smaller size; however, despite their juvenile age, they exhibit enough features to be separated from the only species of *Robinsonites* thus far described. *Robinsonites simionescui* n. sp. differs from *R. caucasiensis* Shevyrev, 1995 by its more involute coiling ( $U=26-28\%$  of  $D$ , instead of  $42\%$ ) and in the position of the lateral nodes, which in *R. caucasiensis* are at  $1/2$  of flank height, while in *R. simionescui* they are at  $2/3$  of flank height. If the difference in the involuteness of the coiling may be slightly influenced by the different size of the specimens, the position of the lateral nodes is not, because the position of these nodes on the holotype of *R. caucasiensis* does not change from the inner to outer whorl (Shevyrev 1995: pl. 12, fig. 7a).

**Occurrence and age.** The genus *Robinsonites* Shevyrev, 1995 was described from the *Laboceras-Megaphyllites* beds in the northwestern Caucasus, which were assigned to the Osmani Zone. These beds were recognized from two localities in the area of the rivers Thach and Acheshbok, and the two faunal lists, dominated by leiostracan ammonoids, include both Bithynian ammonoids, and Aegean taxa (e.g., *Aegeiceras*). More recently the genus *Robinsonites* was

cited by Grădinaru & Gaetani (2019: 96) from Orta Bair (Dobrogea), from an assemblage attributed to the Bithynian, which includes *Acrochordiceras*, *Hollandites*, *Pseudodanubites*, *Ussurites* and *Gymnites*. At Deșli Caira, *Robinsonites simionescui* n. sp. occurs in bed 822 (Grădinaru sampling), together with *Stenopopanoceras transiens*, *Paracrochordiceras denseplicatum*, and *Aegeiceras ugra*, in the lowermost part of the Aegean.

Family Acrochordiceratidae Arthaber, 1911

Genus *Paracrochordiceras* Spath, 1934

Type species: *Acrochordiceras anodosum* Welter, 1915

#### *Paracrochordiceras denseplicatum* Fantini Sestini, 1981

Pl. 1, fig. 6a-b, 7a-b

1970 *Acrochordiceras* ex aff. *anodosum* – Bender, p. 439, pl. 2, fig. 9.

1974 ?*Paracrochordiceras* n. sp. C Assereto, p. 28.

v 1981 *Paracrochordiceras denseplicatum* n. sp. Fantini Sestini, p. 49, pl. 4, fig. 2-3.

v 1992 *Paracrochordiceras denseplicatum* – Gaetani et al., p. 186.

? 2022 *Paracrochordiceras* cf. *denseplicatum* – Ehiro, p. 51, fig. 6.1-6.3.

? 2022 *Paracrochordiceras* sp. B Ehiro, p. 53, fig. 6.9-6.11.

**Material:** Two specimens, LPB III cph 12066 and 12068, from interval 822-822A.

#### PLATE 1

Aegean Ceratitoidea and Gymnitidae from Deșli Caira section in northern Dobrogea (Romania).

Fig. 1 – *Stenopopanoceras transiens* Tozer, 1972, specimen LPB III cph 12295, from level 822A2 Middle: a) lateral view; b) ventral view.

Fig. 2 – *Stenopopanoceras transiens* Tozer, 1972, specimen LPB III cph 12468, from level 822A2 Lower, lateral view.

Fig. 3 – *Stenopopanoceras transiens* Tozer, 1972, specimen LPB III cph 12309, from level 822A2 Upper: a) lateral view; b) ventral view; c) apertural view; d) lateral view after removing part of the outer whorl; e) ventral view of the inner whorl.

Fig. 4 – *Robinsonites simionescui* n. sp., holotype LPB III cph 12060, from a box labelled “822”, probably equivalent to bed 822A2: a) lateral view; b) ventral view; c) enlarged lateral view (x2); d) enlarged ventral view (x2).

Fig. 5 – *Robinsonites simionescui* n. sp., paratype LPB III cph 12483, from a box labelled “822”, probably equivalent to bed 822A2: a) lateral view; b) ventral view; c) enlarged lateral view (x2); d) enlarged ventral view (x2).

Fig. 6 – *Paracrochordiceras denseplicatum* Fantini Sestini, 1981, specimen LPB III cph 12066 from interval 822-822A: a) lateral view; b) ventral view.

Fig. 7 – *Paracrochordiceras denseplicatum* Fantini Sestini, 1981, specimen LPB III cph from interval 822-822A: a) lateral view; b) ventral view.

Fig. 8 – *Aegeiceras ugra* (Diener, 1895), specimen LPB III cph 12475 from bed 822C, a) lateral view.

Fig. 9 – *Acrochordiceras* sp. ind., specimen LPB III cph 12426 from bed 2854, a) lateral view.

Bar scale is 10 mm. Long bar is for Fig. 4c-d and Fig. 5c. Short bar is for all the other figures.



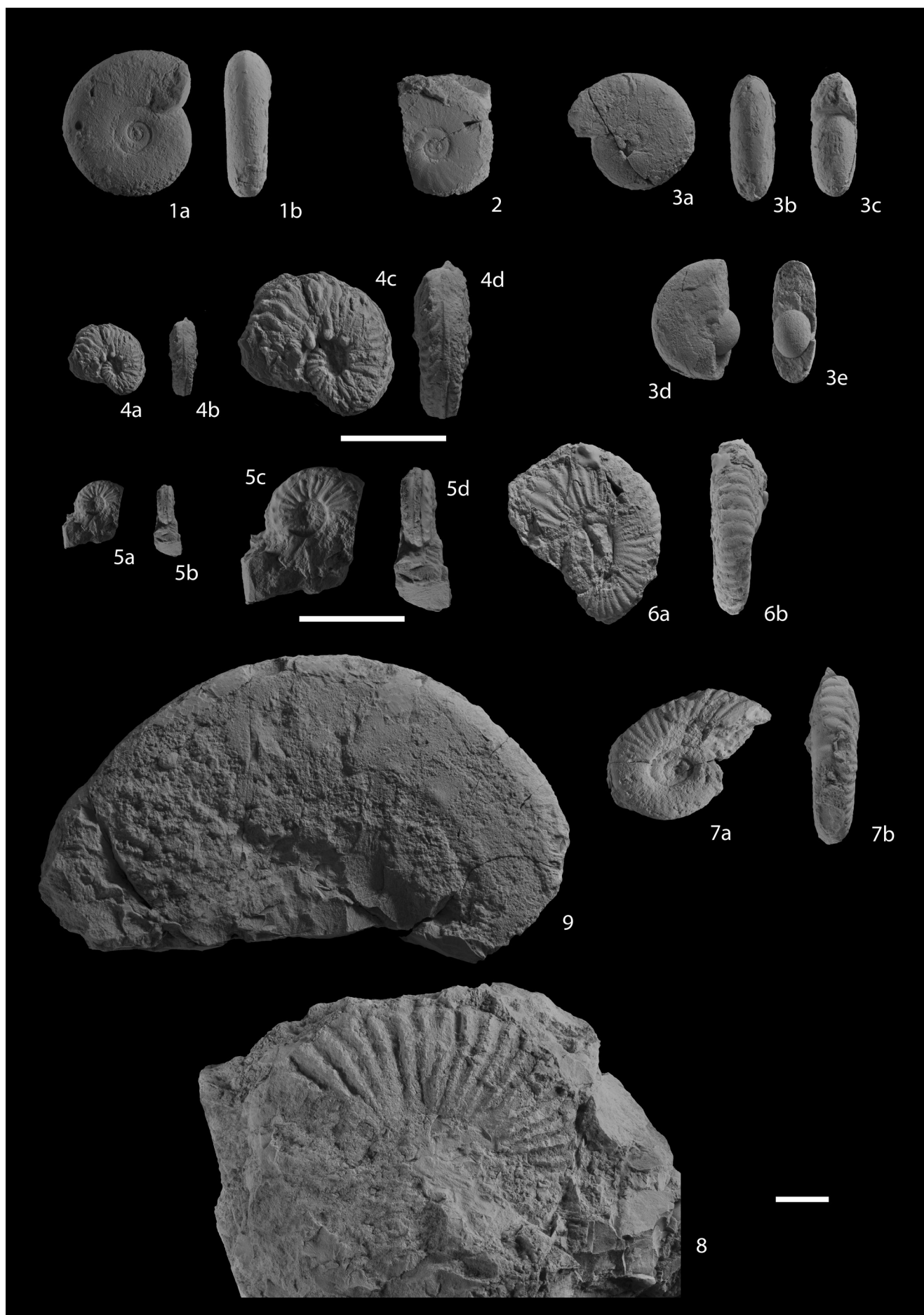


PLATE 1

**Description.** The two specimens are of similar size but their coiling is deformed and elliptical. Both ultimate whorls show a noteworthy increasing of the whorl height. The deformation prevents accurate measurements, but in both specimens, whorl height doubles in the last half whorl.

Ribbing is dense, in specimen LPB III cph 12066 there are about 20-22 ribs in the last half whorl, while they are about 19 in specimen LPB III cph 12068. Ribs are primary, but sometimes they divide at the umbilical margin. All ribs cross the venter (Pl. 1, fig.6b, 7b).

The suture line is not exposed.

**Discussion.** Specimens from Deșli Caira have been directly compared with the type specimens of *Paracrochordiceras denseplicatum* Fantini Sestini, 1981 from Chios. The type specimens exhibit a wide variability in rib density, sculpture and the position of the branching point of some ribs, a feature not described by Fantini Sestini. In most of the types the ribs are primary or branching near the umbilicus, but in two of the type specimens the branching is on the outer part of the flank, near the shoulder. Holotype MPUM 4065 exhibits relatively strong ribbing, but ribbing is weaker on the other variants. The two specimens from Deșli Caira are much closer to the relatively weak but more densely ribbed variants than to the holotype.

We examined three unfigured specimens assigned to *P. denseplicatum* by Fantini Sestini in Gaetani et al. (1992). One of these is attributed to a weakly and densely ribbed variant of *P. denseplicatum*.

The specimens recently described by Ehiro (2022) from Japan, and assigned to *P. cf. denseplicatum* and *P. sp. B*, are similar to *P. denseplicatum* Fantini Sestini, 1981. The two taxa described by Ehiro differ in some features such as coiling and rib density. *Paracrochordiceras* sp. B is more involute and more densely ribbed (fig. 6.9: 24 ribs per half whorl; fig. 6-10a: 21) than *P. cf. denseplicatum*, which exhibits 19 to 20 ribs per half whorl (e.g., fig. 6.1), and with some branching of ribs near the venter (e.g., fig. 6.2). However, taking into account the variability displayed by the type series of *P. denseplicatum*, both taxa could be included within the variability of the species. The suture line of *P. sp. B* (fig. 6.10b) is simpler than that of *P. cf. denseplicatum* (fig. 6.1b), but no comparison is possible with the type specimens because they do not show the suture line.

**Occurrence and age.** *Paracrochordiceras denseplicatum* is known from Chios where it has been reported from samples T329 (Fantini Sestini 1981) and T330 (Gaetani et al. 1992). These samples document the *Paracrochordiceras-Japonites* beds of Assereto (1974) of the Aegean.

Genus *Acrochordiceras* Hyatt, 1877

Type species *Acrochordiceras hyatti* Meek, 1877

### *Acrochordiceras* sp. ind.

Pl. 1, fig. 8

**Material:** One specimen, LPB III cph 12426, from sample 2854. Specimen was collected by us in 2023.

**Description.** Specimen, with estimated diameter of at least 70 mm, is preserved as slightly less than half whorl, and is in part included in hard rock matrix. Only one side is exposed.

The coiling does not seem to be very involute. The ribbing is the one peculiar of the genus, with ribs widening towards the venter (plicate sensu Monnet et al. 2010). Ribs are primary, or divided at very low position on the flank, and about 11 ribs can be counted in 90° of whorl. The incomplete specimen does not show any nodes, neither in the umbilical position nor in a lateral position.

The suture line is not exposed.

**Discussion.** Specimen is attributed to *Acrochordiceras* Hyatt, 1877, because of its large size and wavy-type ribs that widen towards the venter. This genus is the only one within the family Acrochordiceratidae attaining such a large size (Monnet et al. 2013).

A species assignment is at present difficult, because the specimen is only partially exposed on one side and the details of its whorl section, inner whorls and suture line cannot be seen. These features, together with the coiling and compression of the whorl section, are regarded as crucial for species attribution by Monnet et al. (2010), who provided a comprehensive revision of the genus *Acrochordiceras* based on large bed-by-bed collections from Nevada.

Monnet et al. (2010) reduced the number of species of *Acrochordiceras* to four, all characterized by wide variability comprised between two extreme variants, i.e., one with thick whorls and strongly ornamented with nodes, and the other characterized by more compressed whorls, densely ribbed and without umbilical and lateral nodes. In this gener-



al framework, the specimen from Deşli Caira can be regarded as belonging to the compressed and densely ribbed variants of the genus *Acrochordiceras*.

The earliest *Acrochordiceras* from Nevada is *A. hatschekii* (Diener, 1907), reported by Monnet et al. (2010, 2012) from the lowermost part of the Hyatti Zone, the first zone of the Middle Anisian of Nevada. The specimen from Deşli Caira more closely resembles the compressed variety of this species, which is overall less involute than the other three species of the genus.

The suture line of *A. hatschekii* is ceratitic, similar to the suture of *A. hyatti* Meek, 1877, the species typical of the upper part of the Hyatti Zone (Monnet et al. 2010; 2012), while the suture lines of the younger *Acrochordiceras* (*A. carolinae* Mojsisovics, 1882 and *A. damesii* Noetling, 1880) are ammonitic. Because the suture line of the Deşli Caira specimen is not visible, no comparison is possible.

Comparison of the Deşli Caira specimen to the Tethyan record of *Acrochordiceras* is also not conclusive for two main reasons. First, *Acrochordiceras* taxa from the Tethys Realm have never been studied by a population approach, and the only reference is the study of Monnet et al. (2010), which is based on a population analysis of the Nevada collections. Second, in the few sections sampled bed-by-bed, *Acrochordiceras* taxa first occur in the middle part of the Bithynian stage, not from the base (e.g., Gebze: Fantini Sestini 1988; Spiti: Krystyn et al. 2004). This difference implies a time gap in the record of the family between Deşli Caira, and Gebze and Spiti.

**Occurrence and age.** *Acrochordiceras* is an iconic genus in Anisian ammonoid literature, and can be found in many localities, from both condensed and uncondensed successions. In condensed facies (e.g., Schreyer Alm red limestones: Mojsisovics 1882; Han Bulog limestone: Hauer 1892) *Acrochordiceras* apparently occurs together with Late Anisian genera, but its record in uncondensed successions thus far is documented only in the Middle Anisian (e.g., Tozer 1981a; Bucher 1988, 1992; Monnet et al. 2010, 2013). In Nevada the genus first appears in the lowermost part of the Middle Anisian (base of Hyatti Zone). In the Bithynian type section, its FO is in the Ismidicus Zone (Assereto 1974; Fantini Sestini 1988) in the upper part of the Bithynian, but in Spiti (Tethys Himalaya) its FO is just below the base of the Hollandites Zone, around the middle part of the Bithynian (Krystyn et al. 2004, fig. 8). In

Hungary (westernmost Tethys) *Acrochordiceras* has recently been reported from the late Bithynian (Vörös et al. 2022).

