

Carbon-isotope stratigraphy, biostratigraphy and organic matter distribution in the Aptian – Lower Albian successions of southwest Iran (Dariyan and Kazhdumi formations)

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ABSTRACT

The lateral transition from carbonate platforms to intra-shelf basin in Aptian – Early Albian times is documented along a regional transect in the excellent exposures of the Zagros Mountains. An integrated dataset, including carbonate carbon-isotope curves, and ammonite and planktonic foraminifera biostratigraphy constrains the regional correlations, and forms the basis for an age revision of the Kazhdumi and Dariyan formations. Of particular importance in this study is the Kuh-e-Bangestan section, wherein a continuous succession of Aptian – Albian intra-shelf basinal deposits was used to erect a detailed ammonite and planktonic foraminifera biostratigraphic zonation scheme, in combination with a carbon-isotope curve and organic-matter measurements. Key observations are: (1) the oldest Kazhdumi intra-shelf deposits are of Early Aptian age (*D. deshayesi* Zone), indicating a time-equivalent initiation of the Kazhdumi and neighbouring intra-shelf Bab Basin. (2) The presence of well-developed organic matter-rich sediments in the *N. nolani* and *H. jacobi* zones is interpreted as equivalent to part of the OAE1b set. (3) The presence of an exceptionally well-developed Upper Aptian – Lower Albian succession (80 m thick) shows a clear positive carbon-isotope excursion and a faunal crisis, with the turn-over of the planktonic foraminifera assemblage (only small and low diversity *Globigerinelloides* and *Hedbergellids*) and the total absence of ammonites. A composite carbon-isotope curve is proposed based on sections measured in both the platform and basin settings. This curve deserves attention because it has an expanded Upper Aptian - Lower Albian section, which is well dated (ammonites, planktonic foraminifera and orbitolinids).

INTRODUCTION

Whereas recently much progress has been made in the understanding of the mid-Cretaceous stratigraphy of the Arabian Plate in the United Arab Emirates (UAE) and Oman (e.g. Harris and Frost, 1984; Hughes Clarke, 1988; Hughes, 1997; Murris, 1980; Vahrenkamp, 1996; Sharland et al., 2001; Davies et al., 2002; van Buchem et al., 2002; Hillgärtner et al., 2003; Immenhauser et al., 2004; Yose et al., 2006), no detailed stratigraphic and paleontological work has been published of the time-equivalent successions in southwest Iran since the standard work by James and Wynd (1965). As documented from previous work in Oman and the UAE, the Aptian sedimentary system is particularly complex. Any detailed study aiming at a larger scale regional and over-regional correlation of field and subsurface data must hence aim at integrating biostratigraphic, chemostratigraphic and sequence-stratigraphic data in a multidisciplinary manner.

The focus of this study is on the Upper Barremian to Albian deposits of the eastern part of the Arabian Plate exposed in world-class exposures along the Zagros Mountain chain in southwest Iran. This paper presents – for the first time – a detailed Aptian carbon-isotope record from southwest Iran combined with new biostratigraphic data based on ammonite and planktonic foraminifera stratigraphy. In addition, basinal deposits have been analysed for carbonate and TOC (Total Organic Carbon) content. In two related papers, a revision of the orbitolinids in southwest Iran is presented by Schroeder et al. (2010), providing excellent age control for the shallow-water platform successions of the Dariyan Formation, and a sequence-stratigraphic model is proposed for the Barremian – Aptian interval by van Buchem et al. (2010a). The results of these twin studies are applied – where appropriate – in this paper, but the reader should refer to the original manuscripts for more detailed information.

Particular points of interest of the presented data set are:

- (a) According to the authors' knowledge, the Kuh-e-Bangestan outcrop section represents the only fully exposed (330 m) intra-shelf basinal succession of Aptian – Albian age on the Arabian Plate, that is tectonically undisturbed, rich in fossils and in immature organic matter. The scientific value of this section is in the calibration of the Arabian Plate Aptian – Albian depositional system to an international ammonite, planktonic foraminifera, carbon-isotope chronostratigraphic framework. In addition, detailed stratigraphic insight in the Kazhdumi Formation has an economic value since it is one of the richest source rocks in the World. Specifically, the Kazhdumi Formation has sourced the Cretaceous and Cenozoic petroleum systems of southwest Iran (e.g. James and Wynd, 1965; Bordenave and Burwood, 1990; Bordenave and Huc, 1995).
- (b) Carbon-isotope data were obtained from bulk matrix micrites collected in the intra-shelf basin center, at the basin margin and in the surrounding shallow-water platform deposits, and were calibrated with both benthic and planktonic biozonations. This time framework formed the basis for the sequence-stratigraphic correlations across these different environments, which are presented in van Buchem et al. (2010a, b). It also allowed to calibrate the shallow-water platform successions to the ammonite biozonation time scale, and to compare the evolution of the intra-shelf basin in southwest Iran with the Bab Basin in the UAE and Oman.
- (c) In the studied intra-shelf basin a well-developed succession of Late Aptian and Early Albian sedimentary rocks (80 m) is present and accessible. This stratigraphic interval is generally condensed and rarely exposed, and as a result relatively scarcely documented. The present study thus provides the opportunity to analyze the evolution of the faunal associations, the organic-matter content and the carbon stable-isotope signal in an expanded section across the Aptian/Albian boundary.

This paper is organised as in the following manner: first the biostratigraphic and isotopic data are presented, followed by a discussion addressing the proposed age revisions, the positioning of the Aptian/Albian boundary and the regional correlations. In the paleontological appendix of this paper a detailed account is presented of the ammonite fauna, illustrated with nine photoplates.

GEOLOGICAL SETTING

The studied outcrops are located on the flanks of large anticlinal structures along the NW-trending gently folded foothills zone of the Zagros Mountains, which formed during the Late Miocene closure of the Neo-Tethys Ocean (e.g. Wennberg et al., 2007). During the Cretaceous, however, the study area formed the eastern margin of the Arabian Plate, located along the southern margin of the Neo-Tethys Ocean (Figure 1a). A brief summary of the geological history of the study area, based on James and Wynd (1965), Sharland et al. (2001) and van Buchem et al. (2010a, b) is given below. A schematic litho-chronostratigraphic scheme is presented in Figure 2.

During Valanginian – Hauterivian times, a low-angle carbonate platform developed in Fars and Khuzestan provinces (Fahliyan Formation) and progressively prograded to the northwest into the Garau intra-shelf seaway in Lurestan that opened to the Neo-Tethys Ocean. During Barremian times, this vast carbonate platform aggraded with the deposition of alternating carbonate and marl facies (Gadvan Formation and Khalij Member), reflecting phases of siliciclastic influx from the exposed hinterland in the west (present-day Kuwait). During the Early Aptian, a major change in the paleogeography took place with the creation of an organic-matter-rich intra-shelf basin in Khuzestan (Kazhdumi Formation; James and Wynd, 1965; Bordenave and Burwood, 1990; Bordenave and Huc, 1995), surrounded by shallow-water carbonate platforms in Fars and Lurestan (Dariyan Formation; Figure 1b).

During the early Late Aptian, the platform became exposed in Fars, while in Khuzestan and Lurestan orbitolinid-dominated platform sedimentation continued, and prograded towards the intra-shelf basin and in the Garau seaway (Upper Dariyan Formation; Figure 2). During the latest Aptian and Early Albian most of the carbonate platforms were exposed, creating a virtually isolated intra-shelf basin where organic-rich sediments accumulated (Khazdumi Formation). During the Mid- and Late Albian transgression, renewed sedimentation took place on the platforms with the deposition of the shallow-water Orbitolina Limestone, while the intra-shelf basin was characterized by the ongoing deposition of the organic-rich Kazhdumi shales (Figure 2).

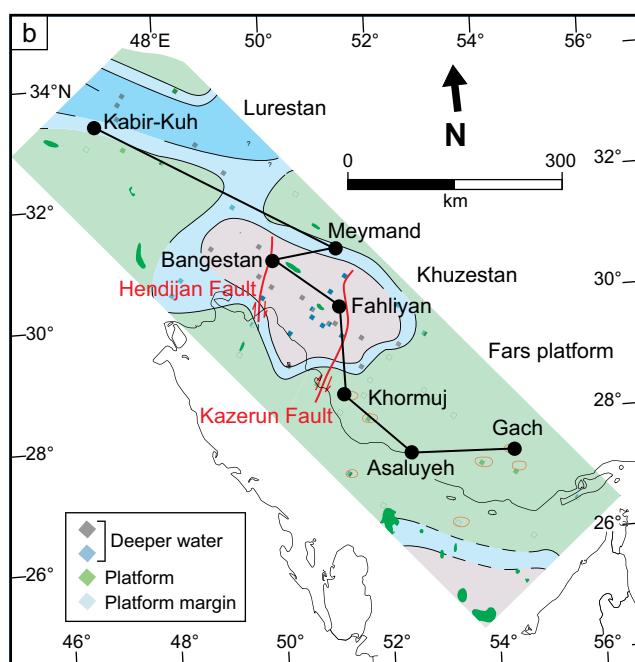
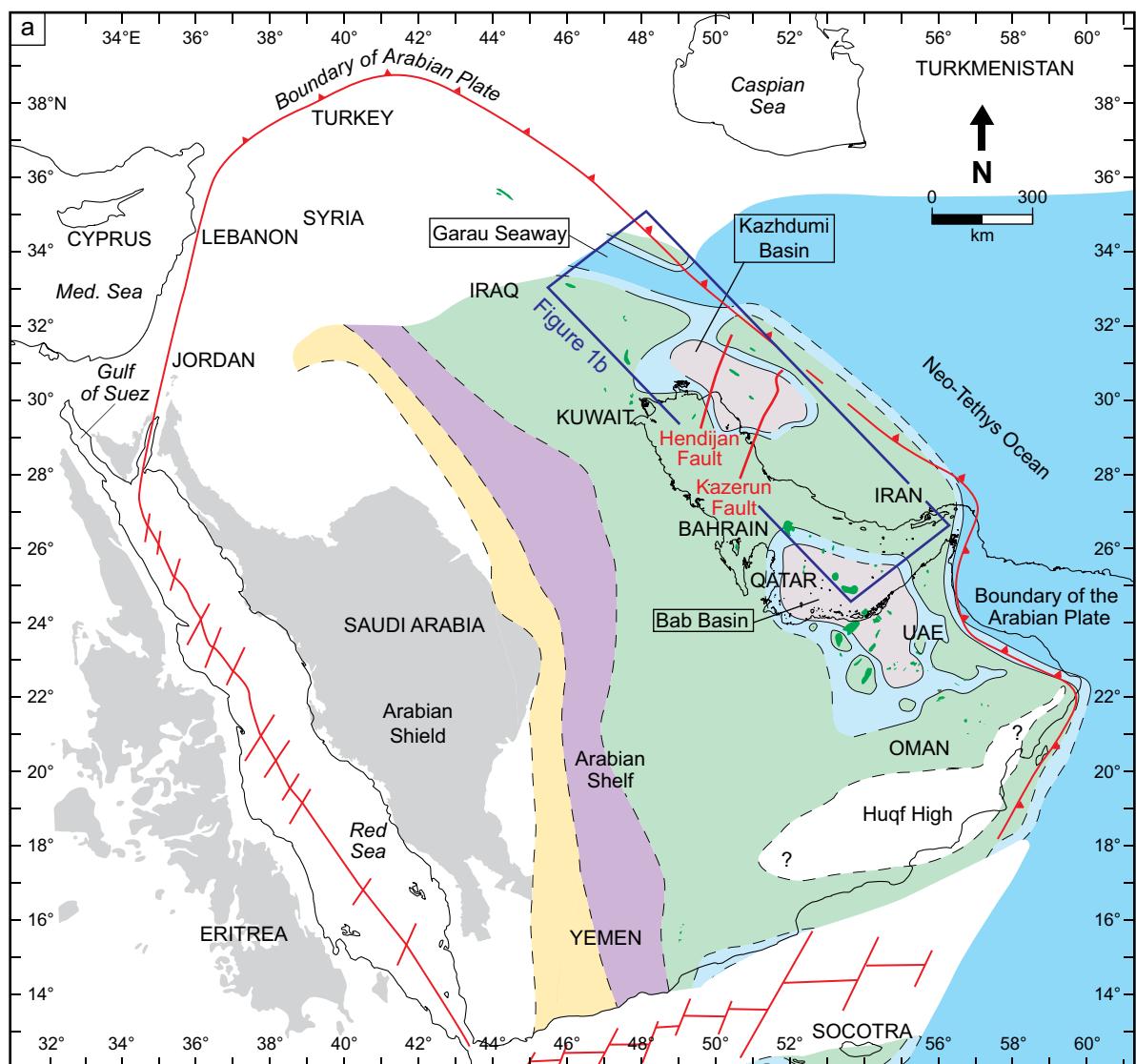


Figure 1: (a) Location of the studied sections in the Zagros Mountains of southwest Iran shown on a paleogeographic map (after van Buchem et al., 2010b).

