The Global Boundary Stratotype Section and Point (GSSP) for the base of the Anisian Stage: Deşli Caira Hill, North Dobrogea, Romania

Eugen Gradinaru
University of Bucharest

M. J. Orchard
Natural Resources Canada

Alda Nicora
University of Milan

Leopold Krystyn
University of Vienna

The Global Boundary Stratotype Section and Point (GSSP) for the base of the Anisian Stage: Deşli Caira Hill, North Dobrogea, Romania

Eugen Grădinaru [1], Michael J. Orchard [2], Alda Nicora [3], Yves Gallet [4], Jean Besse [4], Leopold Krystyn [5], Evgeny S. Sobolev [6], Nicu-Viorel Atudorei [7], Daria Ivanova [8]

[1] University of Bucharest, Faculty of Geology and Geophysics, Department of Geology and Palaeontology, Blvd. Bălcescu Nicoale 1, RO-010041 Bucharest, Romania, E-mail: egradin@geo.edu.ro; [2] Geological Survey of Canada, 625 Robson Street, Vancouver, B.C., V68 513 Canada, E-mail: MOrchard@nrcan.gc.ca; [3] Universita degli Studi di Milano, Dipartimento di Scienze della Terra, Via Mangiagalli 34, 20133 Milano, Italy, E-mail: alda.nicora@unimi.it; [4] Institut de Physique du Globe de Paris 4, place Jussieu - Case 89 - 75252, Paris Cedex 05, France; E-mails: gallet@ipgp.jussieu.fr; [5] University of Vienna, Department of Palaeontology, Geozentrum, Althanstrasse, A-1090, Vienna, Austria, E-mail: leopold.krystyn@univie.ac.at; [6] Siberian Branch of Russian Academy of Sciences, Trofimuk Institute of Petroleum Geology and Geophysics, Akademgorodok, Koptyug Ave. 3, 630090 Novosibirsk, Russia, E-mail: SobolevES@ipgg.nsc.ru; [7] University of New Mexico, Department of Earth and Planetary Sciences, Stable Isotope Laboratory, Northrop Hall Rm. 225C, Albuquerque, NM, United States, E-mail: atudorei@unm.edu; [8] Bulgarian Academy of Sciences, Geological Institute "Strashimir Dimitrov", Acad.G.Bonchev Str., bl. 24, 1113 Sofia, Bulgaria, E-mail: dariaiv@hotmail.com

Introduction

The Deşli Caira Hill is herein proposed as the Global Boundary Stratotype Section and Point (GSSP) for the base of the Anisian Stage, and for the base of the Middle Triassic Series in the Triassic Time Scale. Multidisciplinary research by a multinational Task Group has provided a considerable amount of biostratigraphic, magnetostratigraphic, and chemostratigraphic data that allow us to have a multi-proxied definition of the Olenekian-Anisian (Lower-Middle Triassic) Stage and Series boundary in the section. This report summarises the attributes of the Deşli Caira Hill, which fulfil almost all of the ICS requirements for a GSSP.

The Global Boundary Stratotype Section and Point for the base of the Anisian Stage

(E. Grădinaru)

Geographic location and access

The Deşli Caira Hill lies in the northern part of Dobrogea, a province of Romania situated between the lower course of the Danube and the Black Sea coast, south of the Danube Delta (Fig. 1A). Having an altitude of 175 m, the Deşli Caira Hill is an impressive, isolated hill, located in the middle of hilly agricultural land, approximately 6 km east of Mihail Kogălniceanu village, or approximately 8 km west of Agighiol village (Fig. 1B), both of which are situated approximately 17 km south of Tulcea city, the capital of the Tulcea County. The hill can be easily reached by car, on asphalted roads from Tulcea to the above-mentioned villages, and then on unpaved roads. The coordinates are 28⁰ 48' 08" E and 45⁰ 04' 27" N. The name of the hill, Deşli Caira (in Simionescu, 1910a) or Berge Taşli (in Kittl, 1908), is Turkish in origin, and the feature is actually known in the Romanian toponymy as Stânca Mare (Big Stone) or Muchea Ascuțită (Sharp Summit).

Geological context

Deşli Caira Hill is located in the Agighiol Zone of the Tulcea Unit, a part of the Eo-Alpine North Dobrogea fold and thrust belt. The Tulcea Unit (Fig. 1A), which is famous in the classic literature for the spectacular development of the Triassic ammonoid faunas (Kittl, 1908; Simionescu, 1913), includes both basinal facies with thick marly sequences located in the western part, and carbonate platform facies located in the central-eastern part (Grădinaru 1995, 2000). The Agighiol Zone had an external position in the framework of the Triassic carbonate platform of the Tulcea Unit, westwards in actual geographic position. It is characterized by thick sequences of Hallstatt-type massive limestones, grouped in the Agighiol Limestone, and extending in age from the upper Spathian up to the lower Carnian. The Hallstatt-type limestones are interbedded with, or grade laterally and/or vertically into Ammonitico Rosso-type nodular siliceous limestones. The areal and stratigraphic distribution of these two sedimentary facies suggests complex sedimentary environments, controlled by active syn-sedimentary block faulting whereby raised blocks of seamount-type were separated by intra-platformal depressions. The Hallstatt-type limestone facies were deposited on the top of the seamounts whilst the Ammonitico Rosso-type were deposited in the intra-platformal depressions. As a consequence of the prevailing tectonics, the stratigraphic distribution of the two lithofacies show pronounced diachronic relationships which are elucidated

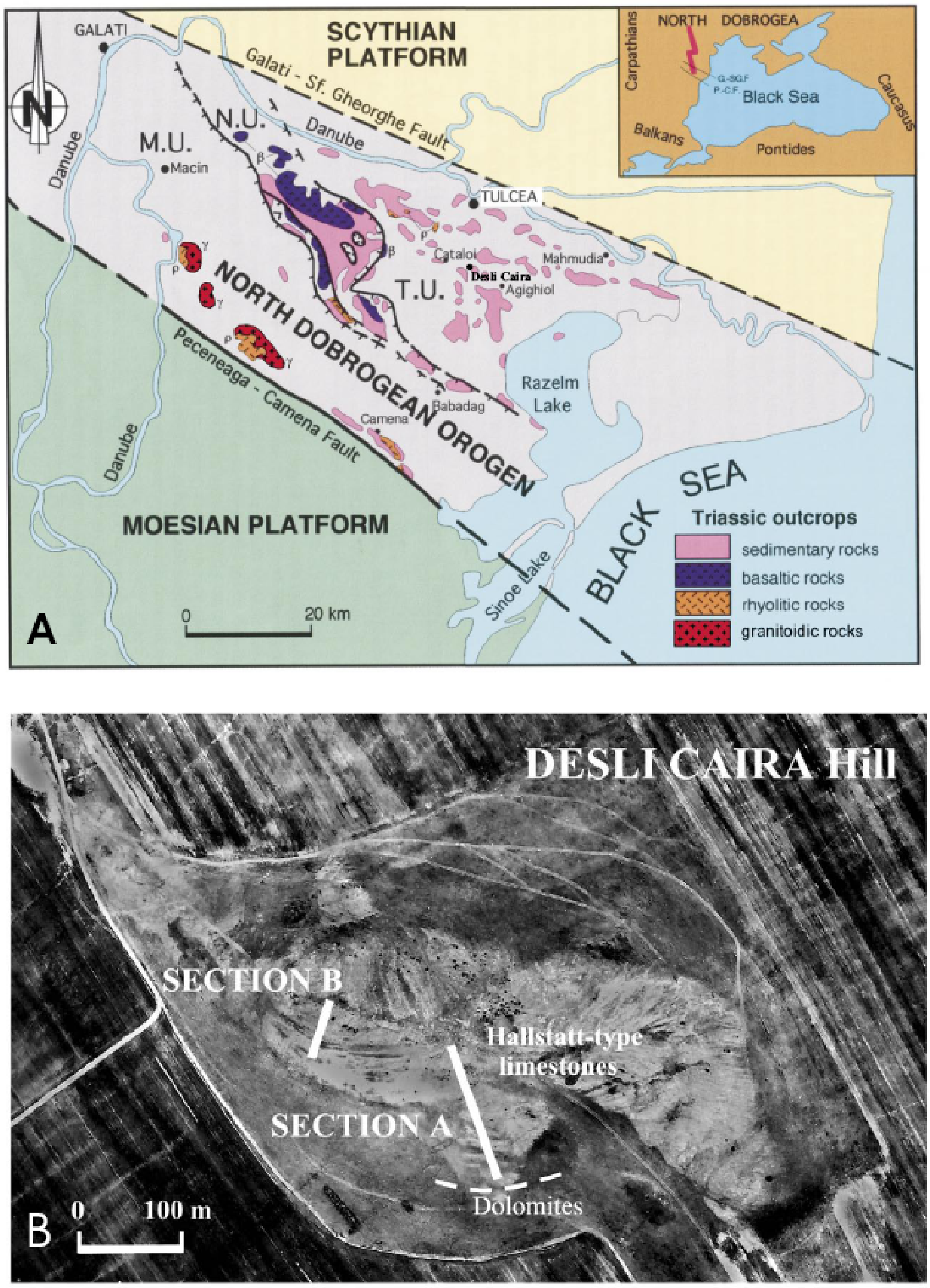


Figure 1: A. Locality map of the Dobrogea region in Romania showing the location of Deşli Caira Hill. B. Aerial photography of the Deşli Caira Hill showing the locations of sections A and B.