At Deşli Caira the present specimen was collected from the uppermost part of the section, where the ammonoid record is not very good. The co-occurrence of the conodont *Chiosella timorensis*, whose LO is at the top of the section (Orchard et al. 2007a; Golding 2021) confirms the age assignment of this *Acrochordiceras* to the Aegean. This occurrence pre-dates the FO of the genus in Nevada as well as Tethyan sites.

Family Gymnitidae Waagen, 1895

Genus *Aegeiceras* Fantini Sestini, 1981

Type species: *Gymnites ugra* Diener, 1895

*Aegeiceras ugra* (Diener, 1895)

Pl. 1, fig. 9; Pl. 2, fig. 1-5, 6a-b

- 1895 *Gymnites ugra* Diener, p. 112, pl. 30, fig. 15.
- not 1907 *Japonites* cf. *ugra* - Diener, p. 88, pl. 6, fig. 1.
- 1915 *Japonites ugra* - Welter, p. 126, pl. 93, fig. 1; text-fig. 26, 27.
- ? 1968 *Japonites ugra* - Shevyrev, p. 220, pl. 19, fig. 1.
- 1970 *Japonites ugra* - Bender, p. 444, pl. 3, fig. 5, G; pl. 4, fig. 2; text-fig. 13-17.
- 1970 *Gymnites* cf. *vasantena* - Bender, p. 443, pl. 3, fig. 4; text-fig. 12.
- 1974 *Japonites ugra* - Assereto, p. 28.
- v 1981 *Aegeiceras ugra* - Fantini Sestini, p. 57, pl. 5, fig. 2.
- v 1992 *Aegeiceras ugra* - Gaetani et al., pl. 16 fig. 1.
- ? 1995 *Aegeiceras bizovae* Shevyrev, p. 107, pl. 18, fig. 1; text-fig. 61.

**Material:** Ten specimens from four levels. One specimen, LPB III cph 12481, labelled “822” is from a box “below 822A”. One specimen, LPB III cph 12475, from 822C. Seven specimens are from bed GR9=828: LPB III cph 11914, LPB III cph 11910, LPB III cph 11911, LPB III cph 11912, LPB III cph 11913, LPB III cph 11939, LPB III cph 11940. One specimen, LPB III cph 11967, from GR10=829=830.

**Description.** The available specimens range in size from about 23 (LPB III cph 11912 and 11940) to about 80 mm of D (LPB III cph 11914, not measured: pl. 2 fig. 6). The shell is platicone, with slightly evolute coiling and a slow growing spiral. The U/H ratio is usually greater than 1.15, while it is about 1 in specimen LPB III cph 11967. The variation of the U/D ratio is between 37 to 44% of D.

The whorl section is highly compressed, with a H/W ratio greater than 1.8. Flanks are nearly flat, and just slightly convex with a maximum width at about 50% of H. The umbilical wall is low, subvertical and distinct from the flanks at the periumbilical margin.

The *clavi*, typical of the genus, are located at middle position on the flank. In specimen LPB III cph 11914 there are at least 9 *clavi* in 90° of whorl. In the specimen LPB III cph 12481 there are about 8 *clavi* in 90°, while on the smaller specimen LPB III cph 11967 they are about 6.

The inner whorls are smooth, and the appearance of the *clavi* occurs at a size that notably differs from specimen to specimen. This appearance takes place at 12.2 mm of H on the well preserved specimen LPB III cph 11967. On the specimen LPB III cph 11911, partly broken, the appearance of *clavi* might be located around 15 mm H (+/-1mm), while on the larger specimen LPB III cph 11914, unfortunately broken, the appearance is between 19 and 22.8 mm of H, in the broken part.

The suture line is not exposed.

#### Dimensions:

Specimen	D	H	U	W	H/W	U/D	U/H
LPB III cph 11967	34.35	13	12.75	6.9	1.88	0.37	0.98
LPB III cph 11913	33	11.4	13.95			0.42	1.22
LPB III cph 11939	30.5	10.8	12.7			0.41	1.17
LPB III cph 11912	23.1	8	10.25			0.44	1.28
LPB III cph 11940	23.1	8	9.2	4.4	1.81	0.39	1.15

**Discussion.** The specimens from Deșli Caira are nearly identical with the specimen from Chios, figured by Fantini Sestini (1981), except for the umbilical wall. On the Chios specimen the flanks decrease slowly to the umbilical suture, while the Deșli Caira specimens show a distinct periumbilical margin separating the flank from the umbilical wall. In this respect, the Deșli Caira specimens fit well with the original description by Diener (1895: 112), which reports a steep inner wall that slopes towards the umbilical seam. Such a feature is also visible on Diener's pl. 30, fig. 5.

*Aegiceras bizovae* Shevyrev, 1995 could be synonymized with *A. ugra* because this species, known only from the holotype, does not show many differences from *A. ugra*. *A. bizovae* was erected by Shevyrev (perhaps following Fantini Sestini 1981: 56-57) on the basis of a single, large type (D about 100 mm), previously assigned to *Japonites ugra* by Shevyrev (1968). This specimen exhibits *clavi* considered by Shevyrev to be larger than those of *A. ugra* (Shevyrev 1995: 107). The size of the *clavi* on this specimen, however, seems to be the same as the specimens of *A. ugra* from Himalaya, Timor and Chios, but their spacing and shape appear to be

different. The spacing is narrower and the shape is rounded, such that that in 90° of whorl, there are about 10-11 *clavi*-like nodes.

The taxonomic significance of these two features, however, is not certain, because in *A. ugra* the same two features are developed in late ontogeny, as shown by the large sized specimen from Chios figured by Fantini Sestini (1981: pl. 5, fig. 2; MPUM 4072) showing the transition between true *clavi* and rounded nodes on the body chamber. Unfortunately, in *Aegeiceras* the *clavi* are never visible on the inner whorls due to the overlap of the whorls; consequently, it is not possible to verify if the type of *clavi* on the late juvenile *A. bizovae* are the same as on the late adult stage, or if they are, as in *A. ugra*, an ontogenetical modification from a juvenile stage featuring true *clavi*.

The lack of *clavi*, and the presence of ribs on the specimen from Lilang (Spiti) described by Diener (1907) are not consistent with the key features of the genus *Aegeiceras*.

#### PLATE 2

Aegean Gymnitidae and Ussuritidae from Deșli Caira section in northern Dobrogea (Romania).

Fig. 1 – *Aegeiceras ugra* (Diener, 1895), specimen LPB III cph 11940 from bed GR9(=828), lateral view.

Fig. 2 – *Aegeiceras ugra* (Diener, 1895), specimen LPB III cph 11912 from bed GR9(=828), lateral view.

Fig. 3 – *Aegeiceras ugra* (Diener, 1895), specimen LPB III cph 11939 from bed GR9(=828), lateral view.

Fig. 4 – *Aegeiceras ugra* (Diener, 1895), specimen LPB III cph 11910 from bed GR9(=828), lateral view.

Fig. 5 – *Aegeiceras ugra* (Diener, 1895), specimen LPB III cph 11911 from bed GR9(=828), lateral view.

Fig. 6 – *Aegeiceras ugra* (Diener, 1895), specimen LPB III cph 11914 from bed GR9(=828): a) lateral view; b) ventral view.

Fig. 7 – *Leiophyllites pradyumna* (Diener, 1895), specimen LPB III cph 11961 from bed GR9(=828): a) lateral view; b) ventral view.

Fig. 8 – *Leiophyllites pradyumna* (Diener, 1895), specimen LPB III cph 12480 from a level below 822A, lateral view.

Fig. 9 – *Leiophyllites pradyumna* (Diener, 1895), specimen LPB III cph 12424 from bed 2847: a) lateral view; b) enlarged view (x2) of the inner whorls, showing the peculiar ornamentation with sculptured growth lines and radial ribs (varices?) ending with ventrolateral node.

Fig. 10 – *Leiophyllites pseudopradyumna* (Welter, 1915), specimen LPB III cph 11986 from bed GR10 (=829=830): a) lateral view; b) ventral view.

Fig. 11 – *Leiophyllites pseudopradyumna* (Welter, 1915), specimen LPB III cph 11982 from bed GR10 (=829=830): a) lateral view; b) ventral view.

Fig. 12 – *Leiophyllites pseudopradyumna* (Welter, 1915), specimen LPB III cph 11987 from bed GR10 (=829=830): a) lateral view; b) ventral view.

Bar scale is 10 mm. Long bar is for Fig. 9b only. Short bar is for all the other figures.



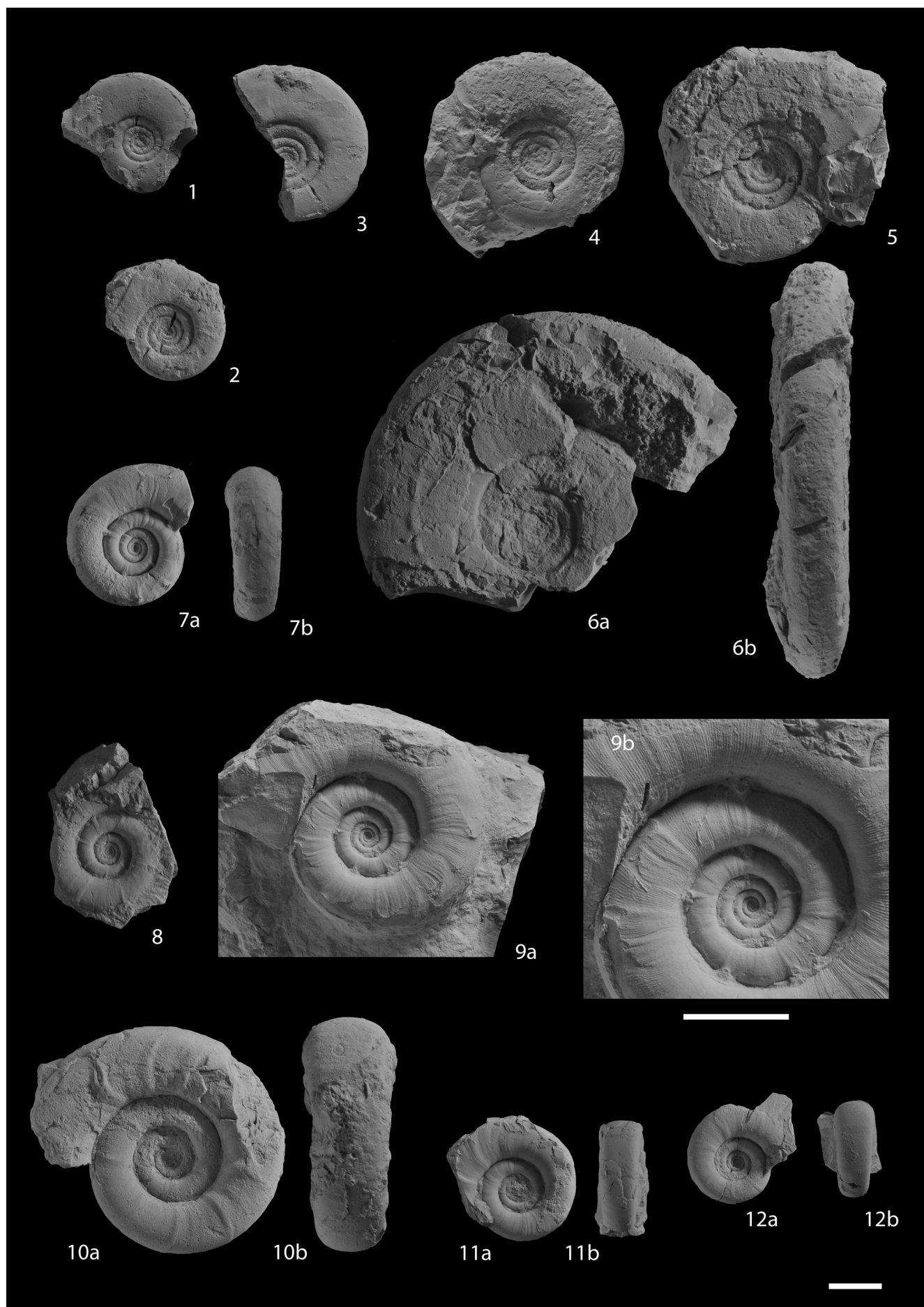


PLATE 2

**Occurrence and age.** *Aegeiceras ugra* is a typical taxon of the Aegean in the Tethys Realm. The species is known from Middlemiss Crag, Chiticum, in southern Tibet (Diener 1895), from Timor (Welter 1915), from Spiti (Krystyn et al. 2004, fig. 7) and from Chios (Bender 1970; Assereto 1974; Fantini Sestini 1981; Gaetani et al. 1992). At Chios the species is typical of the lowest level of the *Paracrobordiceras-Japonites* beds, T329 of Assereto, equivalent to Bender CM II 10.5 m. In Timor and Spiti the position of the species is well constrained and exactly equivalent to its record in Chios. The original description of the species by Diener was based on specimens collected from a block embedded in the Jurassic Spiti Shales (1895: 101-102), but the fauna from this block can be unequivocally assigned to the Aegean (see also the discussion in Bucher 1989).

Superfamily Arcestoidea Mojsisovics, 1875  
Family Cladiscitidae Zittel, 1884  
Subfamily Procladiscitinae Gamsjäger, 1982  
Genus *Gradinaruites* n. gen.

**Derivatio nominis:** the genus is dedicated to Eugen Grădinaru, who spent most of his life collecting fossils from Deșli Caira section.

**Type species:** *Gradinaruites* n. gen. *aegeicus* n. sp.

**Diagnosis:** large sized Cladiscitidae with thick trapezoidal whorl section changing during ontogeny from depressed to slightly compressed. Spiral strigation on flanks and venter. Highly indented suture line, with external suture consisting of six and half saddles. Saddles elongated, deeply indented on both sides and with slightly phylloid top.

**Composition of the new genus:** type species only.

**Discussion.** The specimens here assigned to *Gradinaruites* n. gen. were referred to *Romanites* Kittl, 1908 by Grădinaru (in Grădinaru et al. 2007). However, *Gradinaruites* n. gen. and *Romanites* differ notably in their suture lines, in that the former is typical of Cladiscitidae while in *Romanites* is typical of Joannitidae, because it is notably curved from the shoulder to the umbilicus, with the top of the saddles divided into two parts by a deep indentation (Kittl 1908, fig. 7). In addition to these significant differences, the whorl section of *Romanites* is notably compressed with a more rounded venter. The chronostratigraphic position of the two genera does not overlap, because *Romanites* is known only from the Upper Ladinian to the Lower Carnian, while *Gradinaruites* n. gen. is limited to the Aegean, the lower part of the Anisian.