(b) The studied transect on a Lower Aptian paleogeographical map of the Zagros area. Four different paleogeographical domains are covered: Kabir-Kuh is located at the margin of the Garau intra-shelf seaway in Lurestan, the Meymand section is located in the shallow-water carbonate platforms along the Neo-Tethys margin, the Kuh-e-Fahliyan and Kuh-e-Bangestan sections illustrate the margin and center of the Kazhdumi intra-shelf basin in the Dezful Embayment, and the Khormuj, Asaluyeh and Gach sections are located in the shallow-water carbonates of the coastal Fars region.

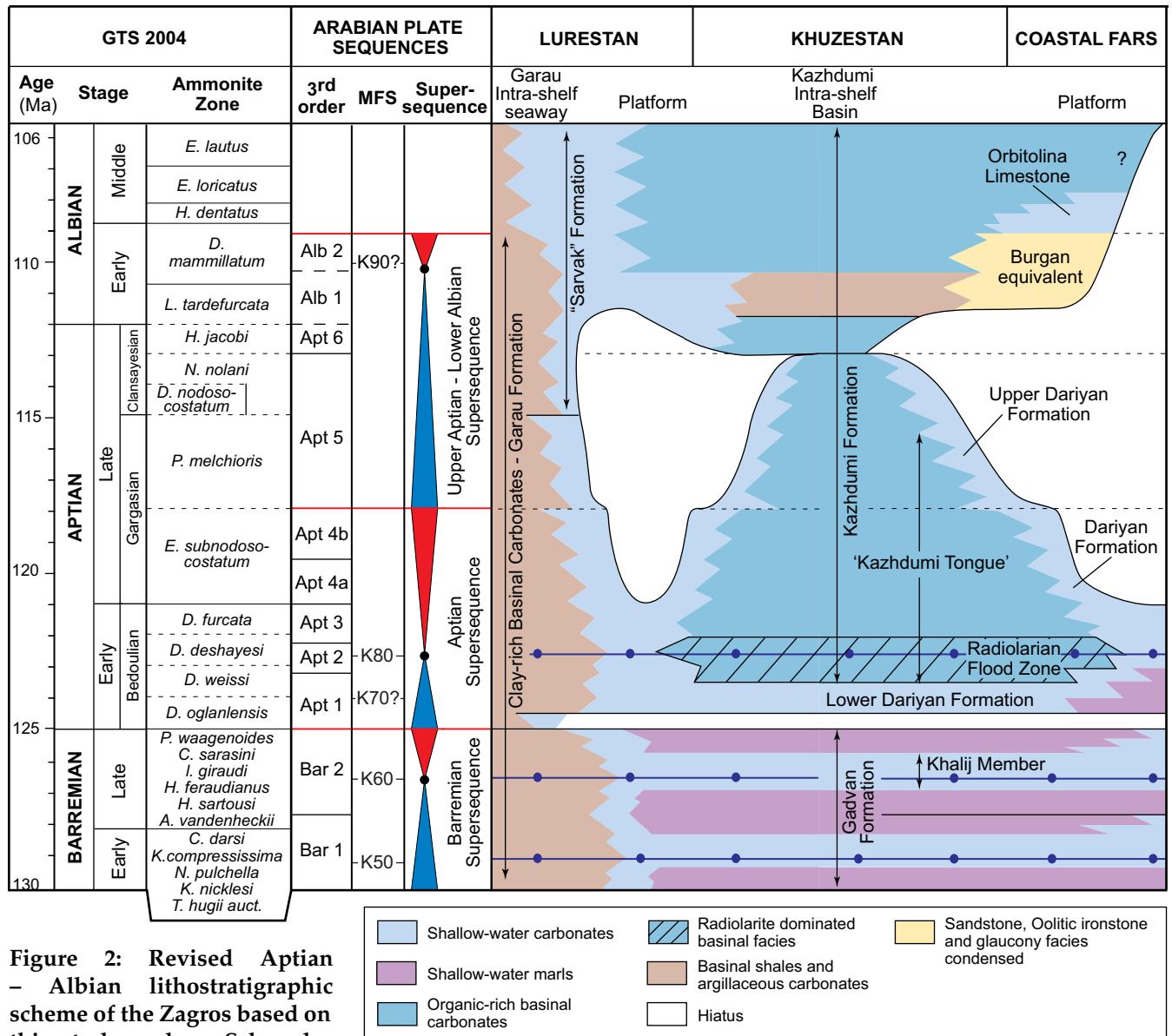


Figure 2: Revised Aptian – Albian lithostratigraphic scheme of the Zagros based on this study and on Schroeder et al. (2010). Notable changes compared to James and Wynd (1965) are the age revision of the base of the Kazhdumi Formation, which is as old as the Early Aptian, and diachronous, and the age revision of the Dariyan Formation, which is largely time-equivalent to the Kazhdumi Formation (except for its very base). The Upper Dariyan is of Late Aptian age.

The biostratigraphy of the Cretaceous of the Zagros is summarized in James and Wynd (1965), and subsequent regional studies have used this scheme (e.g. Setudehnia, 1978). That zonation was mostly based on shallow-water faunal assemblages, mixing both an environmental and a time notion. Information on ammonite biostratigraphy as presented in James and Wynd (1965) is limited indeed. Apart from the early works (e.g. Bordenave and Burwood, 1990; Bordenave and Huc, 1995; Setudehnia, 1978), which are all of a more general nature, no detailed studies have been published in the literature on the here presented outcrops. Several internal company reports dealing with the outcrops in the Zagros have, however, been consulted.

GEOGRAPHIC LOCATIONS, MATERIAL AND METHODS

The sections studied in this paper were placed along a SE-NW transect that represent the main depositional environments in southwest Iran during Aptian times (Murris, 1980; Figure 1b): (1) the Kabir-Kuh section, located at the southern margin of the Garau seaway in Lurestan, which was

connected to the Neo-Tethys Ocean, (2) the Meymand section, located in the High Zagros, is part of a shallow-water carbonate platform separating the intra-shelf Kazhdumi Basin from the Neo-Tethys, (3) the Kuh-e-Bangestan section, which is positioned in the center of the Kazhdumi Basin, and which is the type section of the Kazhdumi Formation, (3) the Kuh-e-Fahliyan section, located at the southeastern margin of the intra-shelf basin, and (4) the Kuh-e-Khormuj, Kuh-e-Assaluyeh and Kuh-e-Gach sections located in the shallow-water carbonate platforms of the coastal Fars area. The geographical position of the seven outcrop sections is given in Table 1. The paleogeographical map in Figure 1b is based on a dataset of 100 control points that were studied in the context of a larger project covering the Cretaceous rocks in the Zagros region.

Table 1: Coordinates of outcrop sections

Kabir Kuh	N33°25'; E46°37'
Kuh-e-Bangestan	N31°03'; E50°03'
Kuh-e-Fahliyan	N30°11'17"; E51°27'53"
Khormuj section	N28°39'21"; E51°24'14"
Kuh-e-Assaluyeh	N27°35'56"; E52°31'31"
Kuh-e-Gach	N27°34'46"; E54°30'06"

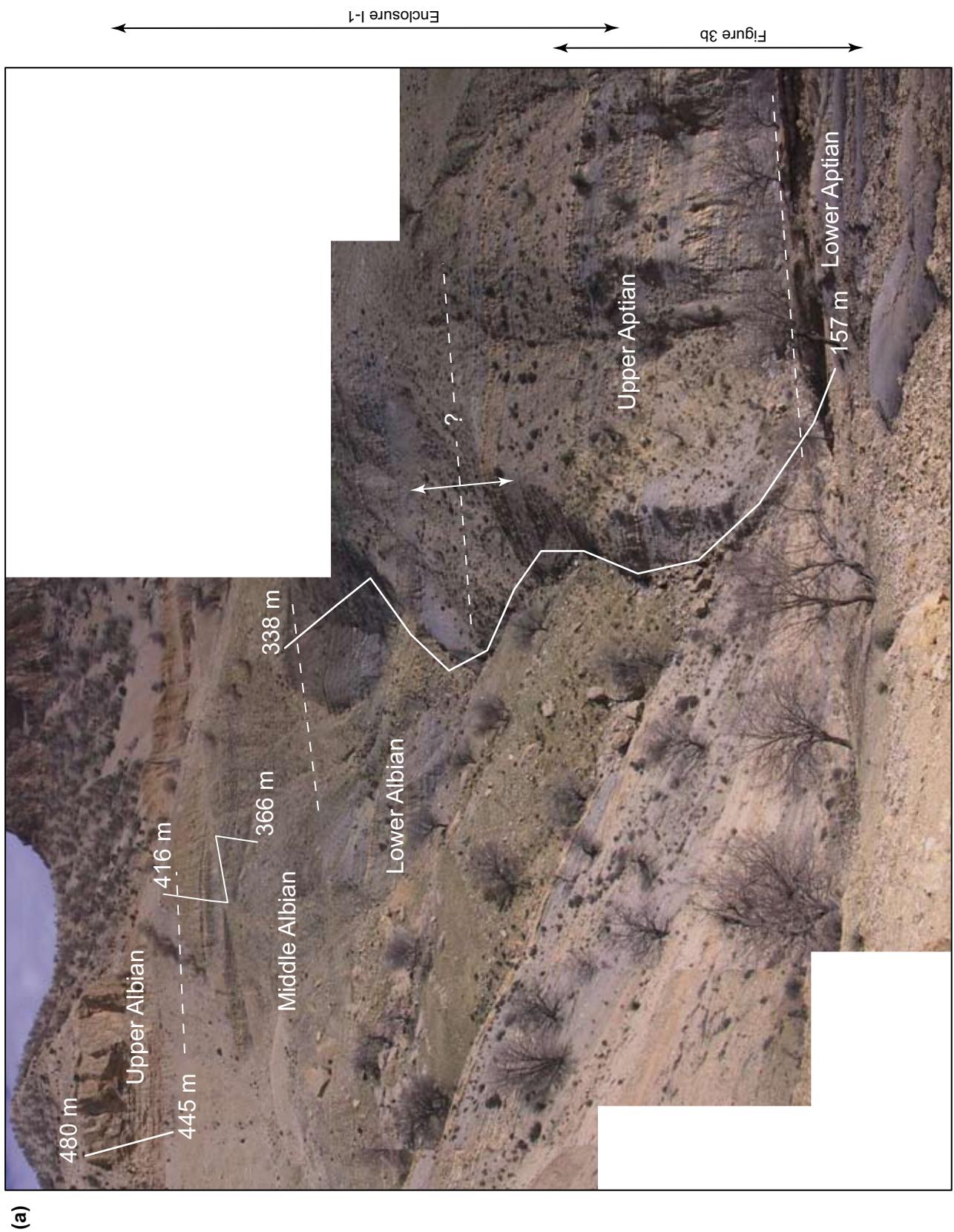
The ammonite faunas collected in Kabir-Kuh, Bangestan, Fahliyan and Khormuj (approximately 500 specimens) were interpreted by L. Bulot, using an updated version of the zonation of Hardenbol et al. (1998). Most of the specimens come from the exceptionally rich Bangestan section. A detailed systematic paleontological analysis of the ammonite fauna is presented in the Appendix, which includes nine photoplates. Planktonic foraminifera of the Kuh-e-Bangestan section were studied by M. Caron in thin sections (590 slides) and selected washed samples (approximately 30) with a sample spacing of up to one meter. They were correlated with the global planktonic foraminifera zones and calibrated against the Robaszynski and Caron (1995) zonation scheme published for the Neo-Tethys. The microfacies analysis was carried out by A.S. Hosseini and interpreted in terms of the biozones as proposed by Wynd (1965).