Geological context

Deşli Caira Hill is located in the Agighiol Zone of the Tulcea Unit, a part of the Eo-Alpine North Dobrogea fold and thrust belt. The Tulcea Unit (Fig. 1A), which is famous in the classic literature for the spectacular development of the Triassic ammonoid faunas (Kittl, 1908; Simionescu, 1913), includes both basinal facies with thick marly sequences located in the western part, and carbonate platform facies located in the central-eastern part (Grădinaru 1995, 2000). The Agighiol Zone had an external position in the framework of the Triassic carbonate platform of the Tulcea Unit, westwards in actual geographic position. It is characterized by thick sequences of Hallstatt-type massive limestones, grouped in the Agighiol Limestone, and extending in age from the upper Spathian up to the lower Carnian. The Hallstatt-type limestones are interbedded with, or grade laterally and/or vertically into Ammonitico Rosso-type nodular siliceous limestones. The areal and stratigraphic distribution of these two sedimentary facies suggests complex sedimentary environments, controlled by active syn-sedimentary block faulting whereby raised blocks of seamount-type were separated by intra-platformal depressions. The Hallstatt-type limestone facies were deposited on the top of the seamounts whilst the Ammonitico Rosso-type were deposited in the intra-platformal depressions. As a consequence of the prevailing tectonics, the stratigraphic distribution of the two lithofacies show pronounced diachronic relationships which are elucidated by biostratigraphic data.

The Tulcea Unit is the lowermost tectonic unit of the Eo-Alpine North Dobrogea fold and thrust belt, which in its turn represents the westernmost prolongation of the Cimmeride Orogenic System. The Niculiţel Unit, situated in the internal part and having thick pillowed basaltic rocks of Middle Triassic age, represents the Cimmerian suture zone of the Eo-Alpine North Dobrogea fold and thrust belt. In the actual regional tectonic framework of the Alpine-deformed regions around the Black Sea, the Tethyan-type Triassic terrains of North Dobrogea have a remote position as compared to the major Alpine-deformed regions. During the Triassic, the North Dobrogea region was included in the main Tethys area but post-Triassic large-scale horizontal movements displaced the North Dobrogea terrane to its present position. It is interpreted as an exotic terrane docked to Eurasia during the Alpine deformations of the Tethys area (Grădinaru, 1995, 2000).

Description of the GSSP section

The Stratotype Section and Point for the base of the Anisian Stage in the Deşli Caira Hill is located on the southern slope of the hill, in its western quarried side (Fig. 2A, B). There, Section B exposes a 60+ m thick sequence made up of Hallstatt-type massive to well-bedded bio-micritic limestones, mostly of wackestone type. In the area of the Deşli Caira Hill, the Hallstatt-type limestones are underlain by lower Spathian pinkish-white dolomites that represent dolomitic cuppolas developed on the higher paleoreliefs of the Variscan granitic basement. Eastwards and southwards, in the area of the nearby hills of Cara Constantin and Orta Bair, the Hallstatt-type massive limestones are overlain by the Ammonitico-Rosso siliceous nodular limestones starting within the basal part of the middle Anisian. On the contrary, in the area of the Uzum Bair Hill, 1 km westwards, the Ammonitico Rosso-type facies starts already in the lower Anisian, demonstrating its diachronic relationships with the Hallstatt-type facies.

Section A, located in the eastern side of the southern slope of the Deşli Caira Hill, includes the lower part of the Hallstatt-type limestone section. Having only scarce fossiliferous beds with poorly preserved ammonoid faunas, the Hallstatt-type limestones of the Section A are placed in the middle part of the Spathian. The dolomites underlaying Section A are interbedded with or grade laterally into bio-micritic and oncoid-bearing limestones that are coeval with the basinal bituminous marly-limestone sequence containing the Early Spathian *Tirolites cassianus* Beds in the Tulcea city area.

Stratotype Section B starts below the small abandoned quarry noted above, the bottom of which exposes cream-coloured limestones whereas the front of the quarry exposes a total of 5 m of mixed reddish to light gray coloured limestones that grade upwards into red-brick coloured limestones at the top of the quarry face. Subordinate "*Posidonia*"-bearing, whitish coquinoid limestones are interbeded with the Hallstatt-type limestones. The quarried sequence has abundant ammonoids and fewer nautiloids of late Spathian age. Other macrofaunas are poorly represented, with rare occurrences of small-sized brachiopods, gastropods and crinoids, and thin shelled bivalves at a few levels.

The Olenekian-Anisian Boundary (OAB) is located just above the top of the quarry (Fig. 2B). Above the OAB, the basal part of the lower Anisian is made up almost exclusively of thick-bedded, red-brick coloured Hallstatt-type limestones, with only rare intercalations of "*Posidonia*"-bearing reddish coquinoid limestones. The Hallstatt-type limestones are extensively bioturbated at some levels, with mottled aspects, and at few levels they show condensed sedimentation features; small open-space features are present in the upper part of the section. Neptunian dykes filled with gray sparry calcite, exposed in the quarried part of the Section B, cut the Hallstatt-type limestone sequence. The tops of the Neptunian dykes, filled with sediment, are located at the level of the *Aegeiceras ugra* Beds, thus suggesting a corresponding time for the dyke opening.

Below the OAB, sampling for macrofaunas is favoured by the now-abandoned quarrying works, whereas above the quarry and below the well-exposed strata of the *Aegeiceras ugra* Beds there is a relatively poorly exposed sequence in the basal part of the Anisian. If not covered by soil, the beds are heavily masked by lichen crusts which make the sampling for fossils difficult. To improve this, extensive trenching was done in the basal part of the Anisian section, just above the quarry. Compared with the upper Spathian sequence, which is very fossiliferous and shows a remarkable continuity in macrofossil occurrence, the basal part of the lower Anisian shows a marked impoverishment in the

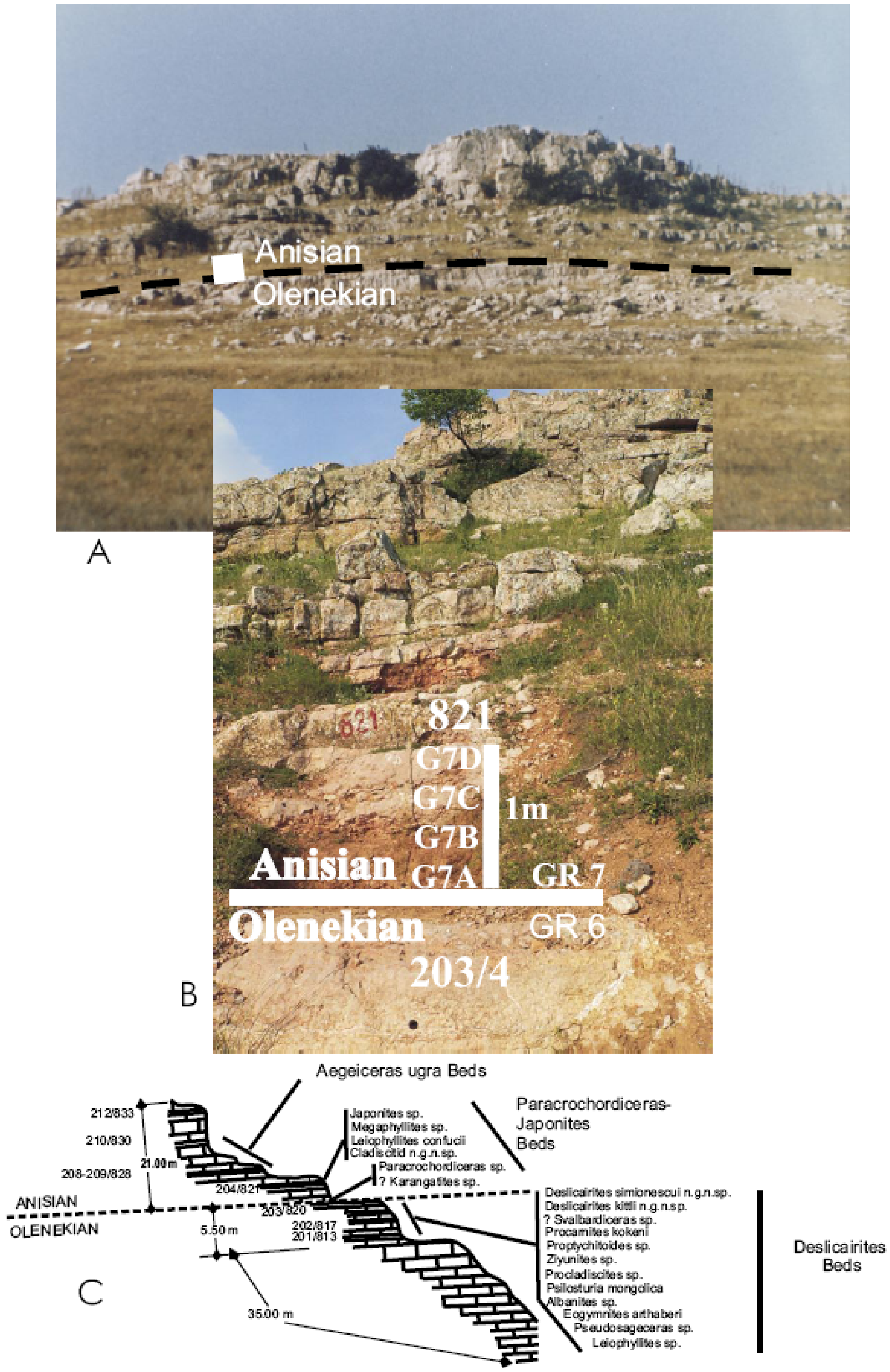


Figure 2: A. Panoramic view of southern slope of Deşli Caira Hill showing the quarry front and the position of the trench exposing the proposed OAB GSSP. B. Photograph of beds straddling the OAB. C. Sketch of the proposed GSSP showing bed numbers, the location of the OAB, and the position and composition of the ammonoid faunas.

macrofossil content. Nevertheless, both macro- and microfossil fauna constrain the position of the OAB.