Within the family Cladiscitidae, *Gradinaruites* n. gen. exhibits more similarities with *Phyllocladiscites* Mojsisovics, 1902, a genus known from the Middle Anisian to the ?Ladinian, based on the updated age of the species assigned to the genus by Gamsjäger (1982). From a morphological point of view, *Gradinaruites* n. gen. is at least two times larger than most of the species of *Phyllocladiscites* and exhibits an external suture line with a much lower number of saddles. Considering as a reference the Bithynian species *P. proponticus* Toulou, 1896, which is the oldest species of *Phyllocladiscites*, *Gradinaruites* has 6.5 saddles on the external suture at about 23.5 mm of H, while the figured type of *P. proponticus* (Toulou, 1896: pl. 20, fig. 12d) has 8.5 saddles at about 15 mm of H. Additional topotypes of *P. proponticus* were collected bed-by-bed from Gebze by Assereto (1974) and classified by Fantini Sestini (1988; MPUM 6069 to 6072). *Phyllocladiscites proponticus* was found in all fossiliferous intervals of the Gebze section (Fantini Sestini 1988, fig. 10), from the Osmani Zone (level 5) to the Balatonicus and Trinodosus zones (level 8). Specimens from these different levels are smaller in size with respect to Toulou's type specimen of the species, but they always exhibit the same type of suture with 9 saddles (e.g., MPUM 6071, pl. 14, fig. 7 from level 5), with the first saddle located on the venter and the second on the shoulder.

Some species of *Procladiscites* Mojsisovics, 1882, exhibit similarities with *Gradinaruites* in the subrectangular whorl section (e.g., *P. griesbachi* Mojsisovics, 1882 see discussion of the species), however the cross section of *Procladiscites* is notably compressed. The external suture line of *Procladiscites* is also composed of many more elements (up to 10), and its lateral saddles are higher than the first saddle (see the revised diagnosis given by Gamsjäger 1982).

**Occurrence and age.** The new genus occurs in northern Dobrogea at the Deșli Caira section (beds 822A2 Middle-Upper to and GR10 equivalent to 830), and in Timor, at Nifoekoko from bed number 2 of the block described by Welter (1915: 102, 103). At both localities the genus *Gradinaruites* occurs together with Aegean taxa. In particular, the bed described by Welter also yielded *Aegeiceras ugra*.

### *Gradinaruites aegeicus* n. gen. n. sp.

Pl. 3, fig. 1a-b, 2a-b, 3a-b, 4a-b; Fig. 9

1915 *Romanites* cf. *simionescui* – Welter, pl. 8, fig. 1a-b, p. 113.

v 2007 “*Romanites*” cf. *simionescui* – Grădinaru et al., pl. 1, fig. 4.



Tab. 3 - Measurements of *Gradinaruites aegeicus* n. gen. n. sp.

Specimen	D	H	U	W	H/W	U/D	U/H	N. of striae	at H
LPB III cph 11895 (Holotype)	64.2	32.45	10	27.5	1.18	0.15	0.30		
LPB III cph 11968 (Paratype)	54.6	25.9	7.15	29.25	0.88	0.13	0.27	32	20
LPB III cph 11949 (Paratype)	32.5	16.1	3.6	19.5	0.82	0.11	0.22	36-37	16.1
LPB III cph 12448 (Paratype)	12.8		15.4	0.83				33-34	12.8

**Derivatio nominis:** From the Aegean substage, first substage of the Anisian in the Tethyan chronostratigraphic scale.

**Material:** Holotype LPB III cph 11895 and four paratypes. One paratype, LPB III cph 11949, from level GR9 (=828); three paratypes from GR10 (=829=830): LPB III cph 11968, LPB III cph 12123, LPB III cph 12448.

**Stratum typicum:** The holotype of the new species here described was reported by Grădinaru as coming from bed 822 (Grădinaru et al. 2007). The number “822” is recognizable in the field pictures shown in figure 5B of the same paper, and the number was still visible in the field in 2023. We thus conclude that the stratum typicum of the new species is equivalent to our beds 822A2 Middle-Upper.

**Diagnosis:** as for the genus.

**Description.** All five specimens are well preserved.

The coiling is involute and the whorls section is thick trapezoidal. During ontogeny (Tab. 3), the umbilicus becomes slightly larger, increasing from 11 to 15 % of D, while the depressed whorl section becomes slightly compressed, with H/W increasing from 0.82 to 1.18. The maximum thickness is at the umbilical margin.

The ornamentation consists only of very fine spiral striae on the flanks and on the ventral side. These striae become thinner and slightly more densely spaced from the outer part of the flank to the shoulder. The number of striae on the flank can be counted on three specimens, and the number does not seem to change during the ontogeny, at least on the available specimens. The smallest specimen, LPB III cph 12448 (Pl. 3, fig. 2) exhibits 33-34 striae at 12.8 mm of H. The striae are 36-37 at 16.1 mm of H in specimen LPB III cph 11949 (Pl. 3, fig. 3), and in the larger LPB III cph 11968 (Pl. 3, fig. 4) they are 32 at about 20 mm of H.

The suture line is visible only the holotype (Fig. 9). The external suture consists of 6.5 deeply indented saddles. The external lobe, on the ventral side, is not well enough preserved to be drawn, but from the few remnants visible, there is one saddle only on the ventral side. The top of saddles is wide and almost phylloid.

**Dimensions:** See Tab. 3

**Discussion.** The specimen from Timor classified by Welter (1915) as *Romanites* cf. *simionescui*

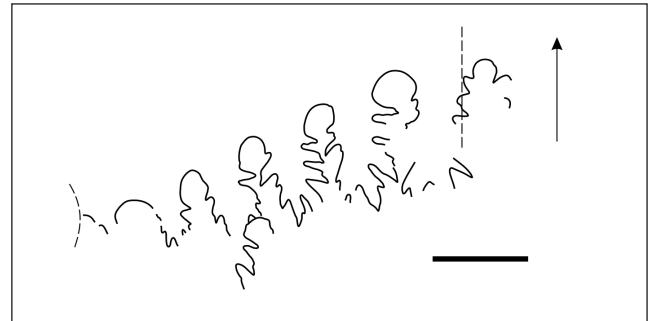


Fig. 9 - Suture line of *Gradinaruites aegeicus* n. gen. n. sp. holotype LPB111 cph 11895. Dashed lined for shoulder and periumbilical margin. Bar scale is 0.5 cm

and here re-figured (Pl. 3, fig. 5a-b), is included in the new species. *Romanites* is a Late Ladinian genus, but the fauna described by Welter is Aegean. It is possible that Grădinaru's classification in Grădinaru et al. (2007) was influenced by that of Welter.

Species similar to *Gradinaruites aegeicus* n. sp. can be found within *Phylloceras* Mojsisovics, 1902, that share a tabulate venter with *Gradinaruites* n. gen., but differ in size and in the number of elements in the external suture (see Discussion of the new genus). The only species of *Procladiscites* Mojsisovics, 1882 that is comparable to *G. aegeicus* n. gen. n. sp. is *Procladiscites griesbachi* Mojsisovics, 1882. This species exhibits a nearly flat venter, similar to *Gradinaruites aegeicus* n. gen. n. sp., but its whorl section is notably compressed with H/W > 1.5 (according to the measurements given by Mojsisovics 1882: 172) instead of 0.8-1.18. Moreover, its external suture line consists of more than 10 saddles, instead of the 6.5 in *Gradinaruites aegeicus* n. gen. n. sp.

**Occurrence and age.** As for the genus.

Order **Phylloceratida** Zittel 1884  
 Superfamily Phylloceratitoidea Zittel, 1884  
 Family Ussuritidae Hyatt, 1900  
 Genus *Leiophyllites* Diener, 1915

Type species: *Monophyllites suessi* Mojsisovics, 1882

***Leiophyllites pradyumna* (Diener, 1895)**

Pl. 2, fig. 7a-b, 8, 9a-b

- 1895 *Monophyllites pradyumna* Diener, p. 106, pl. 31, fig. 3a-b, (not 4a-b).  
 non 1907 *Monophyllites cf. pradyumna* – Diener, p. 107, pl. 13, fig. 9.  
 1910 *Monophyllites pradyumna* – Simionescu, p. 474, pl. 1, fig. 3,8; text-fig. 8-11.  
 1934 *Leiophyllites pradyumna* – Spath, p. 306.  
 1968 *Leiophyllites pradyumna* – Zakharov, p. 124, pl. 23, fig. 2, 3; text-fig. 29h.  
 1970 *Monophyllites pradyumna* – Bender, p. 454, pl. 2, fig. 11.  
 ? 1970 *Leiophyllites aff. pradyumna* – Bando, p. 350, pl. 38, fig. 3.

**Material:** Four specimens. One specimen, LPB III cph 12480, from a level “below 822A”; one specimen, LPB III cph 11961, from GR9; one specimen LPB III cph 12424 from 2847; one specimen, LPB III cph 12465, from GR10.

**Description.** The specimens are preserved with test and undeformed. Three of them are very well preserved, but the largest is included in the rock matrix and cannot be measured.

The coiling, as in many *Leiophyllites*, is evolute with nearly tangential whorls. The specimen LPB III cph 11961 (Pl. 2, fig. 7) exhibits an umbilicus that is 46% of the diameter and nearly 1.5 time the height of the whorl. The whorl section is rounded, without any shoulders (Pl. 2, fig. 7b), and quite thick, with H/W ratio of 0.86.

The ornamentation consists of well sculptured growth lines, and ribs looking like varices (*fimbriae* sensu Diener 1895: Pl. 2, fig. 7a, 8, 9b). Ribs start on the outer part of the flank, and end with a rounded node. Due to the lack of significant overlaps between whorls, the nodes of the inner whorls are exposed. The spacing of ribs is very wide in all specimens, and is about 90°. Ribs with nodes appear very early during ontogeny. In LPB III cph 11961 (Pl. 2, fig. 7a) the first visible rib is at a D of about 1.5 mm (probably not visible on the plate), while in LPB III cph 12424 (Pl. 2, fig. 9b) the first is at a D of about 3.5 mm.

### Dimensions:

Specimen	D	H	U	W	H/W	U/D	U/H
LPB III cph 11961	28.7	9	13.4	10.35	0.86	0.46	1.48

**Discussion.** *Monophyllites pradyumna* was described by Diener (1895) on the basis of two specimens from Middlemiss Crag (Chiticum, Himalaya), both figured (pl. 31, fig. 3, 4). He specifically stated (p. 106) that some specimens exhibit periodic exterior fimbriae or fringed ribs and made reference to the specimen in fig. 3.

This specimen (fig. 3) is of very good quality, and additional details of its ornamentation are well

visible, although they were not described by the author. The *fimbriae*, which resemble ribs, are radially oriented and end with a node on the external part of the flank. These features are here considered as diagnostic of *Leiophyllites pradyumna* (Diener, 1895), following in part the revision of Welter (1915).

The second figured type of *M. pradyumna* (Diener 1895: pl. 31, fig. 4) was not specifically cited by Diener in the description of the species, but differs from the specimen of fig. 3 in its more densely but irregularly spaced rursiradiate ribs that lack nodes. This specimen was used by Diener as a reference for the classification of an incomplete specimen from Lilang in his second publication on the Himalayan Muschelkalk (1907: p. 107, pl. 13, fig. 9).

This difference in ornamentation within *M. pradyumna* Diener, 1895, was noticed by Welter (1915), who synonymized the Diener type specimen of fig. 4 with his new species *Monophyllites pseudo-pradyumna*, characterized by an irregular arrangement of ribs and their backward orientation, at least on the external part of the flank (Welter 1915, p. 117). As a consequence of this revision, the specimen described by Diener in 1907 is confirmed in the synonymy of *L. pseudopradyumna*.

Radial ribs that thicken slightly towards the venter are visible on the specimen described by Bender (1970, pl. 2, fig. 11). The spacing of these ribs is narrower (about 40°) with respect to that of more typical specimens, but it is very constant. Therefore, we confirm in synonymy the identification by Bender.

### PLATE 3

*Gradinarites aegeicus* n. gen. n. sp. from Deșli Caira section in northern Dobrogea (Romania) and from Timor.

Fig. 1 – Holotype LPB III cph 11895, from bed 822A2 Middle-Upper: a) lateral view; b) ventral view. Spiral striae are not preserved because Grădinaru ground them off to expose the suture line.

Fig. 2 – Paratype LPB III cph 12448 from bed GR10 (=829=830, see text): a) lateral view; b) ventral view.

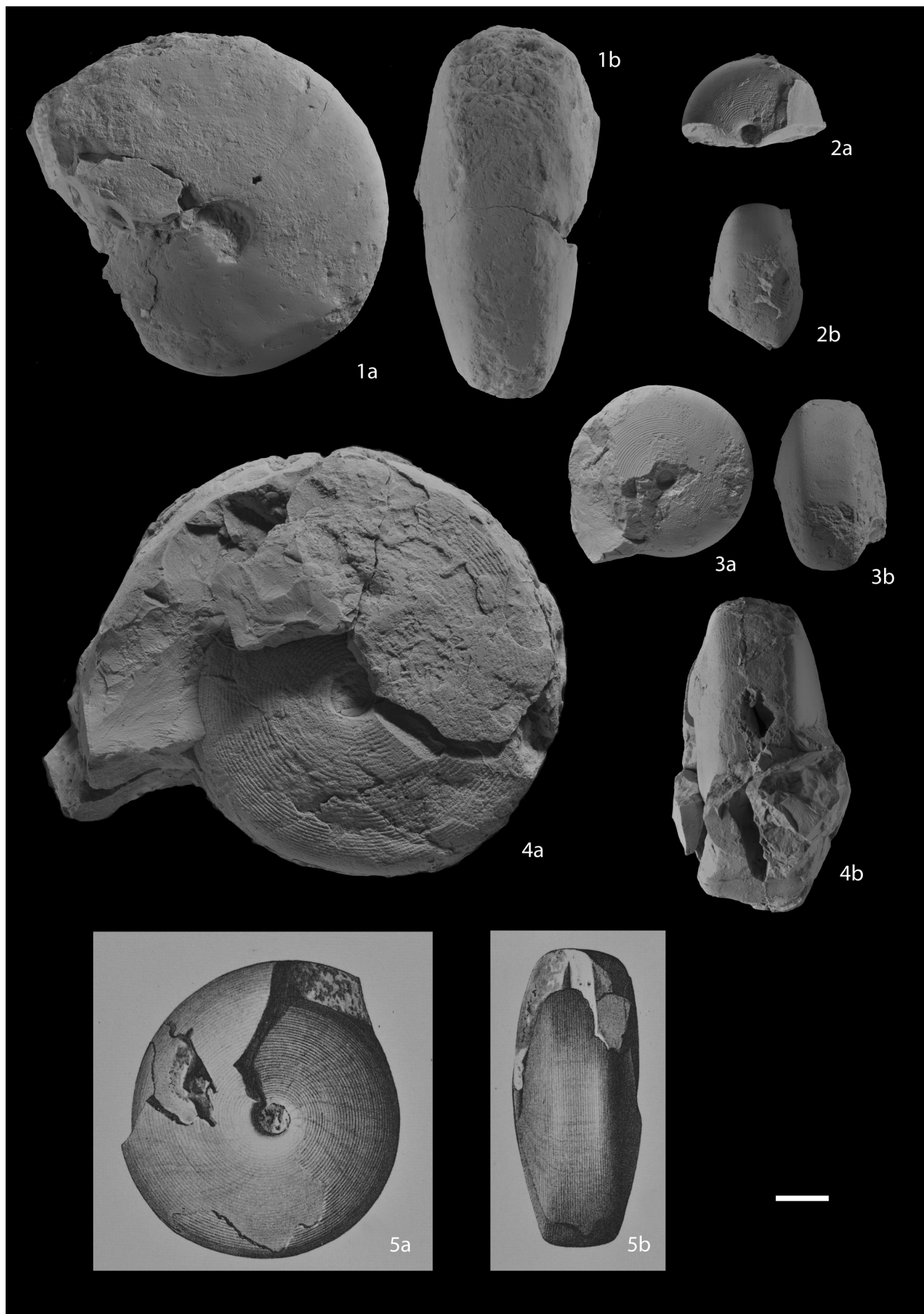
Fig. 3 – Paratype LPB III cph 11949 from bed GR9 (=828): a) lateral view; b) ventral view.