A total of 870 isotope analyses of bulk matrix micrites ($\delta^{13}\text{C}_{\text{carb}}$, $\delta^{18}\text{O}_{\text{carb}}$) were carried out, distributed in seven sections: Kabir-Kuh (116 samples), Meymand (71 samples), Bangestan (162 samples), Fahliyan (62 samples), Khormuj (224 samples along an Aptian to Turonian interval), Assaluyeh (160 samples) and Gach (75 samples). Samples were taken after optical inspection of freshly cut or broken surfaces to avoid cement filled voids or veins. Samples were analyzed at the Geology Department of the Vrije Universiteit Amsterdam, The Netherlands, and the Institute of Geology and Mineralogy, University of Erlangen-Nürnberg, Germany. In both labs, powders were reacted with 100% phosphoric acid at 75°C using a Kiel III online carbonate preparation line connected to a ThermoFinnigan 252 mass spectrometer. For both labs, isotopic values are reported in the standard δ -notation in per mil relative to V-PDB (Vienna Pee Dee Belemnite) by assigning a $\delta^{13}\text{C}$ value of +1.95‰ and a $\delta^{18}\text{O}$ value of -2.20‰ to NBS19. Reproducibility was checked by replicate analysis of laboratory standards and is better than $\pm 0.02\text{‰}$ (1σ) for carbon isotope and $\pm 0.05\text{‰}$ (1σ) for oxygen isotope. The oxygen-isotope data are not presented as curves and are only used to investigate the impact of diagenesis on the stable-isotope signals.

A total of 160 samples have been measured for TOC and carbonate content with a Rock-Eval VI apparatus at the geochemistry laboratory of the Institut Français du Pétrole in Rueil-Malmaison, France.

Results

The biostratigraphic and chemostratigraphic results are presented below. For the Bangestan section a detailed illustration of the exposures, and the faunal and chemostratigraphic data is provided in Figures 3 and Enclosure I-1, because of the importance of this section. In Enclosure I-2 the complete regional dataset is presented. Figure 4 shows the typical planktonic foraminifera of the Kazhumi Formation, whereas the faunal and chemostratigraphic data of the Kabir Kuh section are presented in Figure 5.



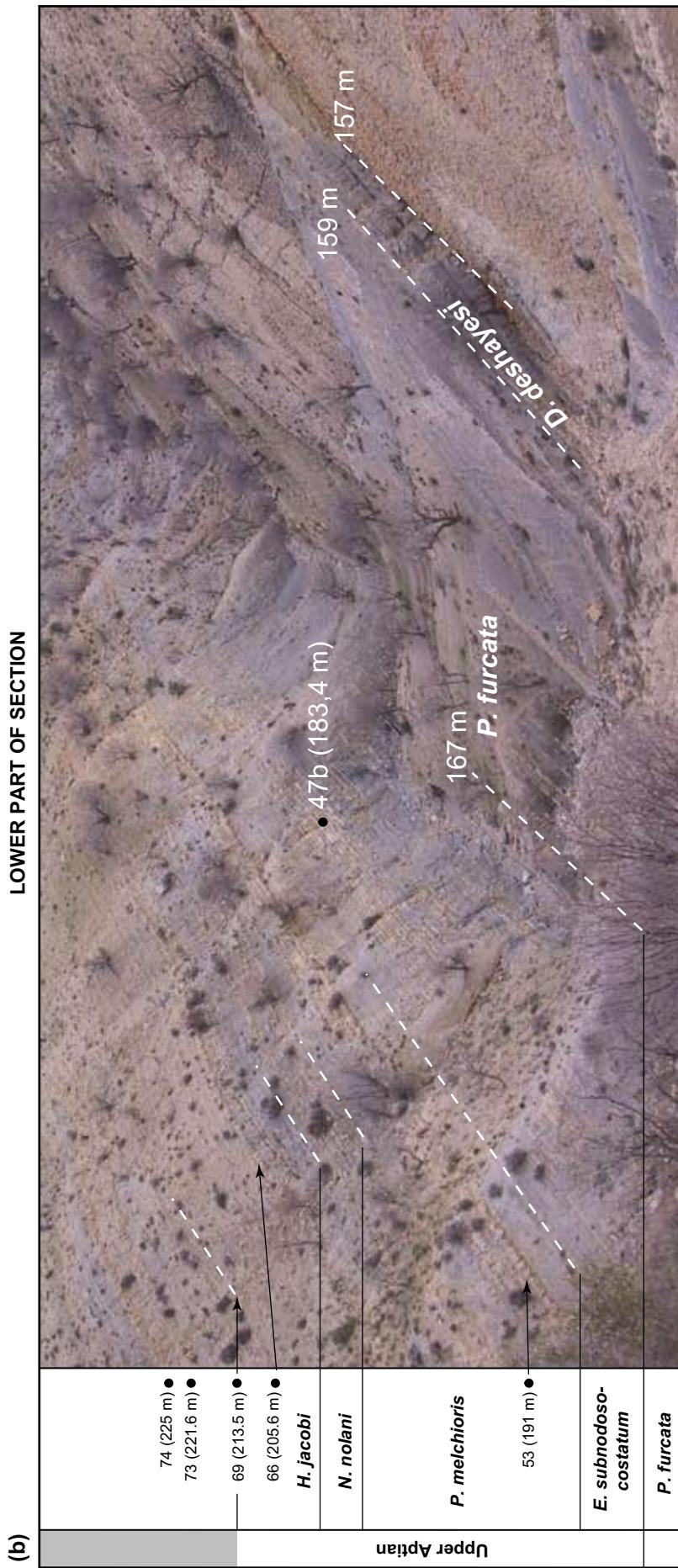


Figure 3: (a) Stratigraphic overview of the Kazhdumi Formation in the type section at Kuh-e-Bangestan. Detailed views presented in Figures 3b and Enclosure I-1 are indicated. White line marks the position of the measured section.

(b) Detailed view of the lower part of the Kazhdumi Formation, showing bedding pattern and numbered stratigraphic marker beds. See Enclosure I-1 for detailed faunal observations. Base of the section, at 157 m is an iron-crusted hard ground.

Biostratigraphy

Bangestan Section (Center of the Intra-shelf Basin)

The intra-shelf basinal deposits of the Kazhdumi Formation in the Bangestan section are 310 m thick, well exposed (Figure 3 and Enclosure I-1) and contain an exceptionally rich ammonite, planktonic foraminifera and radiolaria fauna. For the first two fossil groups, detailed zonal schemes have been established (Enclosure I-1). Coherent results have been obtained for the age of the base of the Kazhdumi shales, which is late Early Aptian (*D. deshayesi* ammonite zone, *D. grandis* subzone), and the position of the Early/Late Aptian boundary (Enclosure I-1).

The positioning of the Aptian/Albian boundary is less well constrained. The planktonic foraminifera show an abrupt change from an association of large size and complex morphotypes of strictly Upper Aptian species of the *P. cheniourensis* Zone (213–226 m; Enclosure I-1), to an interval containing an association of small size *Hedbergella* spp. and *Globigerinelloides* spp. that are not age specific (226–258 m; Enclosure I-1). This interval has, however, been recognized in other basins, and represents a planktonic foraminifera “crisis” that occurs around the Aptian/Albian boundary (e.g. Caron and Homewood, 1982; Kennedy et al., 2000). The ammonite fauna shows just below this interval a diverse assemblage of cosmopolitan and (partly new) endemic species, that have a high Albian affinity (214–230 m; Enclosure I-1). For a more in depth discussion of this fauna the reader should refer to the paleontological notes in the Appendix. The interval corresponding to the planktonic crisis is devoid of ammonites, while they return at 263 m, where an Early Albian age can be confirmed. The Early/Middle Albian boundary is positioned at 333 m, based on ammonites, and between 290 and 315m based on planktonic foraminifera (Enclosure I-1).

Kabir Kuh Platform Margin Section

In the pelagic marls of the Garau Formation in the Kabir-Kuh section, both ammonites and planktonic foraminifera were found (Figure 5). The Early Aptian is dated with planktonic foraminifera (*L. cabri* zone) and ammonites (*D. deshayesi* ammonite zone). There is, however, a difference in the position of the Early to Late Aptian boundary, positioned at about section meter 860 according to the ammonite biostratigraphic scheme and between section meters 800 and 810 based on planktonic foraminifera biostratigraphy (Figure 5). This difference is probably partly due to the scarcity of ammonites in this interval (less than 10 specimens collected). The Aptian/Albian boundary falls for both groups in the same interval. The ammonite zonation places this boundary in a condensed part of the section around section meter 1,060, where a glauconitic and phosphatic level contains a fauna of the *P. melchioris*, *N. nolani*, *H. jacobi* and (?) *L. tardefurcata* ammonite zones. This implies that a large part of the Late Aptian and the earliest Albian are condensed in less than one meter around section meter 1,060 m (Figure 5) below beds rich in *Douvilleiceras*. The position of this interval on top of a shallowing-up trend is in accordance with this interpretation. The planktonic foraminifera zonation is less precise and places this boundary within the interval between 980 and 1,060 m (Figure 5). The lack of precision, only one specimen of *Hedbergella* spp. has been found in this interval, is probably related to the shallowing of the depositional environment, the poor preservation, and the general lack of planktonic foraminifera around the Aptian/Albian boundary (Robaszynski and Caron, 1995).

Fahliyan Platform Margin Section

In the Fahliyan section, an interfingering of orbitolinid-dominated shallow-water platform facies with intra-shelf basinal sedimentary rocks occurs (Enclosure I-2). The dating is based on ammonite and orbitolinid biostratigraphy. The lower package of intra-shelf basinal sedimentary rocks (informally referred to as “Kazhdumi Tongue”) has a late Early Aptian (*D. furcata* ammonite zone) to Late Aptian age (*N. nolani* ammonite Zone). The orbitolinid-rich limestones (Upper Dariyan Formation), have a Late Aptian age based on the presence of *Mesorbitolina parva*, and *M. texana* (Schroeder et al., 2010), whereas the presence 5 m below the top of the Upper Dariyan Formation of *Epicheloniceras gr. clansayense* (Jacob) indicates an age that cannot be younger than the *H. jacobi* ammonite Zone. The overlaying intra-shelf basinal sediments (Kazhdumi Formation) contain a late Early Albian ammonite fauna of the upper part of the *D. mammillatum* ammonite Zone (*Knemiceras persicum* Collignon and juvenile *Douvilleiceras*). The Aptian/Albian boundary is most likely located close to the top of the shallow-water platform deposits (top Upper Dariyan Formation). The Early/Middle Albian boundary is characterized by ammonites of the *L. lyelli* and *H. spathi* ammonite subzones (*H. dentatus* ammonite zone), in combination with the occurrence of *Mesorbitolina aperta* (primitive form) and *Mesorbitolina subconcava*.

Coastal Fars Platform Sections

The shallow-water carbonates of the Dariyan Formation in the Gach and Asaluyeh sections (Enclosure I-2) have been dated with orbitolinids (Schroeder et al., 2010), and give a late Early Aptian age for the top of the Dariyan Formation (*Palorbitolina ultima*; *Palorbitolinoides* cf. *orbiculata*). Ammonites found in the marls overlying the Dariyan Formation indicate a late Early/Middle Albian age for Gach (*Knemiceras persicum*), a Late Albian age for Asaluyeh (*Orbitolina aperta*; *Knemiceras* aff. *iranense* Collignon), and a Middle Albian age for Khormuj (*Knemiceras* cf. *persicum*, *K. aff. kazhdumiense* Collignon). This implies that the Late Aptian and most of the Early Albian time interval is represented by a stratigraphic hiatus on top of the Dariyan Formation.