Biostratigraphy (E. Grădinaru, E. S. Sobolev, M. J. Orchard, A. Nicora, D.Ivanova)

Several fossil groups provide biostratigraphic markers for the boundary interval: ammonoid and non-ammonoid cephalopds studied by E.Grădinaru and E. S. Sobolev, conodonts studied by M. J. Orchard and A. Nicora, and foraminifera studied by D. Ivanova.

Ammonoid and non-ammonoid cephalopods

The Hallstatt-type limestones from the Deşli Caira Hill Section B share a continuous record of ammonoid and non-ammonoid cephalopod faunas around the Olenekian-Anisian boundary. Figure 2B summarizes the occurrence data for ammonoids, and Figure 3 shows the data for non-ammonoid cephalopods. The present data demonstrates that the Deşli Caira Hill Section B has the most complete ammonoid and non-ammonoid cephalopod sequence in the Tethyan realm for the time interval around the OAB (Grădinaru & Sobolev, 2006).

The ammonoid and non-ammonoid cephalopod faunas of the Deşli Caira Hill section were first investigated by Kittl (1908) and Simionescu (1910a, b), who described several new taxa. Both authors emphasized the importance of the locality for the ammonoid biostratigraphy of the Anisian in the Tethyan Realm. During the last decades cephalopod faunas have been intensively collected from several stratigraphic levels by the first author (EG). At least eleven levels of distinct, stratigraphically successive cephalopod faunas were identified in the Deşli Caira Hill Section B (Grădinaru, 2000), and there remains a high potential to improve this record.

The latest Olenekian is documented by the *Deslicairites* Beds (Fig. 2B, levels 203/820 and 203/204) characterized by the occurrence of a very abundant and diversified ammonoid fauna including species of well-known latest Spathian genera such as *Procarnites*, *Albanites*, *Proptychitoides*, *Preflorianitoides*, *Ziyunites*, *Leiophyllites*, *Eogymnites*, *Pseudosageceras*, and several new ammonoid taxa. Of outstanding value is the occurrence in the latest Spathian of an olenekitid-like ammonoid species group informally assigned to the new genus *Deslicairites* (Grădinaru, 2003). Some genera traditionally considered as diagnostic for the early Anisian, such as *Procladiscites* and *Psilosturia*, appear first in the latest Spathian. On the other side, there are also some genera considered as diagnostic for the Spathian, such as *Ziyunites* (Wang, 1978, 1985; Wang & He, 1979) that straddle the boundary level, as Fantini Sestini (1981) already mentioned for Chios.

The basal Anisian is documented by the *Paracrochordiceras-Japonites* Beds (Fig. 2B, level 204/821), in which the presence of a *Karangatites*-akin ammonoid and also '*Romanites*' cf. *simionescui* Welter are recorded. The succeeding interval (Fig. 2B, levels 826 to 830) contains ammonoid assemblages grouped in the *Aegeiceras ugra* Beds.

Until recently, non-ammonoid cephalopods from the OAB interval in the Tethyan areas remained almost completely unknown. It is now established by the data in the Deşli Caira Hill Section B that three orders of non-ammonoid cephalopods are represented in the OAB interval: Orthocerida, Nautilida, and Aulacocerida (Fig. 3). Besides new species of known genera there are also representatives of several new genera. The orthocerids, which are the most numerous amongst those recovered, are represented by the genera *Trematoceras*, *Romanorthoceras* gen. nov. (Pseudorthoceratidae), and *Paratrematoceras* (Orthoceratidae). The nautilids include the genera *Syringoceras*, *Deslinautilus* gen. nov., *Ascutitonautilus* gen. nov. (Syringonautilidae), and *Phaedrysmocheilus* (Tainoceratidae). The aulacocerids have rare representatives of the genera *Atractites*, as rests of phragmocones (Xiphoteuthidae), and *Dictyoconites* (Dictyoconitidae).

The analysis of the stratigraphic distribution of the non-ammonoid cephalopods has resulted in the recognition within the OAB interval at Deşli Caira Section B of five assemblages characterized by specific orthocerids and nautilids (Fig. 3). For the aulacocerids it is not possible to distinguish assemblages due to their rarity.

In the topmost Olenekian, the orthocerid-based "beds with *Paratrematoceras abundans*" are characterized by a rather varied assemblage including five new species assigned to the genera *Paratrematoceras*, *Trematoceras*, and *Romanorthoceras*. The nautilids are grouped in two distinct, successive assemblages: the "beds with *Deslinautilus limatulus*" and "beds with *Syringoceras mediocre*", respectively. The lower assemblage includes three new species assigned to the genera *Deslinautilus* and *Phaedrysmocheilus*. The upper assemblage is represented only by the index species.

In the basal Anisian, the orthocerid-based "beds with *Paratrematoceras conspicuum*" include, besides the index-species, a new species of the genus *Trematoceras* and the species *P. productum*, known also in the underlying beds of the topmost Olenekian. Besides the index species, the nautilid-based "beds with *Syringoceras exiguum*" include representatives of the new genus *Ascutitonautilus*, which is the direct descendant of the Olenekian genus *Deslinautilus*. The *Dictyoconites* species with poorly advanced and thin sculpture are common for the topmost Olenekian, whilst in the basal Anisian there are more roughly sculptured forms (*D. kongazensis* Kittl).

Thus, in the Tethyan Triassic of North Dobrogea there are essential changes across the OAB in the orthocerids and nautilids. Three genera (*Romanorthoceras*, *Deslinautilus*, and *Phaedrysmocheilus*) that are known in the late Olenekian do not pass into the early Anisian, where the new genus *Ascutitonautilus* appears in a more impoverished nautilid assemblage. Among the aulacocerids changes occur only at a specific level.

Conodonts

Conodonts from Deşli Caira were collected over many

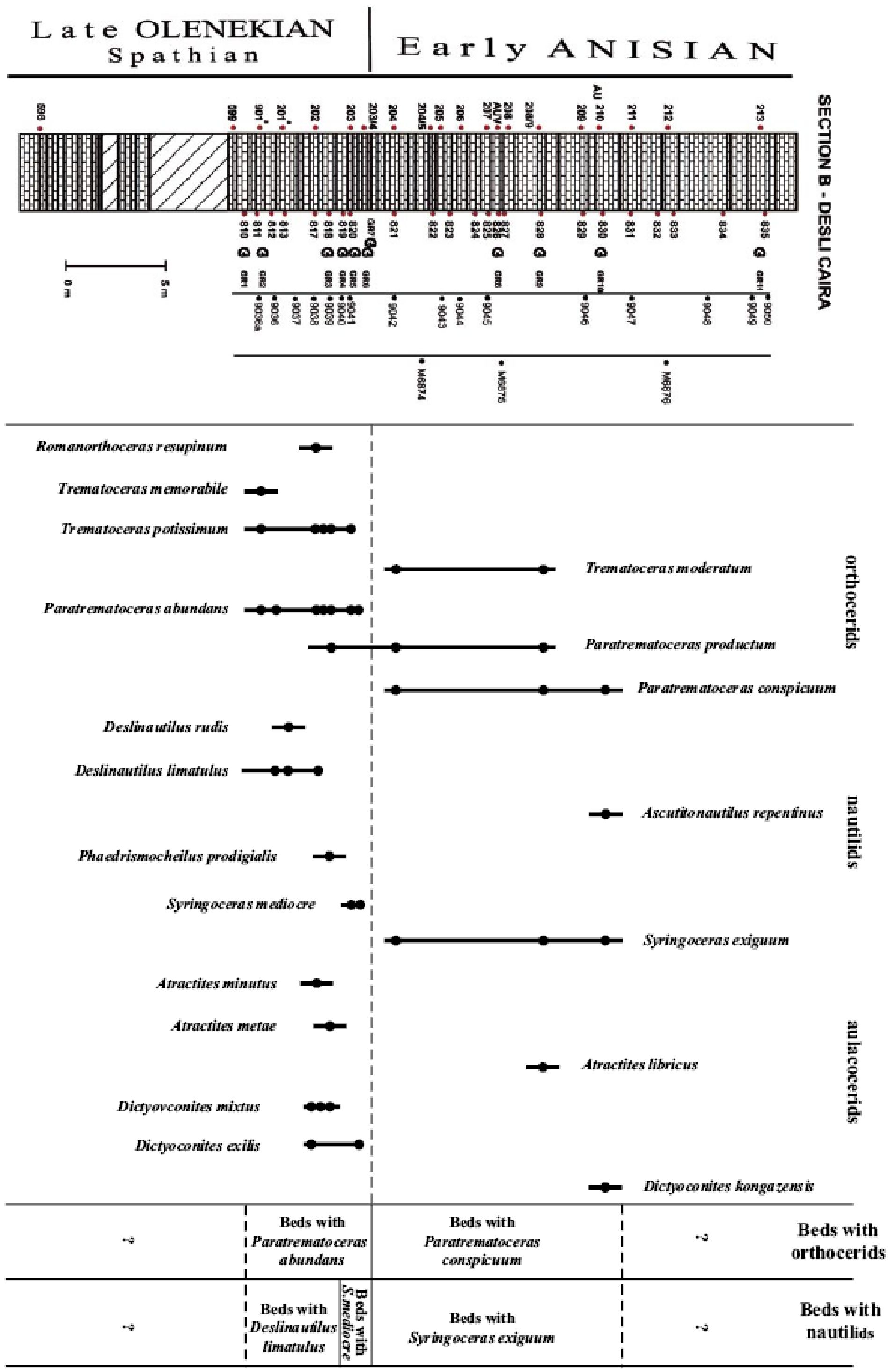


Figure 3: Stratigraphic distribution of non-ammonoid cephalopods across the proposed OAB in the Deşli Caira section (North Dobrogea).

years and by several workers. Some of these data have been presented in preliminary papers by Mirăuță (1974, 2000) and Grădinaru et al. (2002, 2006). The data have most recently been summarized by Orchard et al. (2007a; Figs. 4, 5), and many of the taxa and their distribution were discussed by Orchard et al. (2007b).