Fig. 4 – Paratype LPB III cph 11968 from bed GR10 (=829=830, see text): a) lateral view; b) ventral view.

Fig. 5 – Specimen from Timor classified as *Romanites cf. simionescui* by Welter (1915: pl. 8, fig. 1a-b): a) lateral view, b) apertural view.

Bar scale is 10 mm.





The specimen classified by Bando (1970) as *Leiophyllites* aff. *pradyumna*, is in a doubtful position—because in the description of the specimen the author mentioned growth lines, but in the discussion he also cited the occurrence of fringed ribs, in addition to the growth lines. The illustration is not of good quality and the occurrence of ribs cannot be verified.

**Occurrence and age.** The occurrence of *Leiophyllites pradyumna* (Diener 1895) is well known in the Tethys Realm, i.e., in southern Tibet (Diener 1895), Timor (Welter 1915), Dobrogea (Simionescu 1910), and is usually associated with Early Anisian taxa. The species has been also reported from northeastern Siberia (Zakharov 1968), where it is the index ammonoid for the second zone of the Anisian, the *L. pradyumna* Zone, overlying the basal Anisian *Ussuriophyllites amurensis* Zone (Zakharov et al. 2004). The species may also occur in Japan (Bando 1970).

### *Leiophyllites pseudopradyumna* (Welter, 1915)

Pl. 2, fig. 10a-b, 11a-b, 12a-b

1895 *Monophyllites pradyumna* Diener, p. 106, pl. 31, fig. 4 (not fig. 3).

1907 *Monophyllites* cf. *pradyumna* – Diener, p. 107, pl. 13, fig. 9.

1915 *Monophyllites pseudopradyumna* Welter, p. 117, pl. 90, fig. 4.

? 1930 *Monophyllites* (*Leiophyllites*) cf. *pseudo-pradyumna* – Shimizu, p. 73, pl. 14, fig. 13.

1932 *Monophyllites pseudopradyumna* – Wanner, p. 283, pl. 11, fig. 9.

v 1981 *Leiophyllites pseudopradyumna* – Fantini Sestini p. 58, pl. 6, fig. 3.

**Material:** five specimens. One specimen, LPB III cph 12055, from 822A; one specimen, LPB III cph 12294, from 822A2 Middle; three specimens from GR10=829=830: LPB III cph 11982, LPB III cph 11986 and LPB III cph 11987.

**Emended diagnosis:** *Leiophyllites* with irregularly spaced rursiradiate, primary and convex ribs and with low convex, shouldered venter.

**Description.** The specimens are well preserved in three dimensions and undeformed.

The coiling is evolute with a slight increasing of U/D and U/H during ontogeny. U is from 43 to 50% of D, and U/H ranges between 1.31 to 1.88. Whorls are nearly tangent and the whorl section is slightly depressed ( $H/W=0.76-0.8$ ). The venter is wide, just a little convex, and shouldered (Pl. 2, fig. 10b, 11b, 12b).

The ornamentation consists of rursiradiate, primary and convex ribs, starting from the umbilicus and ending at the shoulder. The spacing of the

ribs is relatively wide, but not constant. The best example of this typical ribbing is shown by the largest specimen, LPB III cph 11986 (Pl. 2, fig. 10a). The wide spacing results in about 3 ribs in 90° of whorl. The innermost whorls are almost smooth, the first rib appears at 6.5 mm of H on the smaller specimen LPB III cph 11987 (Pl. 2, fig. 12a).

The suture line is not exposed.

### Dimensions:

Specimen	D	H	U	W	H/W	U/D	U/H
LPB III cph 11986	47.4	14	23	17.6	0.79	0.48	1.64
LPB III cph 12294	27.15	7.3	13.75	9.5	0.76	0.50	1.88
LPB III cph 12055	22.95	7.15	10.65	8.85	0.80	0.46	1.48
LPB III cph 11982	21.8	6.6	10.15	8.35	0.79	0.46	1.53
LPB III cph 11987	18.4	6.05	7.95	7.75	0.78	0.43	1.31

**Discussion.** The definition of the species by Welter after the revision of the original description of *Monophyllites pradyumna* Diener, 1895, and the wrong classification of this species by Diener (1907), have been already summarized in the discussion of *L. pradyumna*. The comparison of our specimens from Deșli Caira with the type specimens from Middlemiss Crag (Chiticum) figured by Diener (1895: pl. 31, fig. 3, 4) leads us to amend the original diagnosis given by Welter (1915: 117). *Leiophyllites pseudopradyumna* (Welter, 1915) does not differ from *L. pradyumna* (Diener, 1895) in just the ornamentation, as stated by Welter, but also in the ventral part of the whorl section. The venter is slightly convex and shouldered in *L. pseudopradyumna*, while it is well rounded and not shouldered in *L. pradyumna*. This difference is obvious when comparing the apertural views of Diener's pl. 31, fig. 3b (*L. pradyumna*) with fig. 4b (later assigned to *L. pseudopradyumna*), and by comparing our ventral views in pl. 2, fig. 7b (*L. pradyumna*) with fig. 10b, 11b and 12b (*L. pseudopradyumna*).

The relatively brief synonymy does not require much discussion. The single ammonoid described by Shimizu (1930), which probably does not belong to *L. pseudopradyumna*, is not well preserved and the quality of the illustration is not good. Shimizu described periodic constrictions on the internal mold, which are “radial on the inner half of the flanks, and directed slightly forwards on the outer”. These constrictions were interpreted by Shimizu (1930) as corresponding to the ribs of *M. pseudopradyumna*, but this interpretation is not supported in the literature.

The description by Wanner (1932) does not refer to new specimens from Timor, but is based on a re-examination of the specimen described by Welter (1915), in which he describes for the first time its suture line. Wanner emphasized that the suture of Welter's specimen differs from the suture of *L. pradyumna* (Diener, 1895) in the external lobe, which is deeper than the lateral lobe. This difference is potentially interesting; however, very few suture lines of *L. pradyumna* and *L. pseudopradyumna* have been described, and therefore, there are no data regarding their variability for the two species. For this reason, the suture line is not emphasized in our emended diagnosis of the species.

**Occurrence and age.** The species is known from several localities in the Tethyan Realm, i.e., southern Tibet (Middlemiss Crag, Chiticum: Diener 1895), Spiti (Lalung: Diener 1907), Timor (Welter 1915; Wanner 1932), and Chios (Greece: Fantini Sestini 1981). The occurrence in Japan (Shimizu 1930) is presently doubtful (see previous Discussion). The position of the species is bed-by-bed constrained at Chios (Assereto 1974; Fantini Sestini 1981), where *L. pseudopradyumna* occurs in level T329, the lowermost level of the *Paracrochordiceras-Japonites* beds (Aegean).

## AMMONOID BIOCHRONOSTRATIGRAPHY OF THE DEŞLI CAIRA SECTION

The systematic study of Deşli Caira ammonoids is in progress and only selected taxa have been herein described (see chapter Ammonoid taxonomy), but we provide a range chart of the taxa thus far identified (Fig. 10) and the substage classification based on ammonoids. This range chart will be implemented in further contributions. The available data does not yet allow us to resolve the 50-year-old major issue in Aegean chronostratigraphy, namely the fact that since the work of Assereto (1974), the status of the *Paracrochordiceras-Japonites* beds, the only unit recognized within the substage in the tethyan successions, is still informal.

In Fig. 10 we report some conodont data from Golding (2021), i.e., the FO and the range of *Chiosella timorensis* (Nogami, 1968), the only occurrence of *Neogondolella curva* Golding & Orchard, 2018, and the FO of *N. gradinarui* Golding & Orchard in Golding 2021, and a tentative calibration of ammonoids and conodonts with the magnetostratigraphic scale by

Gallet, Besse & Krystyn (in Grădinaru et al. 2007: fig. 4, 7). This calibration is not very precise, because the position of the fossil-bearing beds and the magnetostratigraphy of Deşli Caira section were presented in three different figures by Grădinaru et al. (2007). The synthetic lithologic log with the position of the fossil-bearing beds was shown in figure 3, while the magnetostratigraphy was presented in figure 4 and 7, both of which lack reference to the fossil-bearing levels.

## The record of the Olenekian/Anisian Ammonoid Faunal Turnover at section B

The Olenekian/Anisian boundary (Lower/Middle Triassic boundary) is characterized by one of the major ammonoid faunal turnovers of the entire Triassic (O/A AFT), with the extinction of several Olenekian families and the radiation of new groups that will dominate the Anisian and even Ladinian ammonoid assemblages (Arkell et al 1957: fig. 148-149, L104-L105; Tozer 1981a: fig. 2; Zakharov & Abnavi 2013). Following Tozer's (1981a) suprageneric classification, the families Columbidae, Procarinidae, Paranannitidae, Ophiceratidae, Olenikitidae, Meekoceratidae, Sibiritidae, and Keyserlingitidae became extinct at the end of the Olenekian. The Anisian is characterized by the appearance of the families Parapopanoceratidae, Gymnitidae, Isculitidae, Longobarditidae, and Danubitidae, while the families Japonitidae, Sturiidae and Acrochordiceratidae first appeared just below the O/A AFT.

The O/A AFT as with many other extinction/recovery biotic events, is mostly reconstructed by comparing the fossil assemblages before and after the crisis, usually recorded from different localities. In the case of Deşli Caira, this section is one of the few in the world, perhaps the only one, with an Olenekian/Anisian ammonoid record so complete that it is suitable for direct study of the extinction and the following recovery. Our study confirms the position of the major change in ammonoid faunas at the position given by Grădinaru (2022: fig. 5), between our beds 821A and 822A2. The latter bed (Fig. 7) is equivalent to 822A in Grădinaru & Gaetani (2019: fig. 2) and Forel & Grădinaru (2021: 4), and to 822 in Grădinaru (2022: fig. 5). This boundary interval is about 1.1 m thick and the reason it cannot be better defined is due to the poor documentation from bed 822A1, which up to now has only provided 13 small, fragmentary ammonoids.



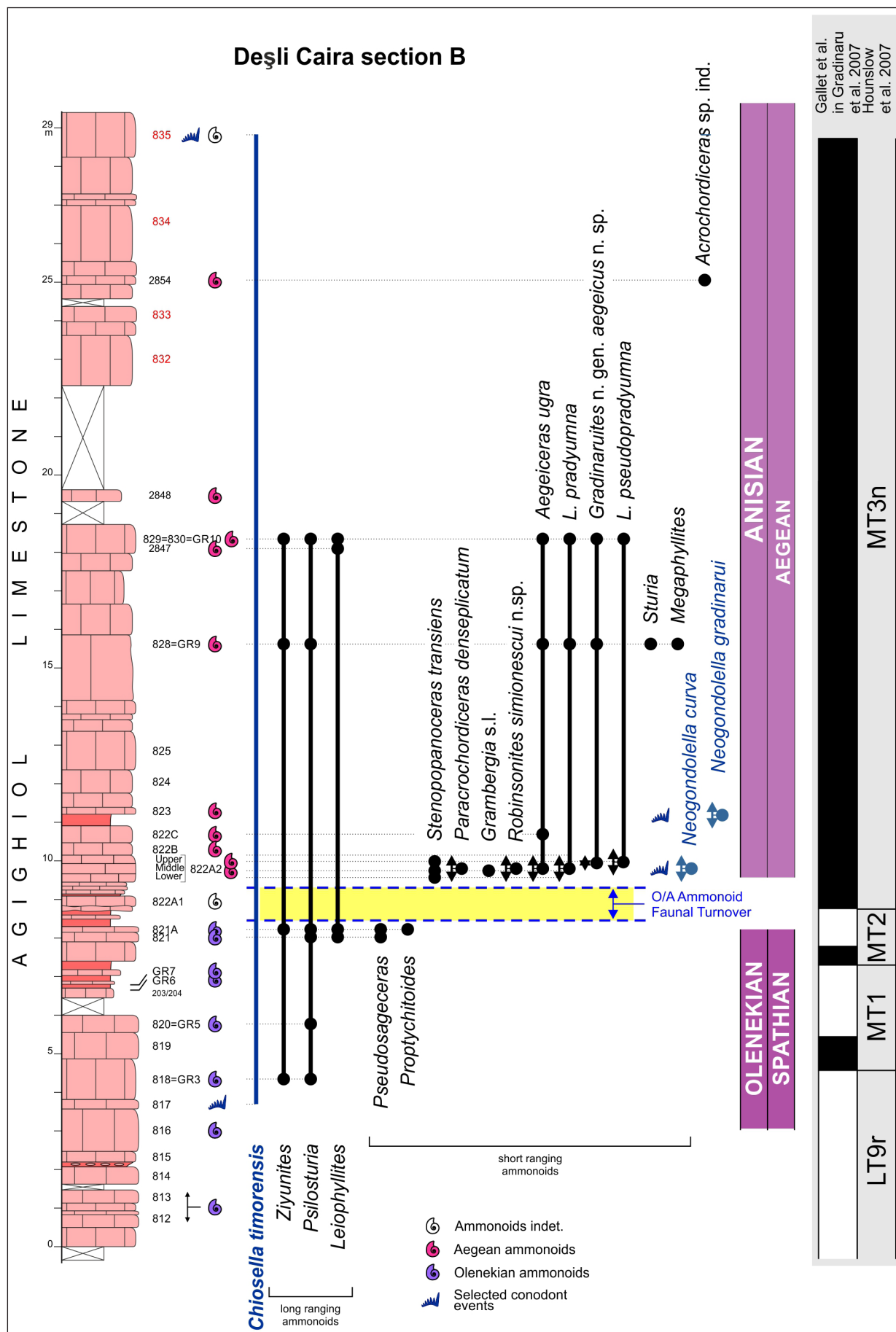


Fig. 10 - Integrated range chart of Deșli Caira section. WGS84 coordinates of the base of the section: N 45° 04' 24.9" E 28° 48' 02".