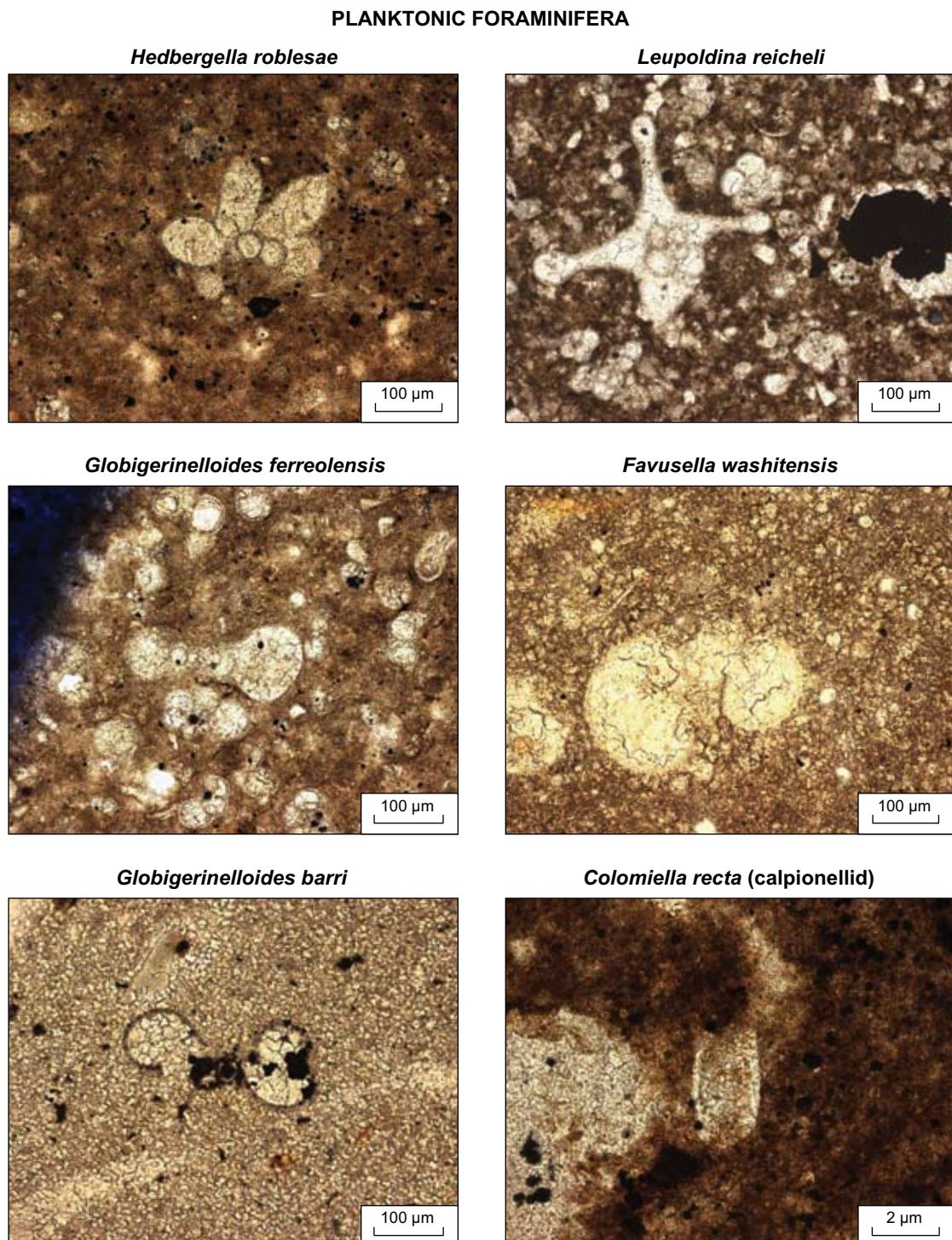


Figure 4: Characteristic planktonic fauna of the Kazhdumi Formation in the Dezful Embayment.

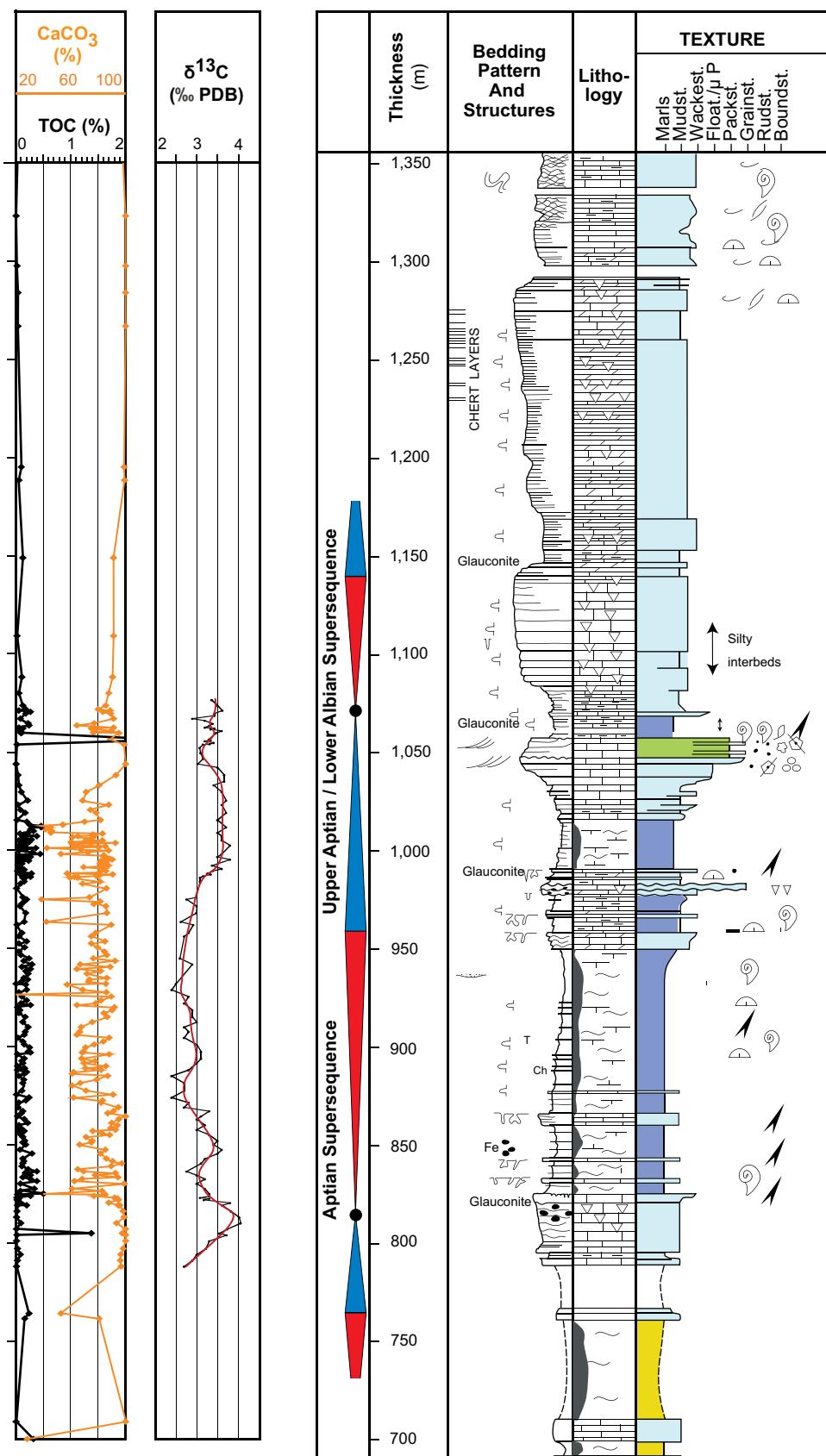


Figure 5: Kabir Kuh outcrop section, exposed in the southern flank of the Kabir Kuh anticline in Lurestan.

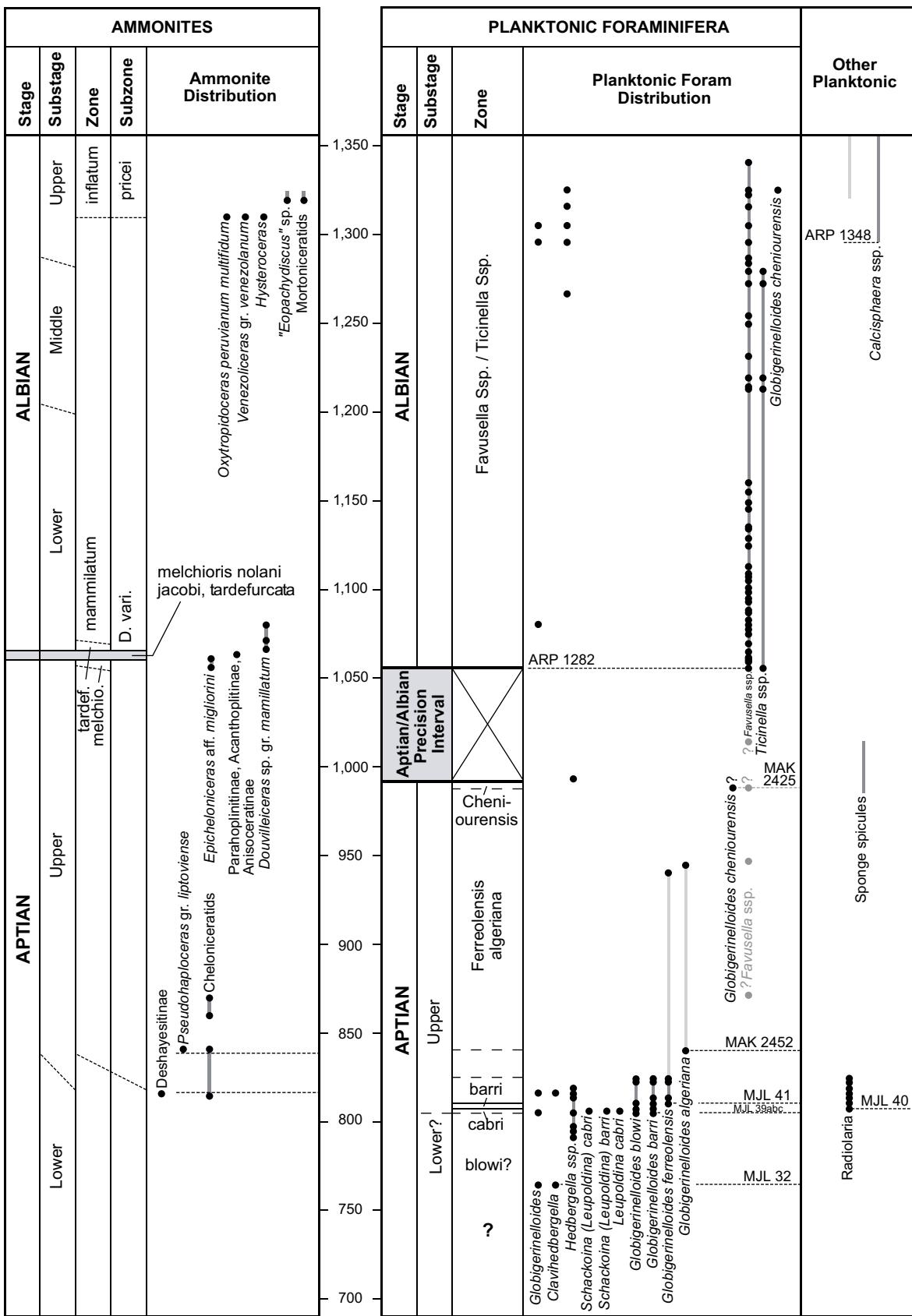


Figure 5: (see facing page for caption).

High Zagros Platform Sections

The Meymand section (Enclosure I-2) has also been dated with orbitolinids (Schroeder et al., 2010). The Dariyan Formation consists of two parts, a lower that covers the Early Aptian, and an upper part that is of latest Aptian to Early Albian in age (*Dictyoconus tunesianus*, *Mesorbitolina texana* and *M. subconcava*). A large part of the Late Aptian is probably missing in this section.

Carbon-isotope Curves

Carbon-isotope curves were obtained in six sections representing the margins of the Garau Seaway and the Kazhdumi intra-shelf Basin (Kabir-Kuh, Fahliyan), the Kazhdumi Basin center (Bangestan), and the surrounding carbonate platforms in coastal Fars (Khormuj, Asaluyeh, Gach) and the High Zagros (Meymand; Figure 1b). The data are presented as both point-to-point curves and curve fit functions using the Weighted Least Square method (Enclosure I-1 and I-2, Figures 7 and 8). In Enclosure I-2 all isotope curves are presented in their relative sampling position of the measured sections and in combination with biostratigraphic age data.