Conodont samples were recovered from about 25 m of section straddling the OAB. Several species present in the samples from the upper Olenekian – *Triassospathodus*, *Cratognathus* spp., *Spathiscuspus*, '*Gladigondolella' carinata*, and new genus A – probably have a longer history prior to the latest Olenekian, so their appearances in this section are not regarded as significant. In contrast, nine conodont appearances (i.e., FAD) and disappearances (i.e., LAD) are identified as guides to identify the OAB in the Deşli Caira section. Several of these are coincident, and all occur within about 4.25 m of strata. For the remaining 20 m of section, the fauna maintains a relatively constant composition (Fig. 4). These conodont events are (with positions relative to the OAB):

1) FAD of *Chiosella gondolelloides* (-3 m)
2) LAD of *Spathiscuspus* (-1 m)
3) LAD of *Neospathodus triangularis* (0 m)
4) FAD of *Chiosella timorensis* (0 m)
5) LAD of '*Gladigondolella' carinata* (0 m)
6) FAD of *Chiosella* n. sp. A (0 m)
7) FAD of *Gladigondolella tethydis* (+0.5 m)
8) LAD of *Triassospathodus* (+1.25 m)
9) FAD of *Neogondolella* (+1.25 m)

These conodont events are grouped so as to define five datums at Deşli Caira:

Datum 1

The first significant datum is the FAD of *Chiosella gondolelloides* at about 3 m below the OAB. The appearance of *C. gondolelloides* is an easily recognized datum since the separation of the species from its apparent forebear and common associate, *Triassospathodus* ex gr. *homeri,* is straightforward.

Datum 2

The LAD of *Spathiscuspus spathi* at 1 m below the OAB is an earlier LAD than is seen elsewhere (e.g. at Guandao, China; Orchard et al., 2007b), where the species ranges into basal Anisian strata. The species is far less common in the Romanian faunas and this datum is not a useful one for correlation.

Datum 3

This is the major faunal change of the succession and is marked by the appearance of *Chiosella timorensis* and *Chiosella* n. sp. A, and the disappearance of both *Gladigondolella carinata* and *'Neospathodus' triangularis*. These four conodont events are not entirely synchronous elsewhere (e.g. Orchard et al., 2007b), but they all cluster around the OAB.

Datum 4

The FAD of *Gladigondolella tethydis* occurs 0.5 m above the OAB. This appearance in the early Anisian is consistent with records elsewhere (e.g. Orchard et al., 2007b).

Datum 5

At 1.25 m above the OAB, the LAD of *Triassospathodus* ex gr. *homeri* coincides with the FAD of *Neogondolella* sp. These two taxa are known to overlap elsewhere in Tethys and also in North America. In Tethyan successions, the overlap is within the basal Anisian, as it is in the Deşli Caira, but in North America it occurs first in the late Spathian. Although the overlap of taxa is not a reliable datum worldwide, the LAD of *T.* ex gr. *homeri* is nevertheless a reliable early Anisian event.

Foraminifera

The studied foraminifera contains very rich, diverse, and well-preserved taxa, including more than 25 species, belonging to eight agglutinated and ten non-agglutinated genera. These were investigated both as isolated forms obtained by dissolution and in thin sections. The stratigraphic distribution of the foraminifera in Deşli Caira Hill Section B is shown in Figures 4, 5.

The lower part of the Deşli Caira Hill Section B contains a rich foraminiferal association, including species which share a high potential for biostratigraphic correlation. These are: *Rectocornuspira kalhori* Broennimann, Zaninetti & Bozorgnia, *Cornuspira mahajeri* (Broennimann, Zaninetti & Bozorgnia), *Glomospira tenuifistula* Ho, *Glomospirella vulgaris* Ho, *Hoyenella* gr. *sinensis* (Ho), *Meandrospira cheni* (Ho), *Meandrospira pusilla* (Ho), *Ammobaculites radstadtensis* Kristan-Tollmann, *Ammobaculites duncani* Schröder, *Ammodiscus parapriscus* Ho, *Trochammina almtalensis* Koehn-Zaninetti, *Textularia racemata* Terquem & Berthelin, *Textularia rectangularis* Deprat, *Earlandia tintinniformis* (Misik), *Bigenerina vallis* (Trifonova), *Nodogordiospira conversa* Trifonova, *N. praeconversa* Trifonova and *Neotolypammina discoidea* (Trifonova). The above-mentioned foraminiferal association, referred to the *Rectocornuspira kalhori - Cornuspira mahajeri* assemblage (Assemblage 1 in Fig. 4), is diagnostic for the upper part of the Olenekian Stage (Spathian Substage) and shows many affinities with globally-distributed taxa.

For the upper part of the Deşli Caira Hill Section B, the foraminiferal assemblage (Assemblage 2 in Fig. 4) includes the following taxa: *Meandrospira dinarica* Kochansky-Devide & Pantic, *Endotriadella wirzi* (Koehn-Zaninetti), *Krikoumbilica peleiformis* He, *Glomospirella grandis* (Salaj, Biely & Bystricky), *Hoyenella* gr. *sinensis* (Ho), *Trochammina almtalensis* Koehn-Zaninetti, *Neotolypammina discoidea* (Trifonova), *Textularia racemata* Terquem & Berthelin, *Textularia rectangularis* Deprat, *Turriglomina conica* (He), *Earlandia tintinniformis* (Misik), *Earlandia amplimuralis* (Pantic) and *Nodosaria* sp. These foraminif-

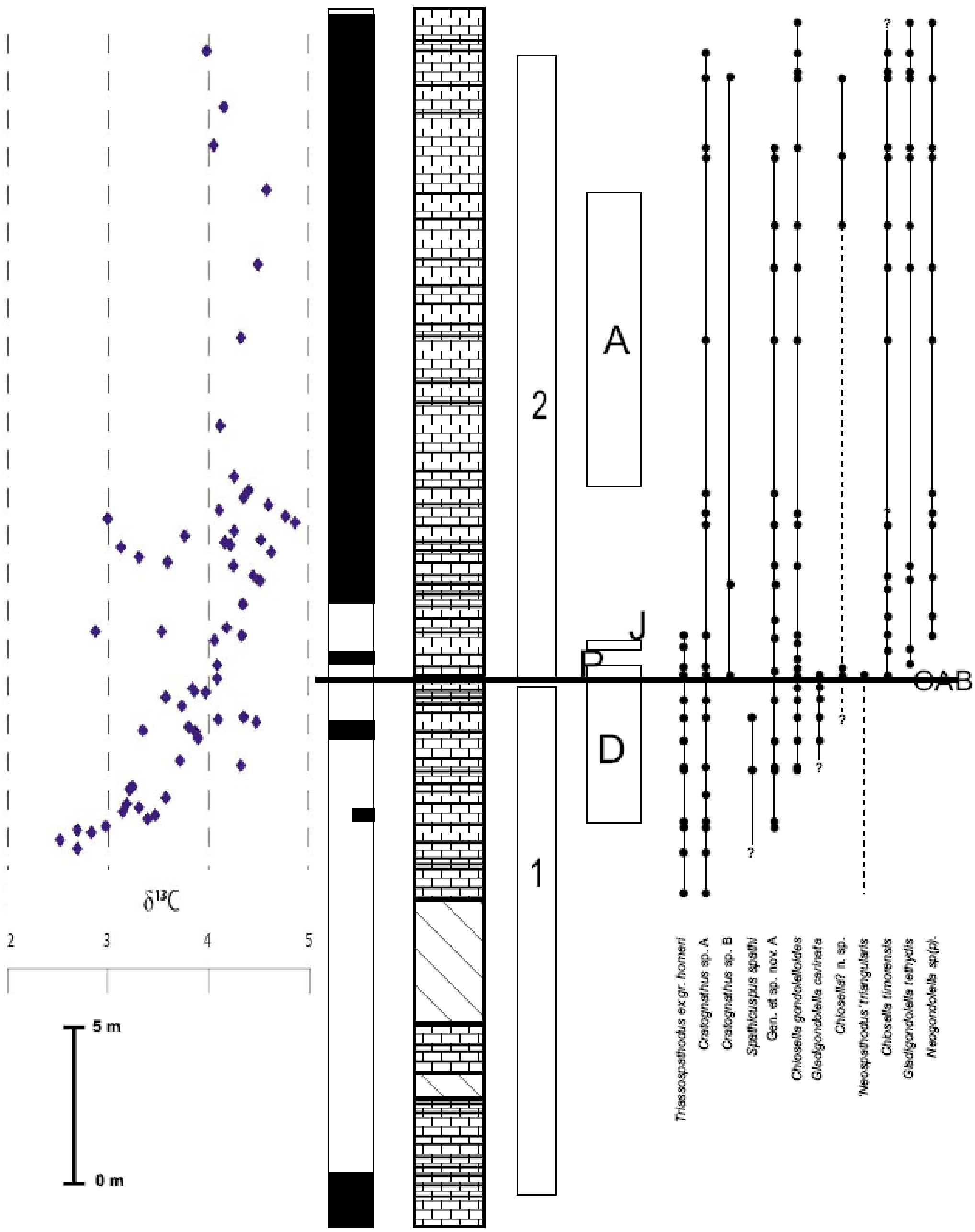


Figure 4: Schematic presentation of (from right) conodont, ammonoid, foraminifers, stratigraphic section, magnetic polarity, and carbon isotope data from Deşli Caira Hill with proposed position of OAB GSSP. For ammonoids, D = Deslicairites Beds; P, J = Paracrochordiceras - Japonites Beds; A = Aegeiceras ugra Beds. See text for details of foraminiferal assemblages 1 and 2.