Beds 816 to 821A yield typical Olenekian faunas, dominated by long ranging *Zijunites* and *Leiophyllites*, but also with *Psilosturia* and *Pseudosageceras*, Meekoceratidae (e.g. *Proptychitoides*) and Dinaritidae. Bed 821A records the Last Occurrence (LO) of Olenekian taxa and yields abundant *Proptychitoides* and rarer *Pseudosageceras*, accompanied by long-ranging, boundary-crossing *Zijunites* and *Leiophyllites*. As already discussed in the Ammonoid taxonomy chapter, the occurrence of Anisian taxa in bed 821 and G7A reported by Grădinaru in Grădinaru et al. (2007) is not confirmed.

The beds from 822A2 to 2854 yield Anisian taxa. *Stenopopanoceras* and the species *S. transiens* have been collected by us from 822A2 Lower, while *Paracrochordiceras densesplicatum*, *Aegeiceras ugra*, *Leiophyllites pradyumna* and *L. pseudopradyumna* are documented in the Grădinaru collection, with labels “822” or “822A”, which is equivalent to our 822A2. These taxa are known only from the Aegean = Lower Anisian. The very rare and unusual *Robinsonites* has been found in the same collection. This genus was regarded as Bithynian by Shevyrev (1995), but its occurrence at Deşli Caira suggests a re-calibration of the occurrence of *Robinsonites* in the northwestern Caucasus (see Occurrence and age in the Systematic descriptions). Bed 822A2 also yielded an interesting group of Longobarditinae, very close to *Grambergia* Popov, 1961. This genus is known to occur in the lower Anisian in the Arctic and Pacific paleobioprovinces (e.g., Popov 1961; Tozer 1967; 1971; Dagys & Ermakova 1981; Tozer 1981a,b; Ehiro 2022), but further study of this Longobarditinae is necessary. Another group that seems to have been part of the Anisian faunal replacement at the O/A boundary, even if to a lesser extent, is the Cladiscitidae, with the FO of *Gradinaruites aegeicus* n. gen. n. sp., in bed 822A2.

The ~9 meters of beds overlying the O/A AFT are still characterized by the occurrence of *Aegeiceras ugra*, *Leiophyllites pradyumna*, *L. pseudopradyumna* and *Gradinaruites aegeicus*. The LO of these taxa in bed 830 may be due to the limited ammonoid documentation from the higher beds of the section, which presently consists of one specimen from level 2854 and eight ammonoids from bed 835 (=GR11; Tab. 1). This interval should be studied with much more precise sampling during future field work. The lack of *Japonites* from this 9 meter interval of Aegean beds is only apparent, not substantial, because

some Japonitidae from the interval are still under study (see Ammonoid taxonomy chapter).

The occurrence of *Acrochordiceras* in sample 2854 is new for the Aegean. This genus has long been regarded as one of the index taxa of the Bithynian substage in the Tethyan successions (Assereto 1974), and occurs throughout the Middle Anisian in North America (Tozer 1981a, b; Monnet et al. 2010, 2012, 2013). However, it is worth noting that there are no successions in the Western Tethys documenting both Aegean and Bithynian ammonoid faunas, and that the uppermost part of the Deşli Caira section, where the occurrence of *Acrochordiceras* is recorded in sample 2854, is still within the range of *Chiosella timorensis* (see next subchapter), which has not yet been reported from the Bithynian.

## INTEGRATED STRATIGRAPHY OF DEŞLI CAIRA SECTION

The integration of the available conodont and magnetostratigraphic data with the new ammonoid range chart (Fig. 10) improves the calibration of the FO of *Chiosella timorensis* and emphasizes the chronostratigraphic significance of the O/A AFT.

The occurrence of *Chiosella timorensis* at Deşli Caira was reported in earlier work (Orchard et al. 2007a; Grădinaru et al. 2007) from the FO at the base of “bed 7”, namely G7A (Orchard et al. 2007: fig. 4; Grădinaru et al. 2007: fig. 5) to the top of the section. The FO of the species was later moved to a lower position, in sample 9038=817 (Golding 2021: fig. 3). This lower position with respect to the O/A AFT was earlier emphasized by Golding (2021) and by Grădinaru (2022). Here, based on the new log of the section, we can precisely locate the FO of *Chiosella timorensis* as occurring 5.7 m below the base of 822A2. There are at least 4 beds in this interval that yield Olenekian ammonoids (Fig. 10). In order to overcome the discrepancy between the position of the candidate conodont marker event and the ammonoid faunal change, Golding (2021) suggested other conodont events that could be used as alternative proxies for the O/A boundary, i.e., the FO of *Neogondolella gradinarui* between bed 822 and 823 (Golding 2021: fig. 3), and the FO of *N. curva*, just below bed 822. These conodont events are undoubtedly much closer to the O/A AFT.

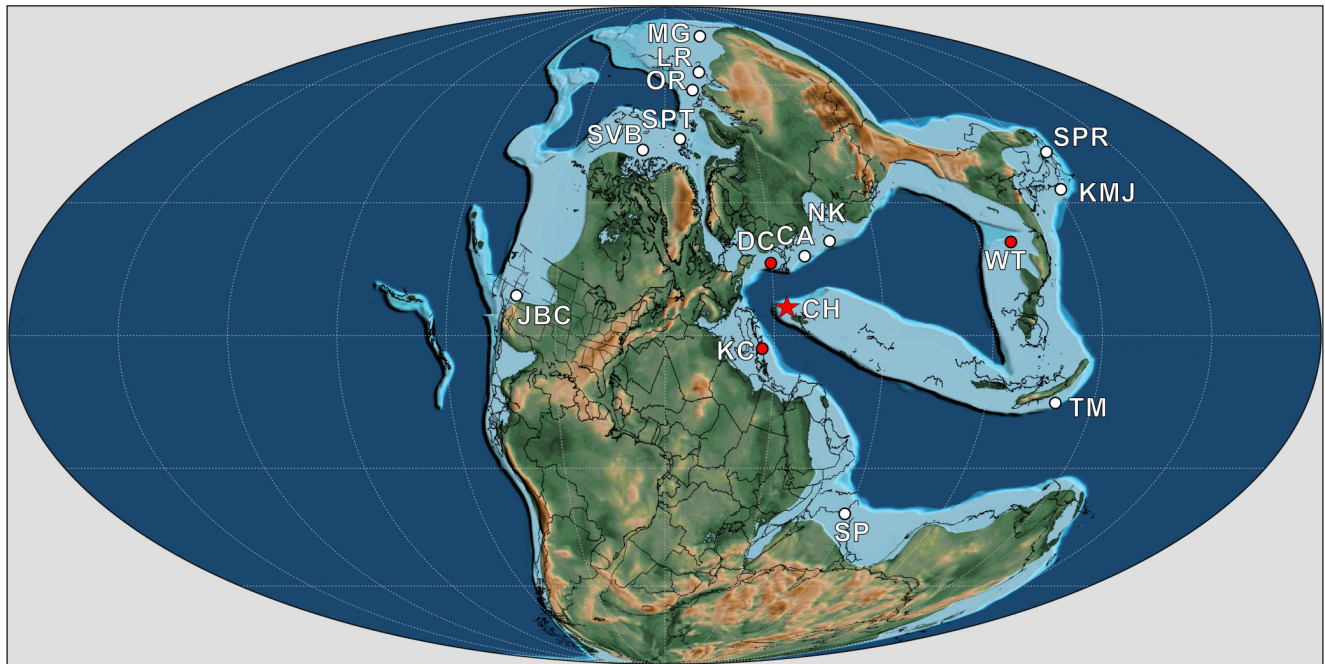


Fig. 11 - Paleogeographic distribution of the most important ammonoid-bearing Olenekian/Anisian boundary successions, based on Scotese (2021) Map 245 Ma. JBC= John Brown Canyon (Northern Humboldt Range, Nevada, USA); DC= Deşli Caira (Dobrogea, Romania); KC=Kçira (Albania); CH= Chios (Greece); CA=Caucasus (Russia); NK=Nakhlak (Iran); TM=Timor (Timor); SP= Spiti (Tethys Himalaya, India); WT=Wantou (south China); KMJ= Kitakami Mountain (Japan); SPR=South Prymorie (far east Russia); SVB=Sverdrup Basin (Arctic Canada); SPT=Sitzbergen (Norway); OR=Olenek River, LR=Lena River, MG=Magadan (Siberia, Russia). Red star for Chios, type section of the Aegean substage, red dots for GSSP candidate sections, white dots for all the other sections.

The new calibration of the ammonoid range chart with the magnetostratigraphy of Gallet et al. (in Grădinaru et al. 2007), although based on a partial ammonoid dataset and on a tentative calibration of the magnetostratigraphy to the new log, suggests a very close position of the O/A AFT to the lower boundary of a long normal magnetozone, forming the normal part of the magnetochron MT3 (Hounslow et al. 2007, fig. 1). This correlation implies a higher position of the O/A boundary in the magnetostratigraphic scale with respect to the base of the magnetochron MT1 suggested by Hounslow et al. (2007, fig. 1) and Chen et al. (2020), and the base of MT2 as suggested by Hounslow & Muttoni (2010, fig. 3). Both of the lower boundary options were probably influenced by the (low) position of *Chiosella timorensis*, but the proposal by Hounslow et al. (2007) may have been influenced by the low and incorrect position of the ammonoid boundary given by Grădinaru et al. (2007).

The new calibration here proposed could mistakenly imply that we are revising the Triassic Geomagnetic Polarity Time Scale, but in actuality, it does not affect the magnetostratigraphic correlations so well documented by Hounslow et al. (2007), Hounslow & Muttoni (2010) and Chen et al. (2020).

## THE OLENEKIAN/ANISIAN BOUNDARY AMMONOID RECORD OF THE GSSP CANDIDATE SECTIONS

In order to demonstrate the importance of the Olenekian/Anisian ammonoid record of the Deşli Caira section, in the next subchapters we will examine the ammonoid record of the most important sections in the world (Fig. 11), which are or have been considered as candidates for the GSSP of the base of the Anisian stage. We present a summary of the ammonoid investigations in the framework of the available magnetostratigraphic scales. We will also use conodonts as an additional tool for calibration, especially for the intervals with poor ammonoid records.

### Chios

The modern understanding of the Anisian stage subdivisions of the tethyan successions is due to the work of Assereto in the early 1970s on the Greek island of Chios and the Kokaeli peninsula in Turkey (Assereto 1972, 1974; Fig. 11). The Aegean substage, the lowest of the Anisian in the Tethyan Scale (Fig. 1), was proposed for the ammonoid faunas from the Marmarotrapeza Limestone in the Mount Marathovouno area, which Assereto (1974) assigned to the



*Paracrochordiceras-Japonites* beds. Assereto's bed-by-bed collected ammonoids were later studied by Fantini Sestini (1981), who also revised an earlier collection made from the same locality by Bender (1970). Further collections (Gaetani et al. 1992) were also classified by Fantini Sestini (in Gaetani et al. 1992), while systematic descriptions of the Olenekian faunas were provided by Mertmann & Jacobshagen (2003).

Certain limitations of the Marathovouno sections were summarized following the earlier work by Bender (1970) and Assereto (1974). The Hallstatt-type sedimentary succession was deposited in a complex setting resulting in lateral changes of facies and thickness over tens of meters, and the ammonoid record, even though rich, is limited to just a very few beds. Aegean ammonoids (Fig. 12) are documented in only four beds (T329, T331 and T333 at Bender's section CMI I= section A-C of Assereto et al. 1980; level T330, between T329 and T331 was found by Gaetani et al. 1992), just a few meters above the beds yielding the Olenekian faunas.

The study of conodonts by Nicora (1977), Nicora in Assereto et al. (1980) and in Gaetani et al. (1992), was crucial for the integration of the discrete ammonoid record into a more complete biochronostratigraphic framework. Among the other species, Nicora identified *Gondolella timorensis* (later attributed to *Chiosella* Kozur, 1988), with the FO in sample CH33n at section C, within the 5.5 m-thick interval without ammonoids between the last occurrence of Olenekian ammonoids (CH23) and bed T329, the base of the *Paracrochordiceras-Japonites* beds (Fig. 12). The LO of the species was recognized in sample CH144 at section D, about 1 m above T329, but below bed T333.

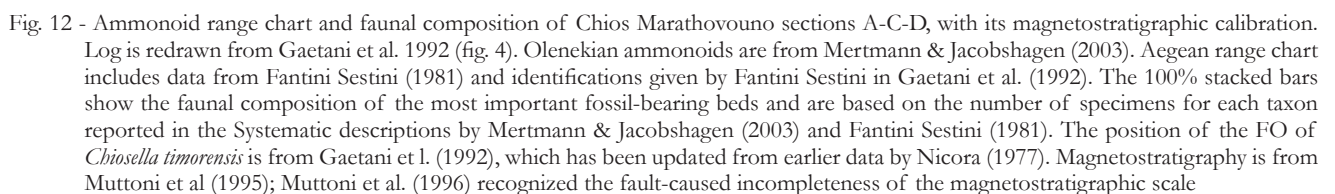
Ammonoid and conodont studies were complemented by magnetostratigraphy (Muttoni et al. 1994, 1995, 1996; Fig. 12), and the Chios-Marathovouno section A-C-D was proposed as a GSSP candidate by Muttoni et al. (1994), with two options for the GSSP. The first is the traditional one, with the boundary drawn at the base of the ammonoid faunal change, i.e., at the base of the *Paracrochordiceras-Japonites* beds, which is near the base of the normal polarity interval Chios C+. The second is at the FO of *Gondolella timorensis*, which is located between the last Olenekian ammonoid and the first Anisian faunas, nearly equivalent to the normal polarity interval Chios C+. This GSSP proposal was soon abandoned when the high-resolution integrated magneto-

and biostratigraphic correlations with the Kçira-A section (Albania) demonstrated the presence of a significant gap between Chios magnetozone B- and C+ due to a fault (Muttoni et al. 1996, fig. 7).

A summary of the available ammonoid data is shown in Fig. 12, which also includes the range of *Chiosella timorensis*, as per Nicora in Gaetani et al. (1992) and magnetostratigraphy from Muttoni et al. (1995). The ammonoid range chart is derived from the integration of the range chart of Olenekian faunas from Mertmann & Jacobshagen (2003), with Anisian faunas from Fantini Sestini (1981) and additional Anisian data by Fantini Sestini in Gaetani et al. (1992). The numbers of specimens classified in each taxon by Mertmann & Jacobshagen (2003) and by Sestini Fantini (1981) have been used for a quantitative description of the Chios faunas. For every ammonoid bearing level, the total number is reported in brackets, and for the richest levels the dominance of leiostracan is shown in 100% stacked bars.

Most of the Olenekian faunas are documented in a 3 m-thick interval between levels CH 6 and CH 14. These faunas are dominated by *Leiophyllites*, *Procarnites* and *Paranannites*, which together represent 70 to 90% of the taxa (Fig. 12), as compared to the eight other genera, including the short ranging *Hellenites* and *Albanites*. This interval was attributed to the *Prohunbarites-Subcolumbites* Zone sensu Kummel (1973) by Mertmann & Jacobshagen (2003). This zone can be correlated with the Subcolumbites Zone of the North American scale (Fig. 1), but it does not document the uppermost Olenekian. Level CH23a, which yielded a single specimen of *Pseudosageceras*, although not specifically cited by Mertmann & Jacobshagen (2003) is here confirmed to belong to the Olenekian. *Pseudosageceras* is a very long ranging taxon, with its FO in the Dienerian substage of the Induan (e.g., Brühwiler et al. 2010), and it has never been reported from the Anisian. However, the age assignment of this occurrence in level CH23a is not based on the assumption that the genus is Early Triassic, but instead, is based on its calibration with *Chiosella timorensis*, whose FO is 4 m above CH23a.