Investigation of the Effect of Diagenesis on the Stable Isotope Signature

Carbon and oxygen isotope records are sensitive to: (1) early diagenetic alteration due to subaerial exposure of the carbonate seafloor (e.g. Joachimski, 1994; Railsback et al., 2003; Vincent et al., 2004; Immenhauser et al., 2008), and (2) to burial diagenesis. Particularly, the $\delta^{18}\text{O}$ ratios of metastable carbonate minerals respond to isotopically light meteoric water whereas the $\delta^{13}\text{C}$ ratios are influenced by isotopically light carbon from soil zone CO_2 (Allan and Matthews, 1982). The data shown in this paper point to an overall limited early diagenetic influence (Figure 6). Exposures were only identified in the Asaluyeh (paleosoil) and Gach sections (thin epikarst and soil zone collapse breccia) at the top of the Dariyan Formation. In both sections, the carbon-isotope values below the main discontinuity are clearly depleted (Enclosure I-2). However, the alteration of the carbon-isotope signal concerns a thin zone of generally less than 3 m thick and immediately underneath main discontinuity surfaces. Further down section, the $\delta^{13}\text{C}_{\text{carb}}$ is not depleted and approaches typical marine Lower Cretaceous values (e.g. Veizer et al., 1999). In the $\delta^{18}\text{O}/\delta^{13}\text{C}$ cross-plots of these two sections, this is illustrated by a limited number of data points that follow a meteoric water line (Figures 6f, g). A possible interpretation of this relatively insignificant depth of alteration is an overall arid climate (e.g. Rodriguez-Lopez et al., 2008) leading to limited availability of $\delta^{18}\text{O}$ -depleted meteoric water and only a thin soil cover with limited biological activity. Alternatively, the top of the Dariyan limestones was truncated and much of the altered zone has been removed. Nevertheless, there is no evidence of intense exposure-related alteration of the stable-isotope signal in the platform sections, and the generally low oxygen isotope values probably mostly result from a thermal re-equilibration during burial (Figures 6d to 6g). Whereas the Meymand, Khormuj, and to a lesser degree the Asaluyeh isotope data plot as dense clouds (Figures 6d to 6f), the Gach data are scattered (Figure 6g). The Gach section has been affected by halokinetic movements, and is positioned next to an extruded salt dome (Gach means salt in Farsi). Consequently multiphase basinal fluid flows probably caused complex diagenetic changes during burial. As a result, the Carbon-isotope pattern observed in the other platform sections is not recognized in the Gach curve (Enclosure I-2).

The carbon-isotope values in the Bangestan section are low with many data points below 1‰ (Figure 6a). An early meteoric diagenesis as an explanation for this pattern can be excluded based on the intra-shelf basinal depositional environment within which these sediments were deposited. The lowest carbon-isotope values are often associated with organic-matter-rich levels, which suggests that microbial degradation of organic matter may have influenced the bulk rock signature through the formation of ^{12}C -rich carbonate ions. No significant relationship exists, however, between $\delta^{13}\text{C}$ and TOC ($R < 0.2$ for linear/polynomial best fits) and we can consider that the primary carbon-isotope signal is preserved. Like for the platform sections, the relatively low oxygen isotope values (Figure 6a) probably results from a thermal re-equilibration during burial.

The Fahliyan section displays highly variable carbon-isotope values, from 0 to 5‰, and low and invariant oxygen-isotope values (Figure 6c). The low carbon-isotope values occur mostly in the Lower Dariyan Formation, and have been observed in other sections (Enclosure I-2). High carbon-isotope values are recorded in the Upper Dariyan Formation, which was deposited at the margin of the Kazhdumi Basin, which became virtually isolated in the Late Aptian (van Buchem et al., 2010a). A possible explanation may be that the accumulation of organic-matter-rich deposits in the center of

the basin (Bangestan section; Enclosure I-2) at that time, caused an enrichment in ^{13}C recorded in the shallow-marine carbonates of the Upper Dariyan.

The Kabir-Kuh section shows the least variant stable-isotope values of the whole dataset (Figure 6b), and is probably the least diagenetically altered section, because of (1) overall deep depositional environment - i.e. no exposures and low permeability of the muddy facies, and (2) low organic-matter content (99% of 285 data below 0.5% TOC). Moreover, the section is located at the margin of the Garau Seaway, which remained connected to the Neo-Tethys Ocean throughout the Aptian – Albian. This prevented any locally influenced deviation from the global seawater composition, contrary to what is observed in the Kazhdumi Basin.

The $\delta^{18}\text{O}$ values observed in the various sections vary between -3 and -6‰ (Figure 6), and indicate a limited recrystallization and/or relatively low temperatures during recrystallization. This is in the Kuh-e-Bangestan section supported by the immaturity of the organic matter.

Primary Pattern of the Carbon-Isotope Signature: The Main Recognizable Trends

In the Khormuj and Asaluyeh platform sections, an expanded Early Aptian interval is present with a dilated expression of the characteristic Carbon-isotope pattern (Enclosure I-2). In the Meymand section, in the High Zagros (Enclosure I-2), the characteristic Lower Aptian isotope pattern is also expressed, albeit with more variant isotope data, whereas the Upper Aptian – Lower Albian interval is characterized by invariant data and the presence of a distinct negative excursion. Both the Fahliyan and Kabir-Kuh platform margin sections show an expanded Upper Aptian interval (*E. subnodosocostatum*, *P. melchioris* and *N. nolani* ammonite zones) with a characteristic Carbon-isotope pattern, whereas the Lower Aptian and Upper Aptian – Lower Albian part of these sections is condensed or missing (Enclosure I-2). The isotope curve of the Bangestan locality is condensed for the Lower Aptian, but shows a well developed Upper Aptian – Lower Albian curve, with a double-peaked positive excursion (Enclosures I-1 and I-2).

TOC and Carbonate Content

The TOC and carbonate content have been plotted next to the Bangestan isotope section (Enclosure I-1). There is an average background organic-matter content of 0.5 to 1% throughout the section, superposed on which there are at least five intervals that show higher amounts of TOC, exceeding 5% (see numerals in Enclosure I-1). The first one occurs in the Upper Aptian (*P. melchioris* to *H. jacobi* ammonite zones; 190–205 m), showing a gradual increase, up to maximum values of 9% TOC, followed by a sudden drop. The second interval occurs in the Lower Albian (approximately in the middle of the *D. mammillatum* ammonite Zone; 275–285 m), and reaches a maximum value of 6% TOC. The third level is higher up in the Lower Albian (*D. mammillatum* ammonite subzone; 310–340 m), where values above 10% are found. The fourth level is in the Middle Albian (upper part of the *H. dentatus* and in the *E. loricatus* ammonite zones; 370–400 m), where maximum values of up to 10% TOC are found. The fifth, and organic richest level occurs in the Late Albian (top *D. cristatum* to base *M. inflatum* zones; 445–455 m), where TOC values of up to 15% occur.

The organic matter is immature throughout the section and of marine Type II origin (HI varies between 350 and 650). Only in the fifth level, an influx of plant material has been observed in hand specimens. The carbonate content varies between 20 and 100%, but is generally higher than 60% up to the late Early Albian, and more variable above (Enclosure I-1).

DISCUSSION

Age Revision

Based on the here presented new biostratigraphic information the following revisions of the age assignment of the Kazhdumi and Dariyan formations are proposed:

The oldest sediments of the Kazhdumi Formation found in the center of the intra-shelf basin in the Bangestan and Fahliyan sections, are of Early Aptian age (*D. deshayesi* Zone). The formation is here very rich in organic matter. The previous dating gave a latest Aptian age for the formation (James and Wynd, 1965). The consequence of this age revision is: (a) the Aptian-age intra-shelf basinal deposits

Figure 6: (a) Bangestan:

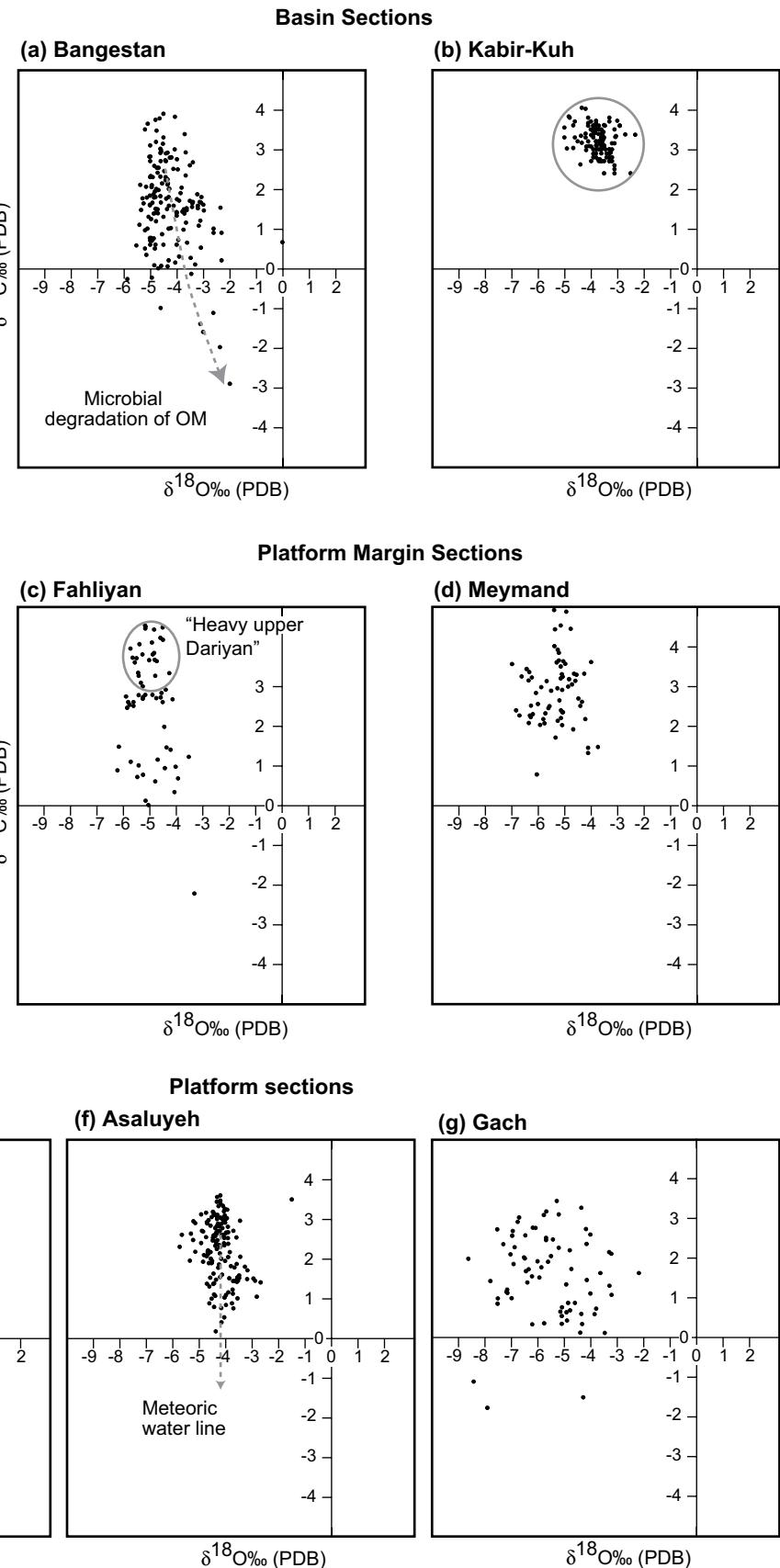
$\delta^{18}\text{O}/\delta^{13}\text{C}$ cross-plots for the outcrop sections. (a) Bangestan: the decrease of $\delta^{13}\text{C}$ values reflects the influence of microbial degradation of organic matter;

(b) Kabir-Kuh: the low variance of both $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ and the absence of covariant trends indicate a weak and homogeneous impact of diagenesis;

(c) Fahliyan: the particularly heavy $\delta^{13}\text{C}$ values corresponding to the orbitolinid-rich facies of the Upper Dariyan Formation, the $\delta^{18}\text{O}$ are weakly variant (see the text for explanation);

(d) Meymand: The low $\delta^{13}\text{C}$ values are here probably due to local weak meteoric alteration, not recognized in the field;

(e) Khormuj: the low variance of both $\delta^{18}\text{O}_{\text{‰}}$ and $\delta^{13}\text{C}$ and the absence of covariant trends indicate a weak impact of diagenesis. No exposure surfaces are recognized in this platform section;



(f) Asaluyeh: the data show evidence for meteoric alteration (a clear meteoric water line), which is supported by the evidence for exposure identified at the top of the Dariyan Formation;

(g) Gach: the high variance of both $\delta^{18}\text{O}_{\text{‰}}$ and $\delta^{13}\text{C}$ and the low $\delta^{18}\text{O}_{\text{‰}}$ values, indicate a strong impact of multiple diagenetic events (see discussion in the text).

of the Kazhdumi Formation are time-equivalent to most of the shallow-water platform deposits of the Dariyan Formation, and (b) that the initiation of the Kazhdumi intra-shelf Basin occurred at the same time as the initiation of the Bab Basin (Hassan et al., 1975; Witt and Gökdag, 1994; van Buchem et al., 2002). Moreover, it appears through the correlation with the Fars sections (Enclosure I-2) that the initiation of the intra-shelf basin, i.e. the drowning of the underlying platform in the basinal sections, is even older (*D. weissi* ammonite zone) and predates the OAE1a as also demonstrated for the northern Tethys margin platforms by Föllmi and Gainon (2008).