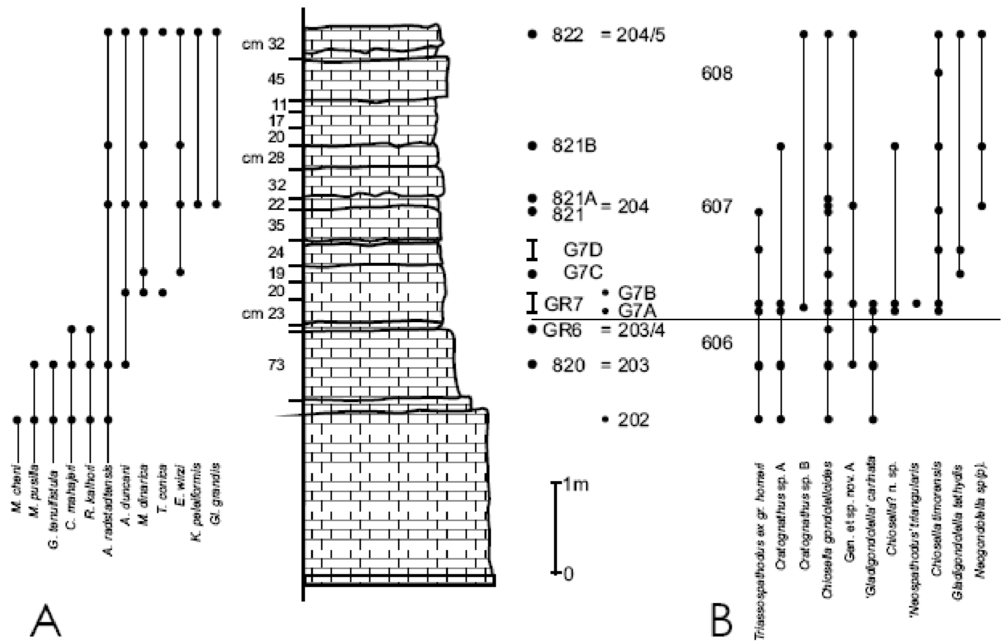


Figure 5: Details of the occurrence of A, foraminifers and B, conodonts, across the OAB at Deşli Caira Hill.

ers is diagnostic for the lowermost Anisian Stage (Aegean Substage) and shows many affinities with globally-distributed taxa.

Some results concerning taxonomic status and stratigraphic distribution of studied foraminifera have to be underlined, as follows:

1) The *Rectocornuspira kalhori – Cornuspira mahajeri* assemblage is known to be widespread in the Lower Triassic of the Tethyan Realm. In several Tethyan sections, it is the first Triassic foraminifera association appearing above the Permian-Triassic boundary, and has been used as an indicator marker for the lower part of Lower Triassic. The predominance of this assemblage in the Deşli Caira Hill Section B confirms the conclusions of Trifonova (1993) and Hips (1996) that the vertical range of the assemblage is not limited to the lower Induan but occurs throughout the Lower Triassic.

2) The age of the species *Bigenerina vallis*, originally reported as a new species from the Spathian of northeast Bulgaria (Trifonova, 1967), is here confirmed in the Deşli Caira Hill section on the evidence of associated conodonts and ammonoids.

3) Based on detailed foraminiferal investigation we are not able to establish the distribution of the genus *Meandrospira* of the lineage *M. cheni – M. dinarica*, which evolves from *M. pusilla*. Although the thin sections and isolated samples were very poor in species of this genus, we are nevertheless able to confirm the results of Rettori et al. (1994) that *M. dinarica* appears during the early Anisian. In terms of systematics, the problem with the species assignment to the genus *Meandrospira* is still open for discussion.

4) *Krikoumbilica peleiformis* has been known in the Middle Triassic of China (Ho, 1984). Rettori et al. (1994) recorded the species for the first time from the Scythian in Hydra Island, Greece "on the basis of the presence of the conodont *Neospathodus homeri* in the same sample". Taking into account that the species *N. homeri* in Deşli Caira Hill Section B range up to the lowest meter of the section above the boundary level (Grădinaru et al., 2002; Orchard et al., 2007a), it seems that the species is earliest Anisian in age.

Only a limited number of papers describe isolated Triassic foraminifera, and these are from only a few isolated levels. The identification of species and genera from Triassic rocks has been essentially done in thin sections. The main problem that arises is how to correlate the taxonomy of foraminifera in thin sections to those ones identified as isolated forms. In the present study we could not resolve these taxonomic problems, but nevertheless we propose realistic assemblages, identified both in thin sections and washed isolated material. Of particular stratigraphic importance are the following conclusions:

- in the Lower Triassic part of the Deşli Caira Hill Section B representatives of the *Glomospira – Glomospirella* microbiofacies are predominant;

- typical Lower Triassic *Rectocornuspira kalhori – Cornuspira mahajeri* assemblage disappears 0.50 m below the boundary level;

- in the Deşli Caira Hill Section B typical Lower Triassic species are identified as *Bigenerina vallis, Nodogordiospira conversa,* and *N. praeconversa*;

- *Meandrospira dinarica* occurs in the lowest meter of the Deşli Caira Hill Section B above the boundary level; in the same thin section we found a single specimen of species *Turriglomina conica*, another characteristic Middle Triassic taxa;

- the typical Middle Triassic species *Endotriadella wirzi* appears first about 0.50 m above the boundary level;

- some characteristic Anisian taxa such as *Krikoumbilica peleiformis* and *Glomospirella grandis* appear first at about 1.20 m above the boundary level. This occurrence is chronologically important because there are no isolated foraminifers from this first meter, and the association is indicative for the Middle Triassic age.

- The agglutinated genera belonging to the foraminiferal Suborders Textulariina, Miliolina, Fusulinina, and Lagenina are predominant in the Hallstatt-type limestones of the Deşli Caira Hill Section B and they have a high taxonomic diversity.

Magnetostratigraphy (Y. Gallet, J. Besse, L. Krystyn)

About 150 samples were collected from the two subsections of the Deşli Caira Hill sections, Section A and Section B. Only the results obtained from Section B are relevant for the OAB. The samples were analyzed in the paleomagnetic laboratory at the Institut de Physique du Globe de Paris.

Thermal demagnetization reveals two magnetic components. A first largely predominant component (LTC) is isolated over a wide temperature range, from the first demagnetization step up to 400°C, and sometimes higher (Fig. 6A). The mean direction obtained for this component is roughly parallel to the present day field at the site (Fig. 6Ba). A high temperature component (HTC) is then isolated up to 580°C or to 640°C-680°C, which indicates that this component is carried by magnetite and/or by hematite (Fig. 6A). In some cases, a large overlap exists between the LTC and HTC components, which precludes the determination of a precise (« end-points») direction for the HTC component; for these samples, however, great circle analyses help to constrain the magnetic polarity of the HTC component (grey circles in Fig. 7). The HTC component has dual magnetic polarities and is interpreted as being acquired during, or very soon after sediment deposition (Fig. 6Bb). The HTC directions (and great circles) define a magnetic polarity sequence which allows us to place the Olenekian (Spathian)-Anisian (Aegean) boundary with respect to the chronology of the geomagnetic field reversals (Fig. 7).

The results of this study show that the OAB is located between two short normal magnetic polarity intervals. These results align well with the magnetic polarity profile at the Kçira section in Albania (Muttoni et al., 1996), and furthermore confirm the incomplete nature of the Chios section (Muttoni et al., 1995) at the Lower-Middle Triassic transition (as recognized by Muttoni et al. (1998).