Aegean ammonoids were collected from four levels (T329, T330, T331, T333) within a 2.5 m thick interval. However, the vast majority of the ammonoids (230 specimens) came from the lower level, T329, whereas three specimens came from T331 and six came from T333 (no quantitative data



are available for T330). This rich assemblage from T329 is dominated by the leiostracan *Megaphyllites* with 165 specimens (71%), while the second most abundant genus in decreasing order of dominance is the trachyostracan *Paracrochordiceras*, with 27 specimens (11.7%), followed by the leiostracan *Sturia* (9 specimens, 3.9%) and *Aegeiceras* (8 specimens, 3.4%). While *Leiophyllites* is very abundant in the Olenekian interval, it is rare in the Anisian interval, with only 4 specimens reported by Fantini Sestini (1981). It is worth noting that as this analysis of quantitative faunal composition demonstrates, the importance of *Japonites*, which had been previously regarded by Assereto (1974) to be a significant stratigraphic marker, is actually not even a key component of the ammonoid assemblages, being represented by only 2 specimens out of the 239 collected from the Aegean beds.

The Olenekian/Anisian boundary at Chios is within a 5.5 m-thick interval between level CH23a and the Anisian ammonoid rich level T329. The FO of conodont *Chiosella timorensis* is recorded in this interval, in sample CH33n, 1.8 m below the Aegean ammonoid bearing level T329.

### Kçira

One of the most important Olenekian to lowermost Anisian ammonoid localities in the world is Kçira, in Albania (Fig. 11). This locality was discovered by Nopcsa (1906), who collected a large group of specimens from red limestones, which eventually became crucial for the taxonomy of late Olenekian ammonoids. Nopcsa's collections were studied by Arthaber, who published two preliminary papers (Arthaber 1908, 1909), and then later described in a large monograph (Arthaber 1911) nine new genera and 66 species, of which 41 were new. Arthaber's taxonomy was in part revised by Spath (1934) and Kummel (1969; see Germani 1997 for a summary).

In the 1990s M. Gaetani organized an integrated study of the locality, with a goal of establishing a high-resolution correlation with the Chios sections. Magnetostratigraphy, supported by ammonoid, conodont and foraminifera data, was published by Muttoni et al. (1996). Germani (1997) described the small collection of ammonoids made by Gaetani, the first ever collected bed-by-bed from the locality (Fig. 13). Conodonts were illustrated by Meço (2010). The integrated correlation of the Kçira-A section with the Chios section A-C-D

(Muttoni et al. 1996) demonstrated the existence of a gap in the Chios stratigraphic record, due to a fault. As a result, the former candidacy of Chios A-C-D for the GSSP of the Anisian (Muttoni et al. 1994) became obsolete. The possibility of considering the Kçira-A section as a candidate for the Anisian GSSP, however, was not emphasized until the very recent re-examination of available data by Muttoni et al. (2019).

The ammonoid data, magnetostratigraphy, range of *Chiosella timorensis*, and the conodont-based age calibration of the intervals with poor ammonoid records are integrated in Fig. 13, redrawn from Muttoni et al. (2019, fig. 4 and 5). For each ammonoid-bearing bed, the total number of specimens described by Germani (1997) is reported in brackets. However, this very small number of specimens does not permit a quantitative description of the ammonoid faunas.

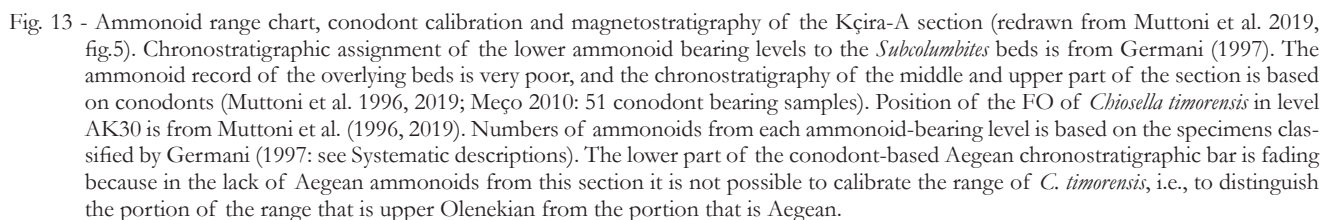
The ammonoid record of the Kçira-A section is very good for the Olenekian part of the section, but is very poor for the Anisian portion. The record consists of three fossiliferous intervals separated by two intervals devoid of macrofossils (Fig. 13). The first interval without ammonoids is 21 m thick, while the second is 13 m thick. Taking into account the overall thickness of the Kçira-A section (42 m), ammonoids are recorded in only 20% of the section.

Interval AK2bis-AK5, in the lowermost part of the section, yielded two Olenekian faunas, including several species and genera of Arthaber's fauna. Diversity is high, with 15 specimens representing 11 taxa in AK2bis, and 10 specimens for 8 taxa in AK5. This interval was attributed to the *Subcolumbites* beds by Germani (1997).

The second fossiliferous interval is about 5.5 m thick and consists of four ammonoid bearing levels (AK31, AK36, AK38 and AK40), which only yielded 9 ammonoids. In earlier works (Muttoni et al. 1996; Germani 1997), this interval was included in the basal Anisian because of the co-occurrence with *Chiosella timorensis* (FO in sample AK30), which at that time was regarded as a more reliable index marker for the base of Anisian. This chronostratigraphic attribution is herein slightly changed.

Level AK31, the lowermost level of this interval, could be assigned with some uncertainty to the Olenekian, because of the co-occurrence of *Eophyllites* and *Procarnites*, two taxa usually regarded as Spathian (e.g., Tozer 1981a), while *Leiophyllites* is





Levels AK36, AK38 and AK40 yielded only long ranging ammonoids, therefore it is nearly im-

possible to pinpoint their exact age. Two specimens of *Leiphyllites* were collected from AK36 and AK40, but this genus ranges from the late Olenekian to the Anisian. Level AK38 yielded two specimens of *Procarnites kokeni*, which is usually regarded as an Olenekian species. However, the attribution of

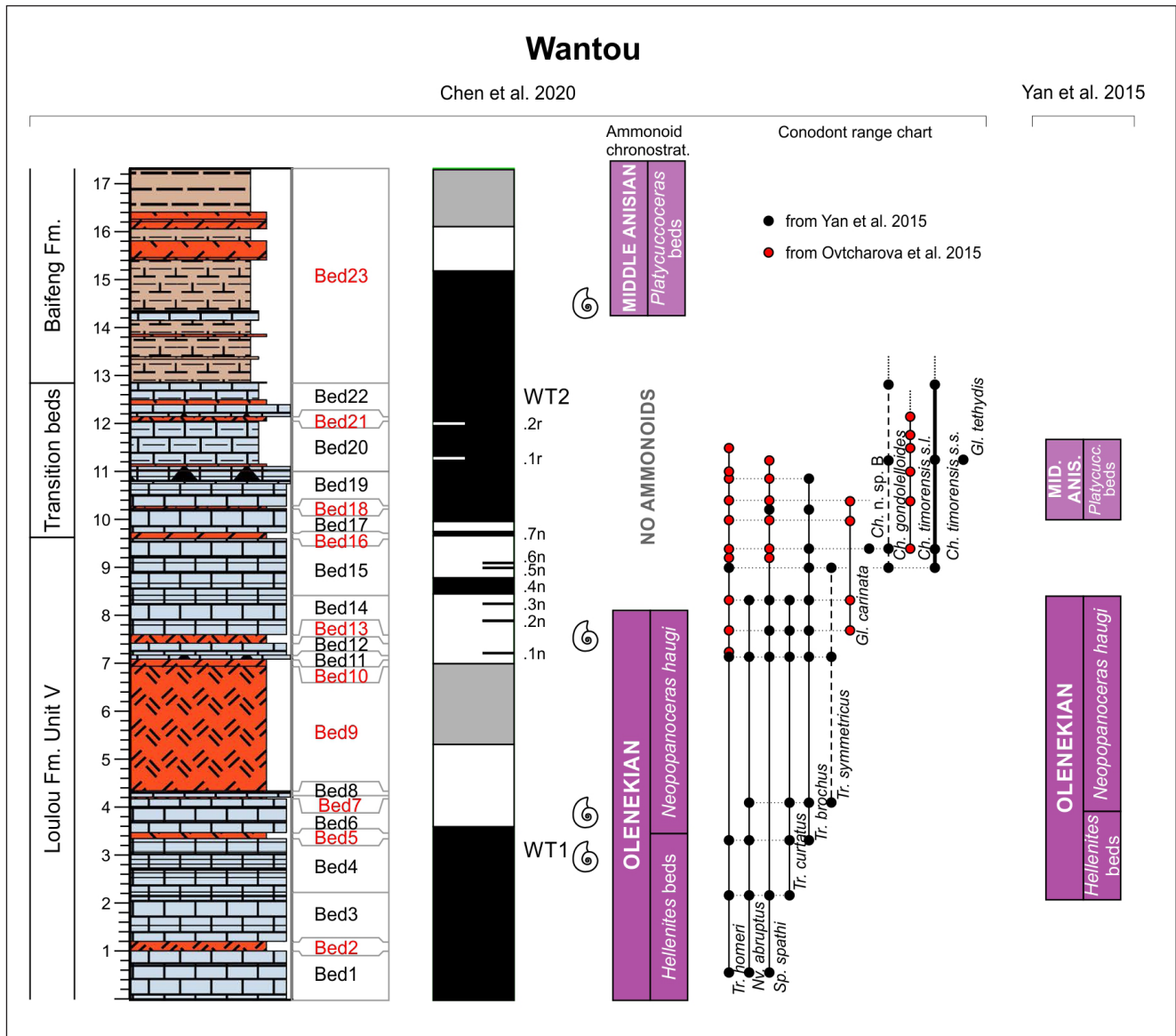


Fig. 14 - Ammonoid zones, conodont range chart and magnetostratigraphy of the Wantou section from Chen et al. (2020, fig. 3). The occurrence of faunas documenting the *Hellenites* beds and the *Neopopanoceras haugi* Zone of the Olenekian and the *Platycuccoceras* beds of the Middle Anisian has been known since the work of Ovtcharova et al. (2006) and Galfetti et al (2007, 2008); these faunas have never been described and no detailed information is available regarding the precise number of ammonoid-bearing beds within the section. According to the Chen et al. (2020) the interval without ammonoids between the Haugi Zone and the Middle Anisian is about 6 m thick, while Yan et al. (2015, fig. 4) placed the *Platycuccoceras* beds in a much lower position, in the transition beds between the Loulou and Baifeng formations. This position reduces the thickness of the interval without ammonoids to 1.6 m, but it implies coeval relationships between Middle Anisian ammonoids and *Chiosella timorensis*.

AK38 to the Olenakian as suggested by Grădinaru (2022: 6) would be an assumption only and not a calibration. Conodont data argues against this assumption and strongly supports an Aegean age for AK 38. First, the LO of *Chiosella timorensis* is recorded in the same AK38 level, and elsewhere in the world this event is recorded in the Aegean/Lower Anisian, not in the Olenekian. Second, the conodont faunas are distinctly Bithynian (Muttoni et al. 1996: p. 505, fig. 2) starting from level AK40, just

above AK38.

The third fossiliferous interval basically consists of a single sample, AK57, that yielded one specimen each of the long ranging genera *Sturia* and *Procladiscites branconi*. These two taxa are Anisian, but due to their long range they are not useful to help recognize which part of the Anisian is represented by these ammonoids. Conodont from the same interval faunas suggest a Pelsonian age (Muttoni et al. 1996: p. 505, fig. 2).

## Wantou

The Nanpanjiang basin (China) is well known for its richly fossiliferous Triassic marine successions. The Lower and Middle Triassic successions, in particular, have been studied by many authors at several localities in the past 20–30 years. These successions provide a nearly unique key for understanding the biotic recovery after the Permian/Triassic mass extinction and related carbon cycle variations as well as the development of Triassic carbonate banks (e.g., Lehrmann et al. 1998, 2006; Lehrmann 1999; Payne et al. 2004, 2006a, b; Enos et al. 2006). These successions are also rich in tuff layers suitable for U/Pb dating (e.g., Lehrmann et al. 2006; Ovtcharova et al. 2006, 2015; Yan et al. 2015), and they have been studied for magnetostratigraphy (Lehrmann et al. 2015), cyclostratigraphy (Li et al. 2016, 2018), chemostratigraphy (Galfetti et al. 2007; Meyer et al. 2011; Sun et al. 2012; Song et al. 2015) and bio-chronostratigraphy (Galfetti et al. 2007, 2008; Orchard et al. 2007b; Sun et al. 2012; Yan et al. 2015; Golding 2021).

Because of the unusually rich stratigraphic record, in the past two decades some stratigraphic sections from Nanpanjiang basin were used as reference for Olenekian/Anisian boundary correlations, such as Guandao and Youping (e.g., Orchard et al. 2007b; Lehrmann et al. 2015; Li et al., 2018). More recently the Wantou section has been proposed as candidate for the GSSP of the base of the Anisian by Chen et al. (2020), who provided a summary of the available literature. An integrated stratigraphy of this section was shown in their fig. 4, which includes data, in part from the literature on magnetostratigraphy, numerical ages, ammonoid zones, conodont ranges,  $\delta^{13}\text{C}_{\text{carb}}$ , and  $\delta^{18}\text{O}$  variations, and sea surface temperatures (T). Magnetostratigraphy, ammonoids, and the most important conodonts are shown in Fig. 14. Ammonoid calibration of the integrated stratigraphy is accomplished by using data from the literature, basically from Ovtcharova et al. (2006) and Galfetti et al. (2007, 2008), who recognized in the Jinya section the *Hellenites* beds and Haugi Zone in the upper Olenekian, and the *Platycuccoceras* beds and the Shosonensis Zone in the Middle Anisian. A conodont range chart is obtained from the literature by combining data from Ovtcharova et al. (2015) and Yan et al. (2015).

Upper Olenekian and Middle Anisian ammonoids have never been described from the Nan-

panjiang basin, but taxa from the *Platycuccoceras* beds and Shoshonensis Zone were listed by Ovtcharova et al. (2006) and Galfetti et al. (2007, 2008). However, the major weakness of the candidacy of the Wantou section for the Anisian GSSP is the complete lack of Lower Anisian ammonoids, which are crucial for the calibration of the Olenekian/Anisian boundary. Overall, this lack of relevant ammonoids is in part compensated by the occurrence of certain conodonts, but the conodont record is also incomplete. The conodont range chart documents only the Olenekian and at least part of the Lower Anisian, but no data are available for the Middle Anisian. This section's conodont record includes a few species of *Chiosella*, comprising *C. timorensis* s.s. and *C. timorensis* s.l.; however these occurrence are not sufficient for the definition of the O/A boundary. The proposal to use the FO of *C. timorensis* as a primary marker is no longer acceptable, because the species is now known to first occur in the late Olenekian (Konstantinov & Klets 2009; Goudemand et al. 2012) and range up into the Aegean. Available data from Wantou, however, at the present do not allow us to distinguish the Olenekian portion of the range of *C. timorensis* from the Aegean portion.