The clay-rich and organic-poor Kazhdumi Formation in the Fars Province, which was deposited on top of the Dariyan Formation, has a diachronous base, and is oldest in the Khormuj and Gach sections (late Early Albian and Mid-Albian), and youngest in the Asaluyeh section (early Late Albian). Previously the Kazhdumi Formation in Fars was dated as Early Albian (James and Wynd, 1965). Taking into account that these deposits onlap an exposure surface, it can be concluded that the Dariyan carbonate platform in coastal Fars was gradually flooded during the Albian, with the central part being flooded last.

The Upper Dariyan Formation in Kuh-e-Fahliyan is of Late Aptian age (*N. nolani* Zone and *H. jacobi* Zone *pro parte*). This makes it much younger than the Dariyan Formation in Fars, which is of Early Aptian age (Schroeder et al., 2010). Previously the Upper Dariyan was dated of Aptian age (unspecified) by James and Wynd (1965).

The lower part of the Sarvak Formation in Kabir-Kuh is of Late Aptian and Albian age. This was previously considered to be of Cenomanian age (James and Wynd, 1965).

Aptian/Albian Boundary and the Early Albian Successions

The Aptian/Albian boundary is in many places around the world affected by either condensation, or a hiatus and non-deposition, depending on the depositional setting. The recorded faunas around the Aptian/Albian transition are characterized by a high degree of provincialism (ammonites) and a drastic fall in paleodiversity in other faunal groups (hardly more than 3 to 4 biostratigraphically significant genera per section and few species) (Kennedy et al., 2000; Robert et al., 2001; Mutterlose et al., 2003; Latil, 2005). The Kuh-e-Bangestan section is unique in this context, because it combines an almost continuous paleontological record with a fairly high sedimentation rate and unusual paleobiodiversity (ammonites) through this critical interval. The sedimentological, biostratigraphic and isotopic dataset acquired in this section allow for a comparison and calibration of the ammonite and planktonic foraminifera biozonations with the chemostratigraphy and to date the organic-matter-rich levels occurring in this interval.

Ammonites

The ammonite biostratigraphy of the Bangestan section is well supported throughout the stratigraphic column by the occurrences of key genera that defines most late Early Aptian to early Late Albian standard ammonite zones. This is the case of *Dufrenoyia* Kilian and Reboul, *Epicheloniceras* Casey, *Parahoplites* Anthula, *Nolaniceras* Casey for the late Early to Late Aptian; *Douvilleiceras* Grossouvre, *Knemiceras* Böhm, *Lyelliceras* Spath, *Pseudobrancoceras* Kennedy, *Mirapelia* Cooper, *Oxytropidoceras* Stieler, *Mojsisoviczia* Steinmann, *Dipoloceras* Hyatt and *Hysterooceras* Hyatt for the Albian (Enclosure I-1; see also the paleontological appendix).

Nevertheless, and despite a high faunal diversity around the Aptian/Albian boundary, this limit remains difficult to characterize with certainty. At this level, the fauna is mainly composed of Acanthohoplinitae that belong to a new genus, related to *Hypacanthoplites* Spath *sensu* Casey, and represented by two, if not three new species (see palaeontological appendix). The associated faunas include evolved Cheloniceratidae (*Epicheloniceras* cf. *clansayense*), rare Engonoceratidae (primitive forms provisionally referred as *Platiknemiceras* cf. *bassei* Bataller), Desmoceratidae (*Uhligella* Jacob, *Beudanticeras* Hitzel *sensu* Casey), Silesitidae (? *Miyakoceras* sp. nov.) and several taxa (genus and species) previously not described. Most of them are briefly discussed and illustrated in the paleontological appendix (photoplates 1 to 9).

As a whole the assemblage shows a mixture of both latest Aptian and earliest Albian faunas none of which are 100% diagnostic of either stage since the key genus *Leymeriella* Jacob is not represented. Due to its high degree of endemism, the ammonite succession recorded cannot be compared with any of

the published data obtained from the reference sections from the northern and southern margins of the Neo-Tethys Ocean (Owen, 1996, 2002; Casey, 1999; Kennedy et al., 2000; Mutterlose et al., 2003; Latil, 2005). In addition, this assemblage is separated from the first true *Douvilleiceras*, a typical Albian genus that occurs in higher levels at Bangestan, by a barren interval of several tens of meters (Enclosure I-1).

It should nevertheless be noted that the pyritic fauna at the base of the barren interval (225–230 m; Enclosure I-1) shows the highest Albian affinities compared to the one collected from the underlying limestone beds. The older Engonoceratidae Hyatt (*Platiknemiceras sensu* Casey) has always been considered as typical Albian taxa (Geyer, 1995; Wright et al., 1996; Robert and Bulot, 2004; Bulot, 2007; Moreno-Bedmar et al., 2009). They are represented in the assemblage; together with primitive Beudanticeratinae that shows strong affinities with typical Albian members of the family (see discussion in paleontological appendix). Pending further ammonite collections, we therefore propose a tentative position of the Aptian/Albian boundary close to the top of this incertitude interval if not in the barren one (between 227 and 235 m; Enclosure I-1).

Planktonic Foraminifera

In the Bangestan outcrop section (Enclosure I-1), the planktonic foraminifera assemblage shows the following evolution around the Aptian/Albian boundary. From section meter 180 to 210 large specimens of *Globigerinelloides* (*G. barri* and *G. ferreolensis*; approximately 300 micrometer) coexist with smaller *Globigerinelloides* and *Hedbergelles* species. From 210 m (level BA68; Enclosure I-1) another large form is observed, *Pseudoplanomalina* (*Globigerinelloides cheniourensis*), the first “monocarenée” species. These *Globigerinelloides* disappear at 226 m (level BA75; Enclosure I-1). Above this level, the planktonic foraminifera assemblages change abruptly to one with exclusively very small and very abundant specimens of *Hedbergella* and *Globigerinelloides* with a simple morphology and a low diversity. This changes at 259 m (level BA86; Enclosure I-1), from where on *Ticinella* ssp. and *Favusella* ssp. are found.

This faunal turnover is an abrupt phenomenon where a diverse assemblage with large planispiral morphotypes like the *Globigerinelloides* (with numerous loges, sometimes perforated, the first loges of the last “tour” generally covered with pustules which can be coalescent; Verga and Premoli Silva, 2003), changes to an assemblage dominated by the small forms of *Hedbergella* and *Globigerinelloides*, with few and thin walled loges. Of interest is the appearance just before this crisis of *Globigerinelloides cheniourensis*, the first carene foraminifera of the Cretaceous (Verga and Premoli Silva, 2003), which is considered as an indication of the high diversity of the Late Aptian. The interval characterized as a planktonic foraminifera crisis corresponds exactly to the interval that is barren of ammonites, except for the very base where small pyritized nuclei of ammonites were found, suggesting a drastic change in the depositional environment.

This turnover event in the planktonic foraminifera assemblage around the Aptian/Albian boundary has been observed by many authors in different locations around the world (e.g. southern Spain: Aguado et al., 1992; northern Japan: Ando et al., 2002; Mazagan Plateau: Herrle et al., 2004; western North Atlantic: Bellier and Moullade, 2002; northeast Mexico: Bralower et al., 1999; Morocco: Leckie, 1984; southern Italy: Luciani et al., 2004; Vocontian Basin: Kennedy et al., 2000; North Atlantic: Huber et al., 2003a, 2003b). It is, as yet, difficult to compare the exact timing of the turnover event in the above mentioned studies. This is because only in a limited number of studies the biozonation is based on ammonites. In addition, the opinions on the positioning of the Aptian/Albian boundary are relatively variable. Nevertheless, it does seem reasonable to assume that the planktonic foraminifera turnover around the Aptian/Albian boundary was a global event. An element of diachronism might, however, be expected in isolated sub-basins. There is a consensus in the literature to explain this turnover as a result of an ecological impact. Plausible causes include the input of nutrients resulting in a change from oligotrophic to eutrophic environment (Caron and Homewood 1982; Caron 1983; Premoli Silva et al., 1989; Premoli Silva and Sliter, 1999; Kennedy et al., 2000; Friedrich et al., 2003). The large *Globigerinelloides*, considered as K-strategists (MacArthur and Wilson, 1967), had a long life cycle and occupied a deep-water habitat in the oligotrophic systems. With the influx of nutrients this habitat disappeared, and the less environmentally sensitive small *Globigerinelloides* and *Hedbergellids*, that are considered opportunistic r-strategists (MacArthur and Wilson, 1967), with a short life cycle, occupied the eutrophic habitats.

In summary of the above discussion, the biostatigraphic data indicate the presence of an ecological

crisis in the Bangestan outcrop between section meter 225 and 259 as expressed by the planktonic foraminifera turnover and the absence of ammonites. This interval occurs around the Aptian/Albian boundary (uncertainty interval), and has been observed worldwide.

Chemostratigraphy versus Ammonite and Planktonic Foraminifera Zonation Schemes

The isotope sections measured in the Bangestan section are dated with both an ammonite and a planktonic foraminifera biozonation (Figure 7). In order to compare the two zonation schemes, the ammonite zones have been calibrated to the planktonic foraminifera zonation scheme of Hardenbol et al. (1998). The comparison of this scheme with the planktonic zonation established in the section (following the Robaszynski and Caron, 1998 scale) shows that there is a difference in the biozonation of the Late Aptian, namely the planktonic foraminifera zonation suggests that the latest Aptian (*T. bejaouensis* zone) is absent, whereas the ammonite zonation suggest a full presence of all Late Aptian zones. Here, carbon-isotope chemostratigraphy is useful as an independent tool for an improved chronostratigraphic framework of both the upper part of the Aptian, as well as the barren interval that corresponds to the planktonic foraminifera crisis. A reference curve for the Alpine Neo-Tethys domain (Herrle et al., 2004) is compared to the carbon-isotope curve from Bangestan (Figure 8).

Following the planktonic foraminifera zonation, the Bangestan $\delta^{13}\text{C}$ curve displays the classic Aptian