Carbon isotope stratigraphy (V.Atudorei)

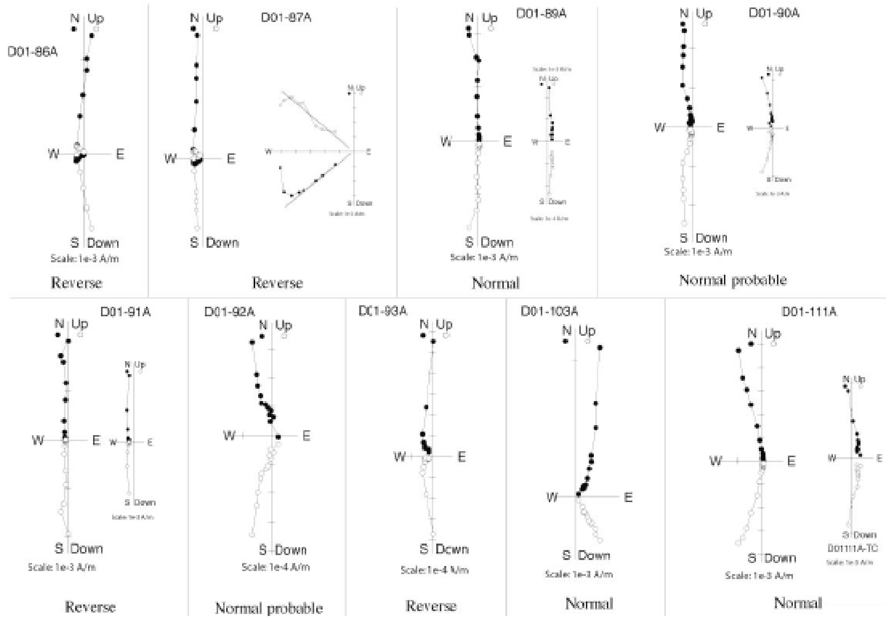
Sixty-five samples were collected for carbon and oxygen isotope analysis, starting with the base of the small quarry in Section B. Most of the results were reported in Atudorei (1999), however here we also include results from a subset of samples from the basal part of the Anisian subsequent to trenching of the rock sequence

At Deşli Caira, the isotope results show a gradual increase in $\delta^{13}C$ values from +2.5‰ recorded at the base of the quarry, to values as high as 5‰ in the middle and the upper part of the section, where they remain relatively constant (Fig. 4). A number of samples just above the proposed boundary yielded $\delta^{13}C$ values outside the general trend, 1-2% lower. We believe them to represent heterogeneities of the original sediment rather than primary changes of the seawater. Also, a diagenetic overprint of the the primary $\delta^{13}C$ values does not appear to be a concern at Deşli Caira because the $\delta^{18}O$ values are relatively high (between –2‰ to –3‰) and they do not show any correlation with the $\delta^{13}C$ values. Further considerations on this subject can be found in Atudorei (1999).

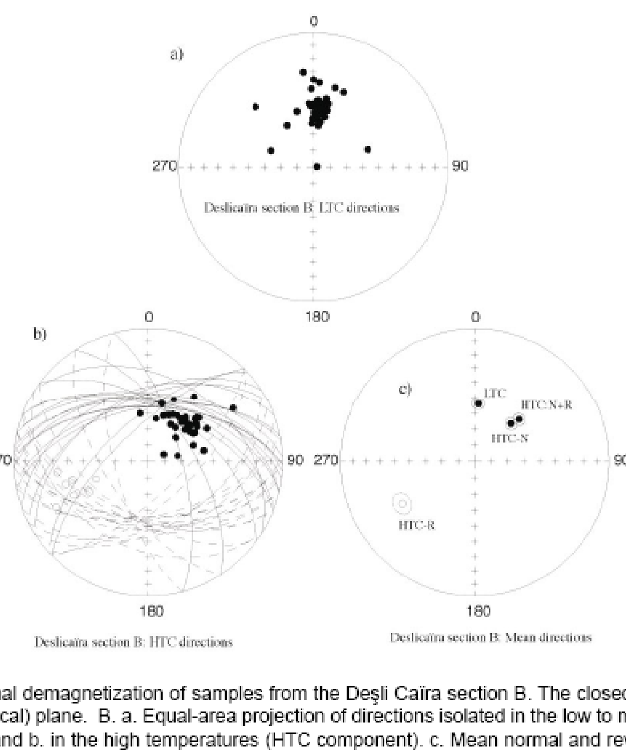
While the upward trend is well marked at Deşli Caira, the peak shape is difficult to visualize when looking at the Deşli Caira data alone, because the background values, below and above the peak, are missing. However, in a composite section including Deşli Caira and several sections located at Dealul Pietros, 6 km southeast of Deşli Caira, the carbon isotope excursion is clearly marked. At the other sections, within the same lithology as at Deşli Caira (Hallstatt-type limestones), the $\delta^{13}C$ values are close to 2‰, which represents the background values for the Upper Olenekian and Anisian (see Atudorei, 1999, Fig. 38). Therefore, it appears that the amplitude of the positive carbon isotope excursion in this area is up to 3‰. In addition, the carbon isotope excursion is recorded in two different sections in the vicinity of Deşli Caira, in different lithological settings: at Dealul cu Cununa (6 km southeast of Deşli Caira), and Uzum Bair (1 km southwest of Deşli Caira).

The proposed OAB is located close to the end of the gradual increase in $\delta^{13}C$ values; however, there is no distinct feature of the carbon isotope curve just across the proposed boundary. The highest values are recorded in an interval 3 to 5 meters above the proposed boundary, although the entire middle and upper part could be considered as a plateau. The gradual increase in $\delta^{13}C$ values just across the boundary suggests that no significant gaps occur at Desli Caira within the proposed boundary interval.

In addition to the current Dobrogea data, previous carbon isotope studies showed the presence of a marked positive carbon isotope excursion across the OAB in Spiti (India), Kçira (Albania), and South China (Atudorei, 1999; Payne et al., 2004; Galfetti et al., 2007). Outside the Tethys, a



A



B

Figure 6: A. Thermal demagnetization of samples from the Deşli Caïra section B. The closed (open) symbols refer to the horizontal (vertical) plane. B. a. Equal-area projection of directions isolated in the low to middle temperature range (LTC component) and b. in the high temperatures (HTC component). c. Mean normal and reversed polarity directions computed after bedding correction from the HTC component. The closed (open) symbols refer to directions in the lower (upper) hemisphere.

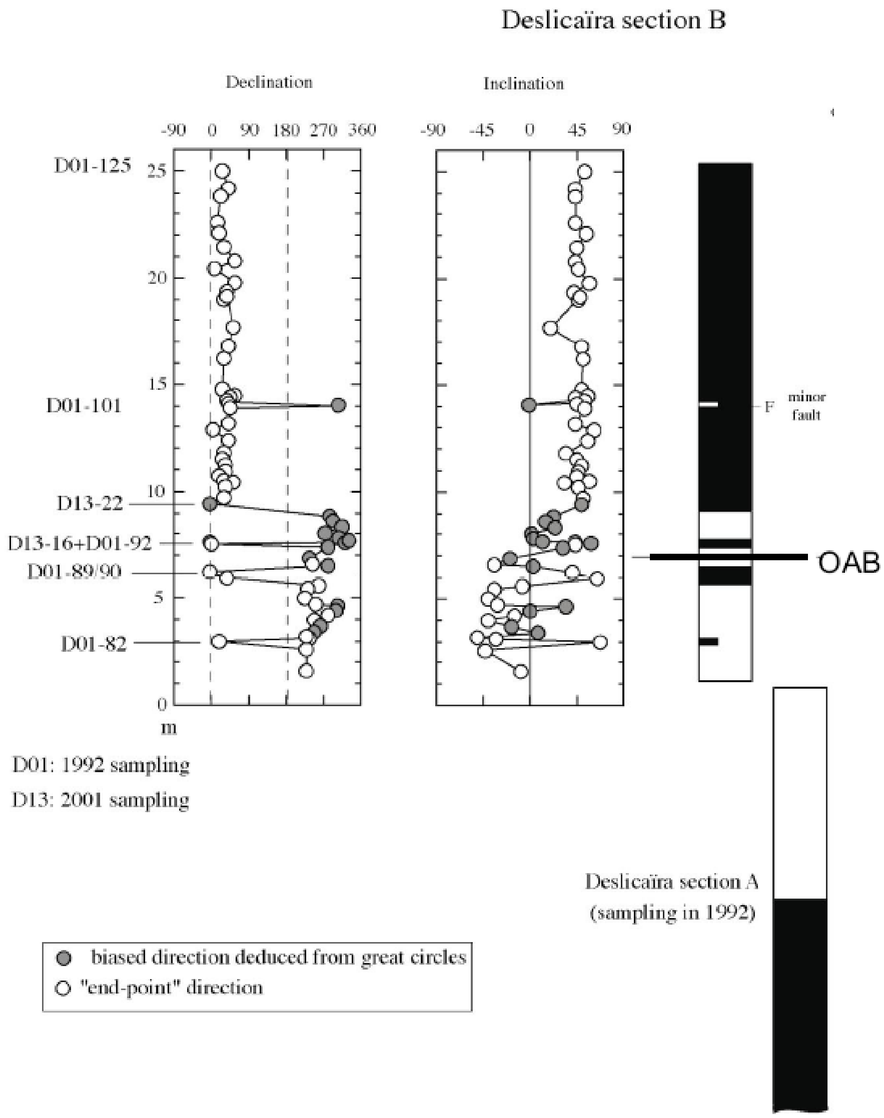


Figure 7: Magnetostratigraphic sequence of the Deşli Caïra section B combining the results obtained in 1992 and 2001. We also indicate the sequence we obtained from section A (sampling in 1992).

positive excursion near the OAB has recently been reported at Ursula Creek (northeast British Columbia, Canada), proving its global extent (Atudorei et al., 2007). This excursion clearly has considerable correlation potential.

Summary

The Olenekian-Anisian Boundary GSSP is proposed between beds GR6 and GR7 (between 203/204 and G7A, respectively) at Deşli Caira Hill Section B, in northern Dobrogea, Romania.

This boundary is recognized by major faunal turnover in widely distributed ammonoids, nautiloids, conodonts, and foraminiferids within continuous fossil sequences. It is characterized further by distinctive magnetostratigraphic and chemostratigraphic profiles.

Amongst the ammonoids, the latest Olenekian is characterized by the *Deslicairites* Beds, which contain a very abundant and diversified ammonoid fauna including species of well-known latest Spathian genera. The base of the Anisian contains the *Paracrochordiceras-Japonites* Beds, and these are followed by the *Aegeiceras ugra* Beds. Some of the ammonoid taxa permit correlation between the Tethyan and the Boreal realms.