A further issue in the Wantou section deserving of a more detailed analysis is the stratigraphic position of the *Platycuccoceras* beds with respect to the Haugi Zone, because Yan et al. (2015) and Chen et al. (2020) show two very different ammonoid calibrations. Chen et al. (2020, fig. 3; Fig. 14) recognize the *Platycuccoceras* beds within the Biafeng Formation, which occurs 6 meters above the Haugi Zone. Beds comprising these 6 meters are devoid of ammonoids. On the other hand, Yan et al. (2015, fig. 4) indentified the *Platycuccoceras* beds in a much lower position, within the limestones and cherty limestones of the uppermost part of unit V of the Loulou Formation and the Transition beds. This position implies that the interval devoid of ammonoids is only 1.6 m thick, instead of 6 meters. However, such a low position for the Middle Anisian *Platycuccoceras* beds is not consistent with the record of Lower Anisian *C. timorensis*, which according to Yan et al. (2015: fig. 4), co-occurs with *Platycuccoceras*. These two different time calibrations of the section, in turn imply very different calibrations for all data obtained with other stratigraphic tools.



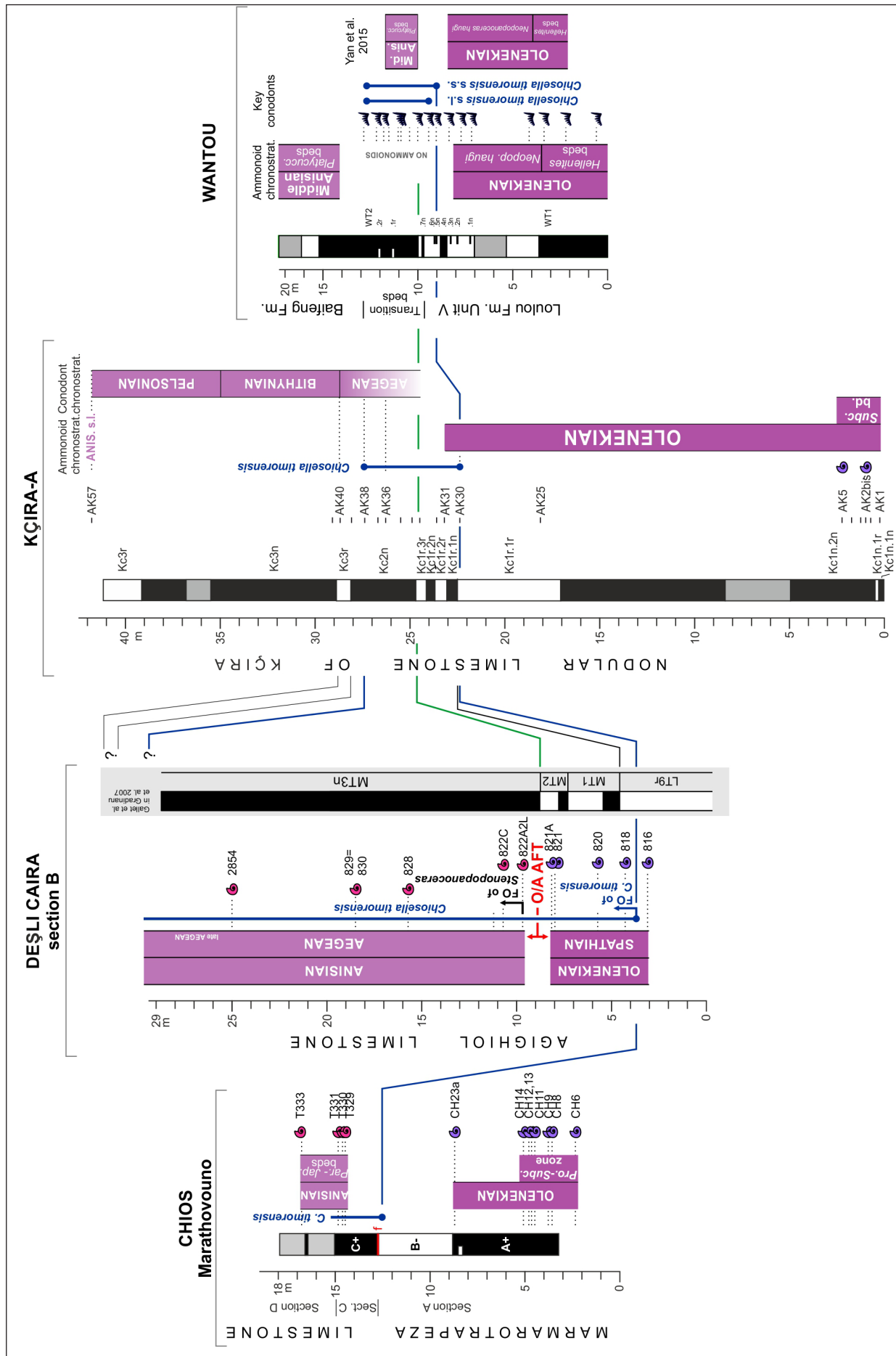


Fig. 15 - Ammonoid record, record of *Chiosella timorensis* and magnetostratigraphy of Deşli Cairă section B, compared to Chios, Marathovouno A-C-D, Kçira-A and Wantou sections (data are from Fig. 10, 12, 13, 14). Thickness of all sections is calibrated to the same scale. O/A AFT: Olenekian/Anisian AFT. Green correlation line marks the base of MT3n, blue correlation lines are for *C. timorensis*.

## INTEGRATED CORRELATIONS OF THE DEŞLI CAIRA AMMONOID RECORD WITH THE GSSP CANDIDATE SECTIONS

Figure 15 presents a comparison of 1) the ammonoid record, 2) range of *Chiosella timorensis*, 3) conodont chronostratigraphy for the intervals with poor ammonoid records, and 4) magnetostratigraphy of the four most important sections for the definition of the GSSP of the base of the Anisian. The thickness of the sections is normalized to the same scale. This integrated correlation chart demonstrates that the best and most complete chronostratigraphic record of the uppermost Olenekian-Aegean is the Deşli Caira section.

The stratigraphic range of *Chiosella timorensis* at Deşli Caira is at least 25 m thick (the species ranges to the top of the section) as compared to about 3 m at Chios, about 5 m at Kçira-A and about 4 m at Wantou. Magnetochrons thickness for MT1, MT2 and MT3 is also much greater at Deşli Caira than at the other sections. Calibration accuracy of the magnetostratigraphy at Deşli Caira with the high resolution log of the section must be improved, but we expect an adjustment of only a few tens of centimeters. Given the available data, magnetochrons MT1 plus MT2 are 4-4.5 m-thick at Deşli Caira, as compared to about 2 m-thick at Kçira-A. The normal portion of magnetochron MT3 is even thicker at Deşli Caira, with a record of about 20 m, while at Kçira-A Kc2n (equivalent to MT3n: Houslow & Muttoni 2010: fig. 3) is about 3-3.5 m-thick. At Wantou, as in other South China sections, magnetostratigraphy is more complex for the interval MT1-MT2, perhaps because of condensation, as suggested by Houslow & Muttoni (2010, fig. 3: 71). No comparisons are possible for the interval MT1-MT2 at Chios, because the section is faulted.

Even though the FO of *C. timorensis* is no longer suitable for the selection of the primary marker of the Anisian GSSP (e.g., Golding 2021; Grădinaru 2022), it is still an important event for long range correlation as shown in Fig. 15. This bioevent is recorded in a reversal magnetozone in all four sections, but the assignment to magnetochrons is slightly different. The position of this event is best controlled at Deşli Caira and Kçira, where it is recorded at the top of LT9r (Houslow et al. 2007; Houslow & Muttoni 2010).

At Wantou (Chen et al. 2020), the FO of *Chiosella timorensis* s.s. is recorded around the base of WT1r.5n and at Youping around YP1r.3n, both of which are referred to MT1n by the authors. These different positions could be due to condensation in the South China sections (Houslow & Muttoni 2010).

Perhaps the best feature of the Deşli Caira section is its ammonoid record. Deşli Caira is the only section with a record of both the upper Olenekian and Aegean ammonoids, and its stratigraphic gap devoid of age-diagnostic taxa is only 1.1m. The Aegean ammonoid record of Deşli Caira is crucial for the two very important age-calibrations.

Deşli Caira is the only section where it is possible to separate the Olenekian and Aegean portions of the range of *Chiosella timorensis* by calibration with the ammonoid record. This issue cannot be resolved in the other sections. At Chios the FO of *C. timorensis* is recorded within the 5.5 m-thick interval devoid of ammonoids, and the LO is within the *Paracrochordiceras-Japonites* beds. There are no age diagnostic Aegean ammonoids in the Kçira section and the Wantou section has no Aegean ammonoids. The Aegean ammonoid record is also critical for the age-calibration of the base of magnetochron MT3, which is very close to the O/A AFT and the base of the Aegean. Until now, the base of this worldwide recognized, long magnetochron (e.g., Houslow & Muttoni 2010) was located within the range of *C. timorensis*, e.g., between the late Olenekian and the Early Anisian, without a more precise age assignment.

## AMMONOID FAUNAL COMPARISON WITH OTHER OLENEKIAN/ANISIAN AMMONOID-BEARING SUCCESSIONS

The few species described in this paper represent only a part of the Aegean ammonoid fauna recorded in the Deşli Caira section. This notwithstanding, these taxa have a very good potential for long range correlation. Herein we discuss the similarities of Deşli Caira ammonoid faunas with those from the most important localities in the world (Fig. 11). The detailed framework of correlations will be defined once the systematic study of the Deşli Caira ammonoids is completed.

## Nevada

The northern Humboldt Range in northwestern Nevada, i.e., John Brown Canyon, provides the best ammonoid record of the O/A boundary in North America (Fig. 1). Faunal diversity is very high for both the Olenekian and Lower Anisian as shown by Guex et al. (2010) and Bucher (1989), respectively. Unfortunately, a 20-30 m gap, occupied by the Brown Calcareous Sandstone, exists between the upper part of the uppermost Spathian Haugi Zone and the base of the Anisian, i.e., the *Japonites welteri* beds (Bucher, 1989; Guex et al., 2010; Goudemand et al., 2012). This unfossiliferous interval negates consideration of this section for selection as the GSSP. A potential section for the O/A boundary interval exists in northeastern Nevada in the Leach Range, i.e., in Immigrant Canyon, Elko County, just a short distance west of Montello. Preliminary sampling indicates the presence of uppermost Spathian Haugi Zone ammonoids and poorly preserved ammonoids of the lower Anisian *Japonites welteri* Zone, i.e., *Paracrochordiceras* sp. and ?*Japonites* sp. (J.F. Jenks, personal commun. 2021). However, this section is on private land and negotiations with the landowner failed to produce an agreement suitable for further study (J.F. Jenks, personal commun. 2021; S.G. Lucas, personal commun. 2021).

Anisian faunas from Nevada are very rich in trachyostracan (Bucher 1989), the ornamented short ranging ammonoids, but many of these taxa are not yet recognized in other paleobiogeographic provinces. Key taxa for correlation with Tethyan sections in general, and with Deşli Caira in particular, appear to be *Paracrochordiceras* and *Stenopopanoceras*. *Paracrochordiceras* occurs from the base (*Japonites welteri* beds) to the top (Caurus Zone) of the Lower Anisian, while the only specimen of *Stenopopanoceras* thus far described from Nevada is from the *Pseudokeyerlingites guexi* beds, the second unit of the Lower Anisian.

## Caucasus

Ammonoid faunas of the northwestern Caucasus were monographed by Shevyrev (1968, 1995), who also summarized the biostratigraphy (Shevyrev, 1996). The ammonoid record is discrete, with certain fossil-rich intervals, but these fossiliferous beds have not yet been sampled bed-by-bed to determine the stratigraphic position of the specimens. Nevertheless, the faunas from these intervals have several

taxa in common with the Deşli Caira faunas.

Shevyrev (1995, 1996) described two Aegean-early Bithynian faunas from two different areas. In the succession exposed at Mount Yatyrgvarta he recognized a fauna dominated by *Stenopopanoceras transiens*, which he attributed to the Aegean Ugra Zone, and that we herein correlate with the lower portion of the Aegean beds at Deşli Caira.

A second fauna was recognized in the area of the rivers Thach and Acheshbok, which was assigned to the *Laboceras-Megaphyllites* beds, Osmani Zone, Bithynian (Shevyrev 1995: 8-9). However, the faunal composition of these beds includes both Aegean (e.g., *Aegeiceras*) and Bithynian (e.g., *Pseudohollandites*) taxa; therefore, we suggest that the *Laboceras-Megaphyllites* beds, consisting of 10 meters of nodular limestones (Shevyrev 1995: 9), may encompass part of the Aegean and the lower portion of the Bithynian, resulting in a partial time equivalence with the *Stenopopanoceras* beds of Mount Yatyrgvarta. This chronostratigraphic revision implies that the age of *Robinsonites* in the type area falls between the Aegean and the early Bithynian, and that its presence in the early Aegean at Deşli Caira may be the FO of the genus.

## Tethys Himalaya

Lower Anisian ammonoids are known from Chitichum in the Hundes (southern Tibet: Diener 1895), and from Spiti Valley (Diener 1907; Krystyn et al. 2004). Bed-by-bed data are available from Lalung (=Lilang of Diener) with a short description of the faunas (Krystyn et al. 2004). These faunas are very similar to those from Chios and Deşli Caira, because many species commonly occur, i.e., *Aegeiceras ugra*, *Leiophyllites confucii*, *L. pradyumna*, *L. pseudoradyumna*, *L. pitamaha*, *Ussurites kingi* and *Paracrochordiceras pandya*. *Japonites* and *Paradanubites* occur in both the Spiti and Chios faunas, but for the moment these genera have not yet been recognized at Deşli Caira. On the other hand, *Stenopopanoceras* has not yet been identified in the Himalayan faunas.

## Timor

Rich, well preserved Triassic ammonoid faunas have been known from Timor since the early 20th century, following their descriptions by Welter (1914, 1915, 1922). The faunas are from blocks of Triassic Hallstatt Limestone embedded in a melange (Bobonaro Scaly Clay: Martini et al. 2000; Bobona-



ro melange complex: Charlton et al. 2009) and the faunal composition is often leiostracan-dominated. Lower Anisian ammonoids were described by Welter (1915) from a single block at Nifoekoko and their taxonomy was later updated by Fantini Sestini (1981). Faunal similarity with Deşli Caira is noteworthy, with several taxa occurring at both sites, i.e., *Aegeiceras ugra*, *Grădinaruites aegeicus*, and *Leiophyllites pseudopradyumna*. *Paracrochordiceras* occurs at both localities, but with different species. *Japonites* and Gymnitidae are important components of the Timor fauna, but these taxa from Deşli Caira are still under study.