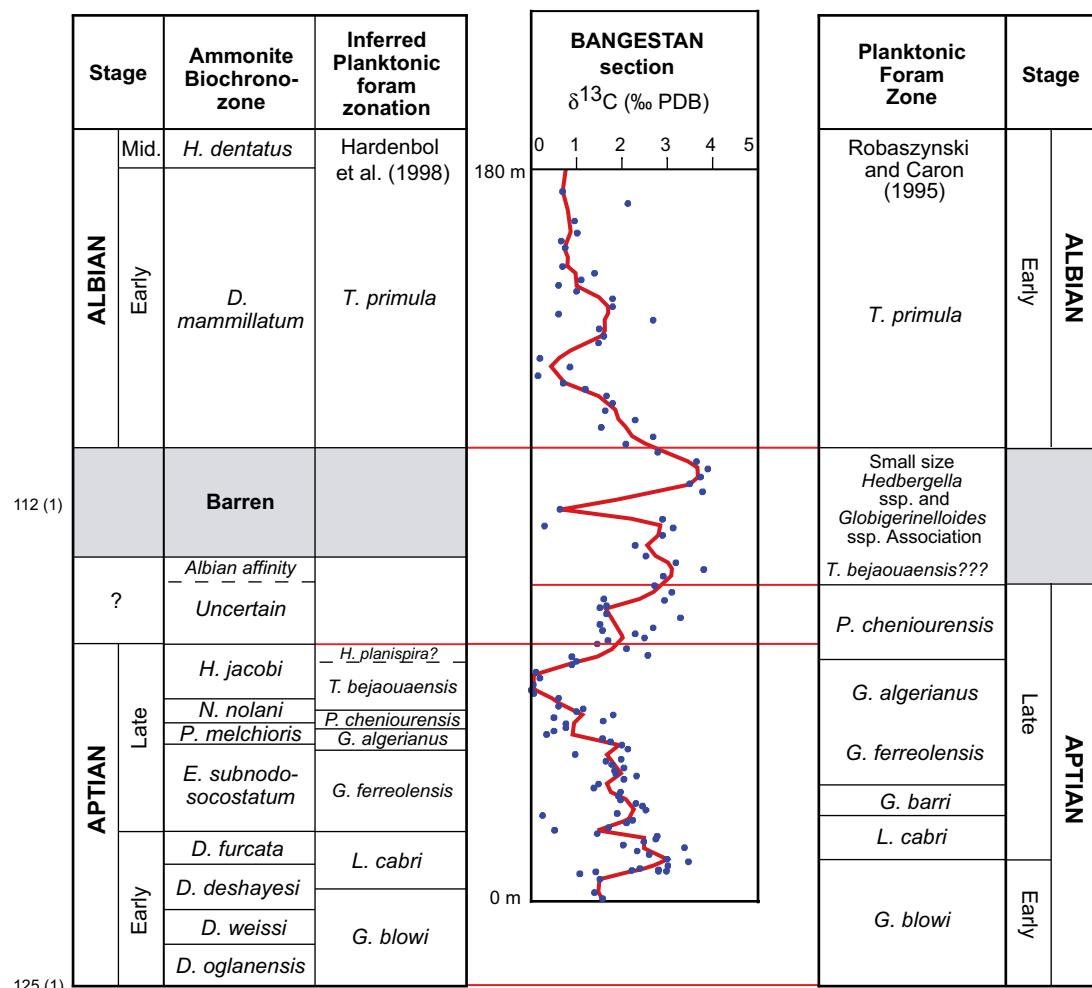


Figure 7: Carbon-isotope curve compared to (a) the ammonite zonation established for this section, and the planktonic foraminifera zonation inferred from this using the Hardenbol et al. (1998) zonation, and (b) the planktonic foraminifera zonation established for this outcrop section following the Robaszynski and Caron (1995) zonation.

pattern of the Alpine Neo-Tethys (e.g. Menegatti et al., 1998, Herrle et al., 2004). The $\delta^{13}\text{C}$ maximum in the *L. cabri* Zone is well expressed. The subsequent decrease in $\delta^{13}\text{C}$ and the negative excursion across the *G. ferreolensis* to *G. algerianus* zones are also present as well as the later shift to higher values in the *P. cheniourensis* zone (Figure 8). The *T. bejaouaensis* and *H. planispira* zones have not been identified in the Bangestan section, but the well-pronounced positive double excursion occurring in the interval containing small size *Hedbergella* ssp. and *Globigerinelloides* ssp. might be considered as a slightly thinner counterpart of the Upper Aptian and lowest Albian of the northern Neo-Tethys (Figure 8). Finally, the Early Albian decrease in $\delta^{13}\text{C}$ is also recognized in the *T. primula* Zone.

Using the ammonite zonation, the Bangestan $\delta^{13}\text{C}$ curve also displays the typical Aptian pattern of the northern Neo-Tethys margin (Figure 8). The ammonite zonation in the Herrle et al. (2004) curve is based on the synthetic work by Bréhéret (1997). Comparing the two curves, the positive excursion of the late Early Aptian is recognized, and the subsequent decrease in $\delta^{13}\text{C}$ of the *E. subnodosocostatum* ammonite zone is also present (Figure 8). The middle part of the Late Aptian (*P. melchioris* and *N. nolani* ammonite zones) is strongly condensed in the Bangestan section, as well as the upper part of the Late Aptian (lower *H. jacobi* Zone; Figure 8). In the *H. jacobi* Zone a sharp and strong negative shift to lower values (around 0‰) is recorded in the Bangestan section, whereas a gradual decrease is observed in the expanded northern margin (Figure 10). Subsequently, across the uncertain zone of the Bangestan section, the $\delta^{13}\text{C}$ gradually increase to heavier values with a maximum reached in the barren interval (3 to 4‰; Figure 8). This overall pattern of a double positive excursion is also observed in the reference curve of Herrle et al. (2004), but in a very condensed section (Figure 8). The Lower Albian decrease in $\delta^{13}\text{C}$ in the *D. mammilatum* Zone is well recorded in both sections.

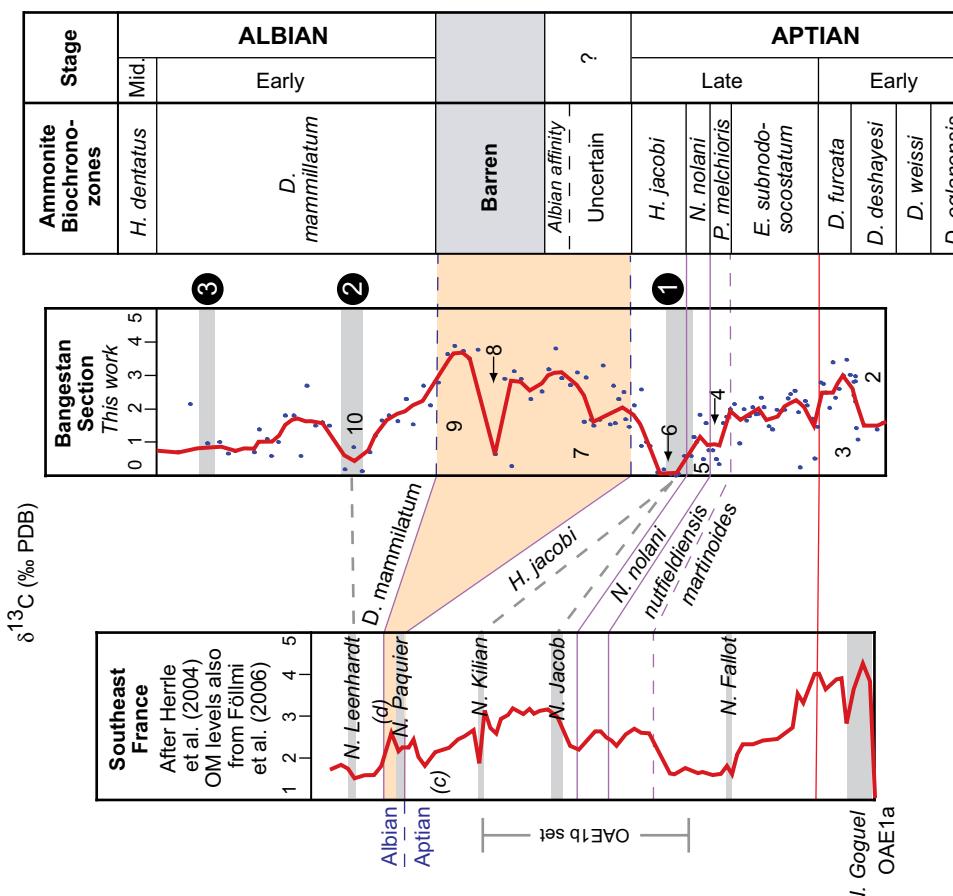
Another aspect that merits consideration is the occurrence of organic-rich horizons, five of which are present in the Bangestan section (Enclosure I-1). The best expressed Aptian organic-matter-rich level reaches a maximum (8% TOC) in the *H. jacobi* ammonite Zone (level 1 in Figure 8), stratigraphically directly beneath the peak of the negative shift in the carbon-isotope curve. According to the planktonic foraminifera zonation scheme, this interval corresponds to the *G. algerianus* Zone and the organic-matter-rich level might be correlated with the Niveau Fallot (Figure 8). According to the ammonite scale this interval matches the OAE1b set and might be considered as a stacked counterpart of the Niveau Jacob and Niveau Kilian (Figure 8). In addition to this, in the barren interval near the highest $\delta^{13}\text{C}$ values (257 m; Enclosure I-1) a less well expressed (3.5% TOC) organic-matter-rich level occurs. Comparing this finding to the section reported in Herrle et al. (2004) this level might correspond to the Niveau Paquier (Figure 8). The second organic-matter-rich level of the Bangestan section (level 2 in Figure 8), in the Lower Albian *D. mammilatum* Zone, might correspond to the Niveau Leenhardt of the OAE1b set.

Of interest for the stratigraphic interpretation of the Bangestan section are two ammonite-dated carbon-isotope curves of Aptian – Albian basinal deposits, one from the Tethys (Azevedo and Rodrigues, 2000) and one from the Chihuahua Basin in Mexico (Beltramo, 2004). Both these curves show a very similar expanded positive excursion around the Aptian/Albian boundary, and a pronounced negative excursion in the *H. jacobi* ammonite Zone (the first one is shown in Figure 9), lending support to the interpretation of the chemostratigraphy following the ammonite zonation.

In conclusion, the authors believe that the ammonite zonation scale is at present more appropriate to biostratigraphically date the carbon-isotope curve because of the more detailed ammonite dataset, the good match with other ammonite dated sections, and the likelihood that the well expressed, Upper Aptian organic-rich level represents the Niveau Jacob, in the *H. jacobi* Zone (OAE1b). The lower resolution of the planktonic foraminifera may well be due to the particular and restricted conditions that existed in this intra-shelf basin. Following the ammonite zonation and the carbon-isotope curves (Kuh-e-Bangestan, Tethys and southeast France; Figure 9) it is thus most likely that the Aptian – Albian boundary is located at the base of the barren interval (around 220–230 m; Enclosure I-1), with the onset of the planktonic foraminifera crisis.

Iranian Aptian – Lower Albian Carbon-isotope Reference

Interpretation Based on Ammonite Zonation

Scenario 2

Interpretation Based on Planktonic Foraminifera Zonation

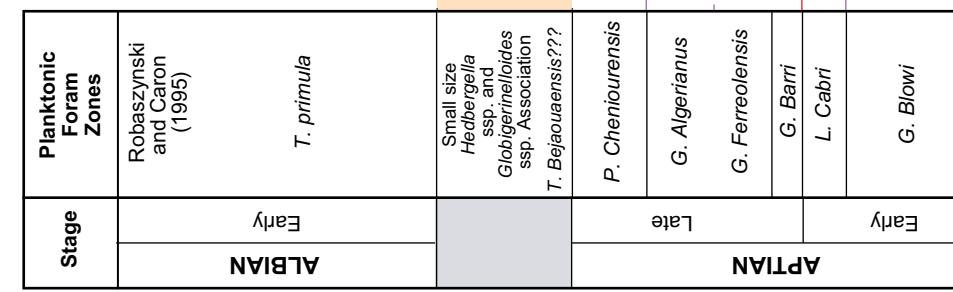
Scenario 1

Figure 8: Correlation and interpretation of the Kuh-e-Bangestan carbon-isotope curve following the planktonic foraminifera dating (scenario 1) and the ammonite dating (scenario 2). In yellow the Aptian/Albian boundary as interpreted by Herrle et al. (2004) is indicated. The ammonite zonation is preferred in this study (see text). Organic-rich levels of the Bangestan section (black circles 1 to 3) as well as black shale horizons of the northern Tethyan margin are indicated in grey. Numbers (1 to 10) indicate typical shifts in the carbon-isotope curve as defined in this study.

Curve and Regional Correlation

Carbon-isotope sections have been measured in seven outcrop sections, representing the intra-shelf basin, the platform margin and the shallow-water carbonate platform environment (Figure 1). The basinal sections were biostratigraphically dated using ammonites and planktonic foraminifera, and the shallow-water successions were biostratigraphically dated with orbitolinids (Schroeder et al., 2010). Three of these isotope curves, from the Bangestan, Kabir Kuh and Khormuj sections, have been combined in a reference $\delta^{13}\text{C}$ curve for the Aptian - Early Albian of southwest Iran (Figure 10). Within this reference curve, 10 characteristic isotopic shifts are distinguished and labelled 1 to 10, and compared to the isotope segments proposed by Menegatti et al. (1998), Bralower et al. (1999) and Herrle et al. (2004). Using this simpler shift labelling, both to lower and higher values, the Iran reference curve is compared to three high-resolution Tethyan curves (Figure 9).