The orthocerids of the topmost Olenekian are characterized as the *Paratrematoceras abundans* Beds whereas the nautilids are differentiated as two successive assemblages, *Deslinautilus limatulus* Beds and *Syringoceras mediocre* Beds, respectively. In the basal Anisian, virtually the entire fauna differs in strata characterized as the *Paratrematoceras conspicuum* Beds for the orthocerids, and *Syringoceras exiguum* Beds for the nautilids, respectively.

Conodonts show a profound turnover about the OAB involving the disappearance of four genera, amongst which *Triassospathodus* is dominant in the late Olenekian. The successive appearance and rise to dominance of five other taxa, notably *Chiosella*, characterizes early Anisian strata.

Amongst the foraminferids, the typical Lower Triassic *Rectocornuspira kalhori - Cornuspira mahajeri* assemblage extends to the top of the Olenekian and is succeeded by a different foraminiferal assemblage diagnostic for the lowermost Anisian.

The paleontologically defined OAB is located in between two short normal magnetic polarity intervals, and close to the end of a gradual increase in $\delta^{13}C$ isotope values; both can be recognized globally.

The proposed GSSP is a multifaceted datum that can serve to identify the OAB and base of the Middle Triassic Series in the standard Triassic timescale.

Acknowledgments

The first author acknowledges the financial support received from the Romanian Academy by the Scientific Grants 84/1999, 368/2001-2002 and 120/2007, and also from the National University Research Council by the Scientific Grant 1669/2007. We also acknowledge the support of provided by IGCP 467, to which this is a contribution.

References

Atudorei, V. 1999. Constraints on the Upper Permian to Upper Triassic marine carbon isotope curve. Case Studies from the Tethys, Thèse de doctorat, Univ. Lausanne, 160 pp.

Atudorei, N. V., Guex, J. Orchard., M., Lucas, S., Zonneveld, J. P. 2007. The Early Triassic carbon, sulfur, and nitrogen isotope record. In: Lucas, S. G. & Spielmann, J. A. (eds), The Global Triassic. New Mexico Museum of Natural History and Science Bulletin, 41: 13.

Fantini Sestini, N., 1981. Lower Anisian (Aegean) Ammonites from Chios Island (Greece). Rivista Italiana di Paleontologia e Stratigrafia, 87 (1): 41-66.

Galfetti, T., Bucher, H., Brayard, A., Hochuli, P.A., Weissert, H., Guodun, K., Atudorei, V. & Guex, J. 2007: Late Early Triassic climate change: Insights from carbonate carbon isotopes, sedimentary evolution and ammonoid paleobiogeography. Palaeogeography, Palaeoclimatology, Palaeoecology, 243: 394-411.

Grădinaru, E. 1995. Mesozoic rocks in North Dobrogea: an overview. In: Field Guidebook, Central and North Dobrogea, Romania, October 1-4, 1995. IGCP Project No. 369, Comparative Evolution of PeriTethyan Rift Basins: 17-28.

Grădinaru, E. 2000. Workshop on the Lower-Middle Triassic (Olenekian-Anisian), 7-10 June 2000, Tulcea, Romania, Conference and Field Trip.- Field Trip Guide, Bucharest: 37 pp.

Grădinaru, E. 2003. Ammonoid biostratigraphy around Olenekian-Anisian boundary in Desli Caira (Romania) – a GSSP candidate.- Triassic geochronology and cyclostratigraphy –a field symposium, abstracts, St. Christina/Val Gardena: 37.

Grădinaru, E., Orchard, M., Nicora, A., Mirăuţă, E. & Atudorei, V. 2002. Conodont succession across Olenekian-Anisian boundary as Desli Caira, Romania. I.U.G.S. Subcommission on Triassic Stratigraphy, STS/IGCP 467 Field Meeting, Veszprém, Hungary, 5-8 September, 2002, Budapest: 11-13.

Grădinaru, E., Kozur, H. W., Nicora, A. & Orchard, M. J. 2006. The Chiosella timorensis lineage and correlation of the ammonoids and conodonts around the base of the Anisian in the GSSP candidate at Deşli Caira (North Dobrogea, Romania). Albertiana, 34: 34-38.

Grădinaru, E. & Sobolev, E.S. 2006. Ammonoid and nautiloid biostratigraphy around the Olenekian-Anisian boundary in the Tethyan Triassic of North Dobrogea (Romania): correlation with the Boreal Triassic. In: Nakrem, H.A. & Mørk, A. (eds.): Boreal Triassic 2006.- NGF Abstracts and Proceedings of the Geological Society of Norway, 3: 56-58.

Hips, K. 1996. The biostratigraphic significance of the *Cyclogyra-Rectocornuspira* Association (Foraminifera; Early Triassic): Data from the Aggtelek Mountains (Northeastern Hungary). N. Jb. Geol. Paläont. Mh., 7: 439-451.

Ho, Y. 1984. Middle Triassic foraminifera from Central and Southern Guizhou, China. Acta Paleont. Sinica, 23 (4): 420-431.

Kittl, E. 1908. Kenntnis der Triasbildungen der nordöstlichen Dobrudscha. Denkschriften d.kais.Akad.d.Wiss. math.-naturw.Klasse, 81: 445-532.

Mirăuță, E. 1974. Über die Conodontenfaunen des oberen Werfens und des tieferen Anis der nördlichen Dobrudscha/Rumänien. Geologica et Palaeontologica, 8: 149-158.

Mirăuță, E. 2000. Conodont biostratigraphy in the Deşli Caira section. In: Workshop on the Lower-Middle Triassic (Olenekian-Anisian), 7-10 June 2000, Tulcea, Romania, Conference and Field Trip.- Conference Section, Bucharest: 81-84.

Muttoni, G., Kent, D. V. & Gaetani, M. 1995. Magnetostratigraphy of a Lower-Middle Triassic boundary section from Chios (Greece). Physics of the Earth and Planetary Interiors, 92: 245-260.

Muttoni, G., Kent, D. V., Meço, S., Nicora, A., Gaetani, M., Balini, M., Germani, D. & Rettori, R. 1996. Magnetostratigraphy of the Spathian to Anisian (Lower to Middle Triassic) Kçira section, Albania. Geophys. J. Int., 127: 503-514.

Muttoni, G., Kent, D. V., Meço, S., Balini, M., Nicora, A., Rettori, R., Gaetani, M & Krystyn, L. 1998. Towards a better definition of the Middle Triassic magnetostratigraphy and biostratigraphy in the Tethyan realm. Earth and Planetary Science Letters, 164: 285-302.

Orchard, M. J., Grădinaru, E. & Nicora, A. 2007a. A summary of the conodont succession around the Olenekian-Anisian boundary at Desli Caira, North Dobrogea, Romania. In: S.G., Lucas, S. G. & Spielmann, J. A. (eds), The Global Triassic. New Mexico Museum of Natural History and Science Bulletin, 41: 341-345.

Orchard, M. J., Lehrmann, D. J., Jiayong, W., Hongmei, W. & Taylor, H. 2007b. Conodonts from the Olenekian-Anisian boundary beds, Guandao, Guizhou Provice, China. In: Lucas, S. G. & Spielmann, J. A. (eds.), The Global Triassic. New Mexico Museum of Natural History and Science Bulletin, 41: 347-354.

Payne J. L., Lehrmann, D. J., Wei, J., Orchard, M. J., Schrag, D. P. & Knoll, A. H. 2004. Large perturbations of the carbon cycle during recovery from the end-Permian extinction. Science, 305: 506-509.

Rettori, R., Angiolini, L. & Muttoni, G. 1994. Lower and Middle Triassic foraminifera from the Eros Limestone, Hydra Island, Greece. Journal Micropaleontology, 13: 25-46.

Simionescu, I. 1910a. Studii geologice şi paleontologice din Dobrogea. III. Fauna triasică dela Deşli-Caïra. Acad. Rom., Publ. Fond. V. Adamachi, 26: 465-494.

Simionescu, I. 1910b. Sur quelques point fossilifères du Trias. Annales Scientifiques de l'Université de Jassy: 7 pp.

Simionescu, I. 1913. Studii geologice şi paleontologice din Dobrogea. VI. Fauna amoniților triasici dela Hagighiol. Acad. Rom., Publ. Fond. V. Adamachi, 34: 271-371.

Trifonova, E. 1967. Some new Triassic Foraminifera in Bulgaria. Ann. Univ. Sofia, Geologie et Geographie, Geologie, 60 (1): 1-8.

Trifonova, E. 1993. Taxonomy of Bulgarian Triassic foraminifera. II. Families Endothyriidae to Ophthalmidiidae. Geologica Balc., 23 (2): 19-62.

Wang, Y-G., 1978. Latest Early Triassic ammonoids of Ziyun, Guizhou - with notes on the relationships between Early and Middle Triassic ammonoids. Acta Paleont. Sinica, 17 (3): 151-179.

Wang, Y-G., 1985. Remarks on the Scythian-Anisian Boundary. Rivista Italiana di Paleontologia e Stratigrafia, 90 (4): 515-544.

Wang, Y-G. & He, G-X., 1979. Triassic ammonoid sequence of China. Rivista Italiana di Paleontologia e Stratigrafia, 85 (3-4): 1207-1220.

Plate 1

All specimens are housed in the Faculty of Geology and Geophysics, University of Bucharest.
All figures natural size, if otherwise stated.