### Japan

Lower Anisian ammonoids have been known to occur in the Kitakami Mountains, northeastern Japan since the early work of Mojsisovics (1888), who described a few ammonoids including *Ceratites planiplicatus*, the type species of *Japonites* Mojsisovics, 1893 from this area. Further systematic descriptions were provided by Shimizu (1930) and in part by Bando (1970), but this knowledge has been notably improved by the recent work of Ehiro (2022), who described a large group of ammonoids collected bed-by-bed from the Fukkoshi Formation.

As is typical for localities in the Kitakami Mountains (e.g., Mojsisovics 1888; Shimizu 1930), ammonoids described by Ehiro (2022) are not well preserved, with preservation often limited to just one side and details of the venter are usually not exposed. Fortunately, suture lines are usually preserved, which is critical for classification, due to the limited information on the whorl section.

Ammonoids were collected from eight levels in the middle-upper part of the Fukkoshi Formation (Ehiro 2022), and the faunal list is quite rich, consisting of 21 genera and 30 species. Faunal analysis and comparisons were admirably accomplished by Ehiro, who emphasized the co-occurrence of certain Olenekian taxa (e.g. *Hemilecanites*, *Pseudosageceras* and *Metadagnoceras*) with Aegean genera and species (e.g. *Paracrochordiceras* and *Japonites*) in the lower fossiliferous levels. Overall, the Aegean fauna is dominated by *Leiophyllites*, followed by *Paradanubites*, *Parapopanoceras*, *Psilokhvalynites*, *Paracrochordiceras*, *Danubites*, and Longobarditidae, but *Japonites* is rare. These faunas are very similar to those from Chios, with the exception of the Longobarditidae (*Groenlandites*, *Lenotropites*, *Grambergia* and *Arctohungatites*),

which is not documented in the type locality of the Aegean. Similar to the Deşli Caira faunas is the abundance of *Leiophyllites*, as well as the occurrence of *Paracrochordiceras*, Japonitidae and Longobarditidae (both under study). Danubitidae (*Danubites* and *Paradanubites*) apparently do not occur at Deşli Caira. The occurrence of *Aegeiceras* in the Fukkoshi Formation, which Ehiro (2022) cited with doubt, is not confirmed because the only specimen exhibits a keeled venter and spiral ornamentation with three ridges, instead of clavi.

### South Primorye

South Primorye (east Russia) is well known for its Triassic marine successions, which are important for the correlation of Tethyan-Pacific successions with those from the Arctic. The Olenekian to Anisian successions have been investigated in detail during the past 20 years by Zakharov and co-authors. These include several sections that straddle the O/A boundary (Zakharov et al. 2004, 2005a, 2005b), and apparently the best section is at Atlasov Cape (Zakharov et al. 2005a). The sections and the position of the ammonoid faunas have been well described, but their systematic descriptions have not yet been published.

At Atlasov Cape the uppermost Olenekian is represented by the *Subcolumbites multiformis* Zone, while the Lower Anisian is divided into a lower *Ussuriphyllites amurensis* Zone and an upper *Leiophyllites pradyumna* Zone. The richest fauna is from the *U. amurensis* Zone, whereas the *L. pradyumna* Zone is documented by only a few taxa.

At Atlasov Cape, the *U. amurensis* Zone consists of three fossiliferous levels (Zakharov et al. 2005a). The basal level, which marks the base of the Anisian and the *U. amurensis* Zone in the regional chronostratigraphic scale, yielded only *Prohungarites*?. *Prohungarites*, that is not present at Deşli Caira, is actually a middle Spathian ammonoid (e.g., Mertmann & Jacobshagen 2003; Guex et al. 2005, 2010; Jenks et al. 2013), and is also reported in the second level of the *U. amurensis* Zone, which yielded additional genera not documented at Deşli Caira, i.e., *Arctohungarites*, *Ussuriphyllites*, *Ussurites*, and *Parasageceras*. The second level also yielded *Megaphyllites*, a genus very common in the Lower Anisian of the Tethys Realm and Deşli Caira, and *Tropigastrites*, an Upper Anisian genus described by Smith (1914) from the Humboldt Range of Nevada (USA). The fauna from the

third level of the *U. amurensis* Zone is more similar to the Deşli Caira faunas, because of the occurrence of *Megaphyllites*, *Paracrochordiceras* and *Leiophyllites*, but these taxa are also accompanied by *Paradanubites*, a tethyan taxon not documented at Deşli Caira as well as *Ussuriophyllites* and *Arctohungarites*.

The *L. pradyumna* Zone at Altasov Cape has a poor ammonoid record (Zakharov et al. 2005a). At other localities (Zakharov et al. 2004), the zonal index co-occurs with taxa that are of Middle Anisian age, such as *Hollandites* and *Ptychites* at Zhitkov Peninsula, *Balatonites* at Tchenyschew Bay, and *Hollandites* and *Tropigastrites* at Golyi Cape.

### Arctic

Olenekian and Lower Anisian ammonoid-bearing successions are known from several areas of the Arctic, including the Sverdup Basin (Canada: e.g., Tozer 1967, 1994), Spitsbergen (Norway: e.g., Ishibashi & Nakazawa 1989; Weitschat & Dagys 1989), and Siberia (e.g., Popov 1961; Dagys 1987, 1998, 2001 cum litt.; Dagys et al. 1979, 1996; Konstantinov & Kletz 2009). In Siberia, which has the most complete sections, the most important areas include the Taimyr Peninsula, the Olenek and Lena River basins, and the Magadan area. Three ammonoid zones are recognized in the Lower Anisian, i.e., *Grambergia taimyrensis*, *Lenotropites solitarius* and *Lenotropites caurus*, and the first two zones are further subdivided into subzones.

Comparison of the Triassic Boreal ammonoid faunas with those from the Tethys is always complex, due to paleobioprovincialism, whereas faunas from North America sometimes share several taxa with the Boreal faunas (Tozer 1981a,b; Dagys 1988). This is true also for the Lower Anisian, characterized in the Arctic by Arctohungaritidae and several Groenlanditinae, both of which have never been reported from the Tethys, and *Lenotropites*, which occurs in North America from high to low paleolatitudes in British Columbia and Nevada, respectively (the occurrence in the Tethys, Quingai: Wang 1985; He et al. 1986 are not confirmed: see Bucher 1989). The Longobarditinae occupied several paleobioprovinces, with *Grambergia* occurring in the Arctic and Pacific, but with a doubtful occurrence in Qinghai (see Bucher 1989). *Grambergia*-like Longobarditinae are documented at Deşli Caira, but further study is necessary to clarify the taxonomy of this group of ammonoids and their possible use-

fulness for correlation with Pacific and Arctic successions. The Popanoceratidae were limited to the Arctic and Pacific paleobioprovinces, but during the Early Anisian *Stenopopanoceras* was quite common in the Tethys, at least along the southern margin of Laurasia (Deşli Caira, Caucasus, and Nakhlaq, Iran). This genus, which occurs in Siberia in the *Grambergia taimyrensis* Zone (e.g., Dagys et al. 1979; Dagys & Ermakova 1981; Konstantinov et al. 2007), currently appears to be the best marker for Tethys-Pacific-Arctic correlation of the Deşli Caira succession, at least with regard to the Aegean portion of the section.

*Paracrochordiceras* may possibly be another useful marker, as it is known from the Mulleri Zone of northeastern British Columbia and probably from the Caurus Zone of the Arctic (Tozer 1994). The occurrence of this genus in Siberia is probable, but its systematic and stratigraphic position is complex (see discussion in Monnet et al. 2013).

### POTENTIAL MARKER EVENTS FOR THE DEFINITION OF THE BASE OF THE ANISIAN GSSP

During the past 30 years the method for defining the base of the Anisian stage has become a matter of discussion, and several non-ammonoid events have been examined to integrate/replace the ammonoid boundary suggested by Assereto (1974). Gaetani et al. (1992), noted the position of the FO of *Chiosella timorensis* below the ammonoid boundary and the FO of *Neogondolella regale* above it. Muttoni et al. (1996) used the FO of *C. timorensis* to approximate the O/A boundary, but did not act on its formalization. The definition of the Anisian GSSP was discussed during a business meeting of the STS in 2002 at Veszprem (Hungary: Warrington 2003) and a majority of the participants voted for the FO of *C. timorensis*. Although the vote was informal, it notably influenced the interpretation of the Lower-Middle Triassic time scale for several years (e.g., Krystyn et al. 2004; Grădinaru et al. 2007; Orchard et al. 2007a; Hounslow et al. 2007; Hounslow & Muttoni 2010). This influence was notwithstanding that uncertainties regarding the possible co-occurrence of the types of *C. timorensis* with Olenekian ammonoids were reported in the original description of *Gondonella timorensis* by Nog-

ami (1968: 117; Nicora 1977: 93), as remarked by Konstantinov & Klets (2009: 179) a few years before the discovery of *C. timorensis* within the Haugi Zone in the Northern Humboldt Range, Nevada (Goudemand et al. 2012). An alternative boundary solution based on magnetostratigraphy was proposed by Hounslow et al. (2007, fig. 1 and 2), who proposed the base of the magnetochron MT1 as the best boundary solution after the calibration of a complex correlation chart including South China, Chios, Kçira, Deşli Caira, Spitzbergen and non-marine sections. Some years later, Muttoni et al. (2019) revitalized the discussion of the O/A boundary by revising available data from Kçira-A, and suggested six possible events recorded in the section (Fig. 13), including three conodont events and three magnetozone boundaries. Chen et al. (2020) proposed a combination of the FO of *Chiosella timorensis* and the base of MT1n.

In this work we emphasize the fact that the O/A AFT is higher than the combination of the FO of *C. timorensis* and MT1n. In actuality, it is very close to the base of the magnetochron MT3 (Fig. 10, 15), a worldwide marker, as shown by Hounslow & Muttoni (2010), Chen et al. (2020) and Lucas (2023), which is much easier to detect in local magnetostratigraphic scales than MT1n.

We propose to define the base of the Anisian by using the O/A AFT in combination with the base of magnetochron MT3. The O/A ammonid faunal revolution probably represents the most significant faunal turnover in the history of Triassic Ammonoidea, consisting of the extinction of eight families and the appearance of five new families, following Tozer's (1981a) suprageneric systematics. This faunal revolution was of such importance that it affected all Triassic paleobioprovinces, and it supports the use of this event to mark the base of the Anisian. Further research is necessary at Deşli Caira to 1) precisely locate the faunal turnover within the interval between the top of bed 821A and the base of 822A2, and 2) to select a specific ammonoid event as the primary marker for the GSSP, in order to provide a univocal reference for definition of the GSSP.

The importance of the ammonoid faunal turnover and its position very close to an easily recognizable magnetostratigraphic boundary serve as an absolutely powerful combination for selecting an easily correlatable GSSP. The support of oth-

er tools such as conodonts and chemostratigraphy will be necessary in order to present a successful proposal.

Conodonts are under study by Golding, who recently identified the FO of *Neogondolella curva* in sample 204/205 (Golding 2021), which is equivalent to 822 of Grădinaru et al. (2007) and Orchard et al. (2007a), which in turn is equivalent to our 822A2.

Two sets of chemostratigraphic data are available:  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  discussed by Atudorei (in Grădinaru et al. 2007), and  $\delta^{13}\text{C}$  from Horachek & Grădinaru (2023). Unfortunately, all of these data were referred to a synthetic log of Deşli Caira section, therefore further work is necessary to reposition these samples in our high resolution log.

## CONCLUSIONS

Our initial study of the Grădinaru collection from the Deşli Caira section (Northern Dobrogea) housed at University of Bucharest and of the fossiliferous locality itself produced a number of results, which are summarized as follows:

1. Examination of the collections left by co-author E. Grădinaru led to the identification of 833 ammonoids, whose stratigraphic position is known. To these must be added 126 ammonoids collected by us bed-by-bed.
2. The Deşli Caira stratigraphic section B has been located and re-measured. Most of the ammonoid bearing beds have been identified in the field.
3. Ammonoids are not re-elaborated, but they are often preserved as "hollow phragmocones" with geopetal filling of sediment and cement, resulting from early dissolution of the septa prior to orduring burial.
4. The lack of suture lines, which are rarely preserved, makes the classification of ammonoid taxa quite difficult and complex. Despite these issues, several Aegean taxa have been recognized and described as follows: *Stenopopanoceras transiens* Tozer, 1972, *Paracrochordiceras denseplicatum* Fantini Sestini, 1981, *Aegeiceras ugra* (Diener, 1895), *Leiophyllites pradyumna* (Diener, 1895) and *L. pseudopradyumna* (Welter, 1915). In addition to these taxa, a new genus and new species, i.e., *Gradinarnites aegeicus* n. gen. n. sp., and a new species, i.e., *Robinsonites*



*simionescui* n. sp., have been described, and a single specimen has been classified as *Acrochordiceras* sp.

5. The Olenekian/Anisian AFT, which probably represents the largest turnover in the history of Triassic Ammonoidea, has been indentified in the ~1 m thick interval between the top of bed 821A and the base of bed 822A2. At the present time, this positioning cannot be more precise due to small number of fragmentary specimens thus far collected from 822A1.
6. Calibration of the ammonoid range chart, intergrated with the two conodont events (FO of *Chiosella timorensis* in bed 817 and FO of *Neogondolella curva* in bed 822A2) and magnetostratigraphy by Gallet et al., in Grădinaru et al. (2007), although slightly imprecise, allows us to demonstrate that A) the section is not affected by hyatuses, because all upper Olenekian to lowermost Anisian magnetochrons are documented (LT9 to MT3); B) the O/A AFT is recorded in the lowermost part of MT3, near its lower boundary.
7. The ammonoid record of the two Anisian GSSP candidate section Kçira (Albania) and Wantou (China), as well as of Chios (Greece), type locality of the Aegean substage of the Anisian, have been re-examined in detail on the basis of data from literature, and compared with the published magnetostratigraphy. Kçira and Wantou do not have a good record of Aegean/Lower Anisian ammonoids. Chios is rich in ammonoids, but most are from a single bed. Faunal comparison with other important localities from the Tethys, Pacific and Arctic paleobioprovinces are discussed.
8. After a review of the possible marker events for the Anisian GSSP thus far suggested in the literature, we propose that this boundary be defined on the basis of the combination of the O/A AFT, which affected all Triassic paleobioprovinces, and the base of magnetochron MT3.

The main goal of our 2023 research program has been achieved; that is, we have demonstrated that the Deşli Caira section is perfectly suitable for the definition of the Anisian GSSP.

Ongoing research includes high-resolution sampling of the O/A AFT, in order to more precisely locate this faunal change and to identify an ammonoid event for use as a primary marker for the GSSP. Field work is scheduled for September 2024. The systematic study of ammonoids is in progress and will be completed in 2025.

Scheduled research on ammonoids is coordinated with new sampling for conodonts and possibly new sampling for chemo and magnetostratigraphy.

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