Fig.1. *Japonites* sp.; GE 211 (level 821, lower Anisian)
Fig.2. ?*Karangatites* sp.; GE 189 (level G7A, lower Anisian)
Fig.3. *Paracrochordiceras* sp.; GE 190 (level G7A, lower Anisian)
Fig.4. '*Romanites*' cf. *simionescui* Welter; GE 215 (level 822, lower Anisian)
Fig.5-6. *Deslicairites simionescui* Grădinaru, n.gen.n.sp.; GE 135 (level 820, uppermost Olenekian); Fig. 6 - x 2
Fig.7-8. *Deslicairites simionescui* Grădinaru, n.gen.n.sp.; GE 123 (level 820, uppermost Olenekian); Fig.8 - x 2
Fig.9-10. *Deslicairites kittli* Grădinaru, n.gen.n.sp.; GE 98 (level 820, uppermost Olenekian); Fig.10 - x 2
Fig.11-12. *Deslicairites kittli* Grădinaru, n.gen.n.sp.; GE 91 (level 820, uppermost Olenekian); Fig.12 - x 2
Fig.13. *Procladiscites* sp.; GE 120 (level 820, uppermost Olenekian)

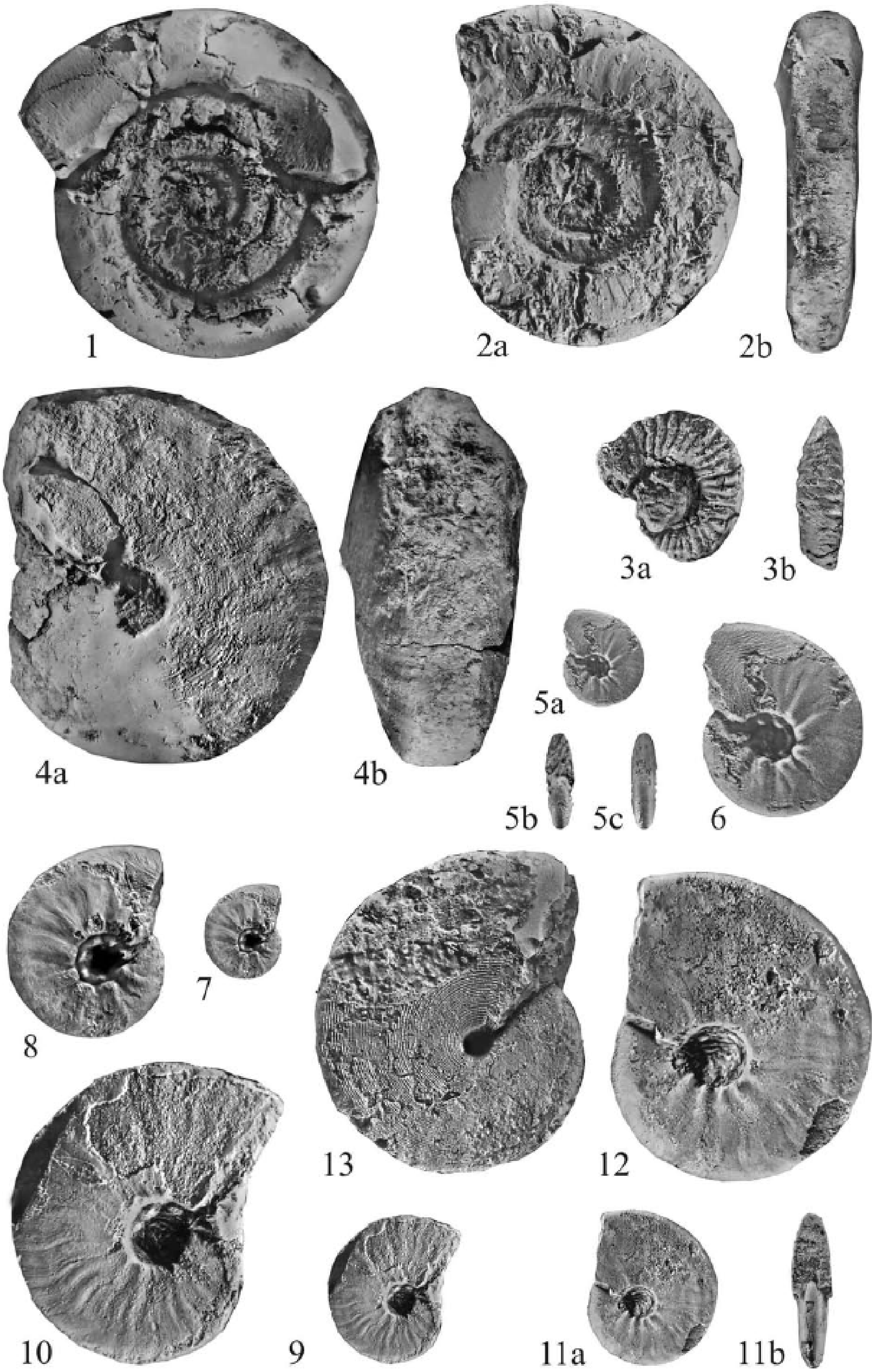
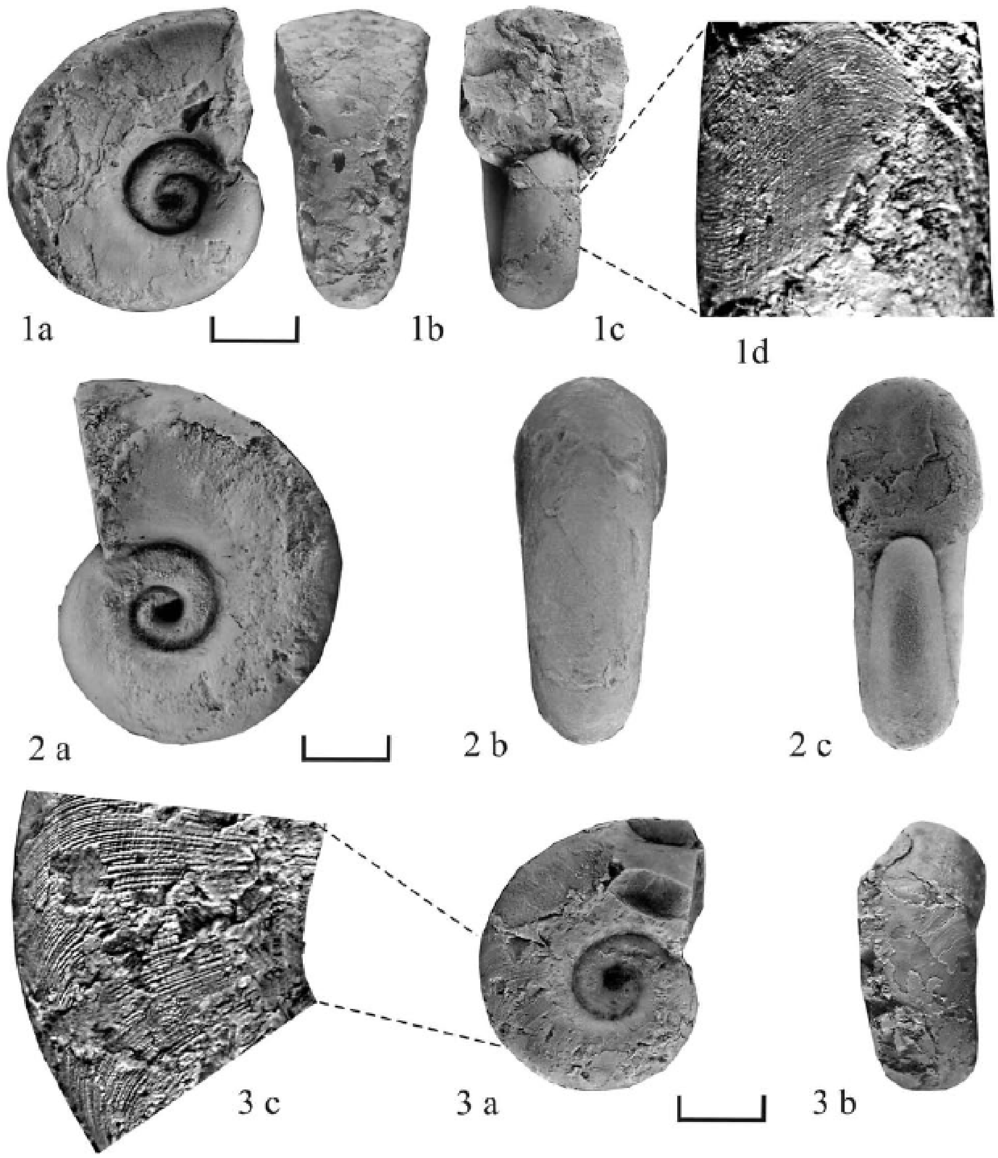

1
2a
2b
4a
4b
3a
3b
5a
5b
5c
6
8
7
13
12
10
9
11a
11b

Plate 2

All specimens are housed in the Faculty of Geology and Geophysics, University of Bucharest. The bar corresponds to 1 cm; Fig.1 d - x 5; Fig.3 c - x 3.

Fig.1. *Deslinautilus limatulus* Grădinaru & Sobolev, n.gen.n.sp.; GE 7 (level 202a, uppermost Olenekian).
Fig.2. *Syringoceras mediocre* Grădinaru & Sobolev, n.sp.; GE 41 (level 203, uppermost Olenekian)
Fig.3. *Syringoceras exiguum* Grădinaru & Sobolev; n.sp.; GE 51 (level 208/209, lower Anisian)


1a
1b
1c
1d
2 a
2 b
2 c
3 c
3 a
3 b