Early Aptian

The Khormuj section in coastal Fars, yields the least invariant isotope record amongst the shallow-water localities (Dariyan Formation) (Enclosure I-2). The pattern observed in the $\delta^{13}\text{C}$ curve resembles an expanded Lower Aptian northern Neo-Tethys curve (alpine and Provence; cf. Erbacher and Thurow, 1997; Herrle et al., 2004; Figure 9; Moullade et al., 1998) and compares well to the Pacific curve (Jenkyns and Wilson, 1999; Figure 9). At the base of the section, a moderately expressed negative shift is observed that might correspond to the isotope minimum commonly found near the Barremian/Aptian transition. The subsequent positive shift to values of about 3.5‰ labelled 1 in Figure 10 corresponds to the lowermost Aptian rocks and is followed by an Lower Aptian shift to lower values (ca. 1.7‰; negative shift 2) that commonly occurs in the *D. weissi* and *D. deshayesi* ammonite zones (top *G. blowi* and base *L. cabri* planktonic foraminifera zones) when sea level rose worldwide and the black shales of OAE1a where deposited. Noteworthy is the absence of a well-developed organic matter-rich level in the late Early Aptian intra-shelf basinal deposits of the Kuh-e-Bangestan section at the position of the OAE1a; only a small peak (3.5% TOC) is recognized at the very base of the section in the *D. deshayesi* zone (157–160 m; Enclosure I-1). In Khormuj, this negative excursion is expanded (Figure 9), which is interpreted as the aggrading phase of the carbonate platform during the Early Aptian transgression. Isotope segment 3 (high values of about 4‰), dated as late Early Aptian with orbitolinids (Schroeder et al., 2010), is interpreted as the equivalent of the positive excursion of the *L. cabri* zone. It is important to note, that without biostratigraphic dating, a Late Aptian age might have been assigned to this section, in analogy with the curves of the northern margin of the Tethys. In the shallow-water succession of the Meymand section, in the High Zagros, the Early Aptian curve is more variant. Supported by orbitolina-dating, both an expanded negative trend, corresponding to the transgressive phase, and a trend towards more positive values is observed, that is interpreted as isotope shift 3, of late Early Aptian age (Figure 9).

Late Aptian

The Kabir-Kuh and Fahliyan sections are both positioned at the platform margins and have a strongly condensed Lower Aptian succession and a well-developed Upper Aptian interval, which consists of prograding lowstand deposits (Enclosure I-2; see also van Buchem et al., 2010a). The carbon-isotope data from these sections compare well to those reported from the northern Neo-Tethys (Figure 9). In both sections the gradual negative trend to values of about 3‰ (isotope shift 4 in Figure 10) as found in the *E. subnodosocostatum* and *P. melchioris* ammonite zones (*G. ferreolensis* and *G. algerianus* planktonic foraminifera zones) is followed by a positive shift that nearly reaches 4‰ (isotope shift 5 in Figure 10) in the *N. nolani* ammonite zone (*P. cheniourensis* planktonic foraminifera zone). The biostratigraphic scheme is based on ammonites and orbitolinids in the Fahliyan section and ammonites and planktonic foraminifera in the Kabir Kuh section. Based on the better fit of the overall chemostratigraphic pattern, the ammonite based Early/Late Aptian boundary in the Kabir-Kuh section is preferred. The Neo-Tethys isotope sections, presented in Figure 9, are generally calibrated by planktonic foraminifera. In particular the Pacific curve of Resolution Guyot, (Jenkyns and Wilson, 1999), revised by Ando et al. (2002), compares well with the Kabir-Kuh section. Both display in this stratigraphic interval more detail than most of the published northern Neo-Tethys curves.

Latest Aptian to Early Albian

The Bangestan section comprises a condensed Lower and Upper Aptian succession, whereas the upper part of the Upper Aptian (upper part of the *H. jacobi* zone) and the lowest part of the Albian interval are expanded. For the interpretation of the condensed Aptian curve, the high-resolution ammonite

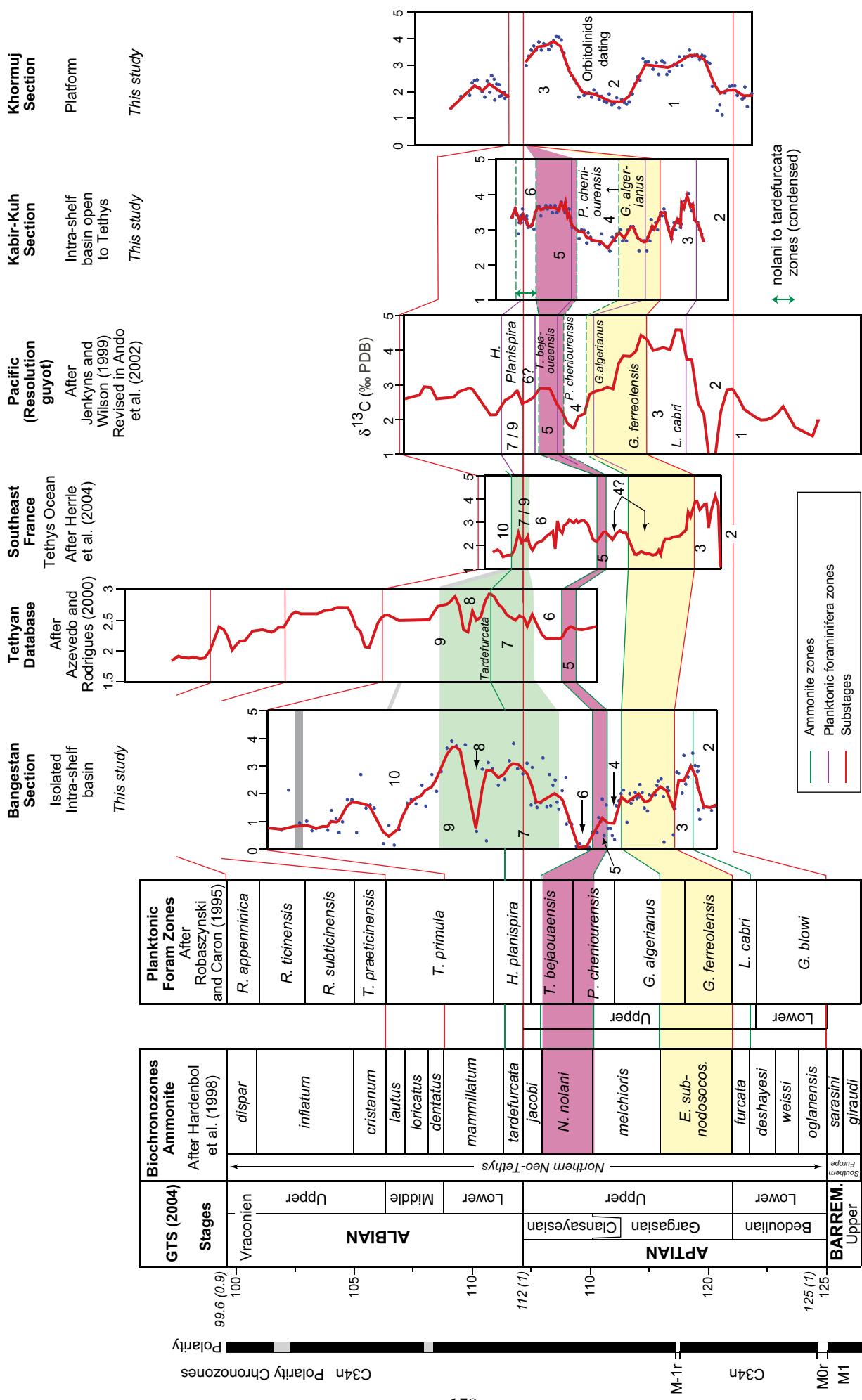


Figure 9: Comparison of the carbon-isotope curves obtained in the Bangestan, Kabir-Kuh, and Khormuj sections with three other high-resolution carbon-isotope curves from the Neo-Tethys and Pacific. For the Bangestan and Kabir-Kuh sections the ammonite dating is used. Numbers (1 to 10) indicate typical shifts in the carbon-isotope curves as defined in this study.

zonation from this locality has been used (Figure 8). In the *H. jacobi* ammonite zone (*T. bejaouensis* to *H. planispira* foraminifera zones) a sharp negative $\delta^{13}\text{C}$ peak (isotope shift 6) is recorded, which coincides with a high TOC, up to 8%, at this level. The combination of the ammonite biostratigraphy, the Carbon-isotope signature and the high organic matter concentration suggest that this interval may correspond to a condensed interval comprising the Niveau Jacob and Kilian of the OAE1b (e.g. Leckie et al., 2002; Föllmi et al., 2006). The Carbon-isotope value of 0‰ found in the Bangestan section is however lower than any of the negative shifts in the reference sections shown in Figure 9, and may be partly enhanced by diagenesis (see above). In the overlying interval, that is devoid of ammonites and characterized by planktonic foraminifera crisis (labelled “uncertain age” in Figure 9), a well expressed positive excursion (values 3-4‰) is recorded, which includes a sharp isotope shift to values below 1‰ (segment 8 in Figures 9 and 10). In Iran, this pattern has also been observed in the more proximal deposits of the Meymand section (dated with orbitolinids; Enclosure I-2); in addition the sections by Azevedo and Rodrigues (2000) display a very similar pattern (Figure 10). The isotope pattern above the segment labeled 9 in Figure 10 is characterised by Carbon-isotope minimum (isotope shift 10) followed first by a moderate shift to values around 2‰ and subsequently by a trend to lower values of about 1‰. Based on the matching isotope pattern of the Iran, Tethyan and perhaps the Atlantic section, dated with ammonites, the uncertainty interval of the Bangestan section is assigned a latest Aptian - Early Albian age, with the stage boundary tentatively positioned at 240 m (Enclosure I-1 and Figure 8). The high $\delta^{13}\text{C}$ values recorded in the Early Albian in Iran, but also in the Tethys and Chihuahua Basin (Beltramo 2004), may be explained by a reduced carbonate production at the global scale (a carbonate crisis, despite the few persisting platforms in e.g. High Zagros, this work; Tunisia, Chaabani and Razgallah, 2006; East Mediterranean area, Bachmann and Hirsch, 2006) and the coeval massive organic carbon burial (OAE1b set).

In conclusion, the composite Carbon-isotope reference section for southwest Iran, derived from both shallow-water platform and intra-shelf basinal sections, compares well to other Tethyan curves but also adds detail to the Upper Aptian and Lower Albian interval. Clearly, Iran’s composite section with its excellent biostratigraphic framework based on both ammonites and planktonic foraminifera schemes merits attention. From the point of view of the definition of the Aptian/Albian boundary, the Bangestan section is of particular interest: it combines an almost continuous paleontological record, a fairly high sedimentation rate and unusual paleobiodiversity (ammonites) through this critical interval, which allows to evaluate the events occurring around this stage boundary in more detail.

Signature of Global Events, Depositional Sequences and Organic-Rich Intervals

The sequence stratigraphic analysis of the Iranian sections (van Buchem et al., 2010a) points to an overall sea-level rise during the Early Aptian when platforms aggraded and the intra-shelf basin formed. The transgression reached a maximum in the *D. deshayesi* zone, and was followed by a sea-level drop in the early Late Aptian (end *E. subnodosocostatus* zone) that led to the subaerial exposure of the surrounding platforms. This observation is consistent with other studies in the region (e.g. Yose et al., 2006, 2010; Raven et al., 2010). The early initiation of the intra-shelf basin is associated with an orbitolinid bloom in the shallow-water proximal sections of coastal Fars and the High Zagros (Enclosure I-2). During late transgression no dominance of microbial facies is observed in Iran, unlike the sedimentation pattern observed in North Oman, where this widespread occurrence of the microbial facies is interpreted as the expression of OAE 1a (Hillgärtner et al., 2003; Immenhauser et al., 2005). In the seaway margin sections of Kabir-Kuh, in Lurestan, which had an open connection with the Neo-Tethys Ocean, no significant increase in TOC is observed, nor a drop in carbonate content, or discontinuity in the sedimentary record. In the intra-shelf basin in the Bangestan section only a very thin, condensed interval of intra-shelf basinal deposits, with a TOC of 3.5%, is observed in the *D. deshayesi* ammonite zone, which corresponds to the maximum flooding interval of the Aptian sequence. Compared to organic matter concentrations higher up in the section, this value is relatively low, and does not make a strong case of an OAE 1a equivalent.

Most of the Late Aptian is characterised by a sea level lowstand. At this time (*N. nolani* and *H. jacobi* ammonite zones) a gradual increase in organic matter is observed reaching its acme in the *H. jacobi* ammonite zone. Based on the presented age dating, this organic-rich level is interpreted as a condensed equivalent of the Niveaux Jacob and Kilian of OAE1b (e.g. Leckie et al., 2002; Föllmi et al., 2006;

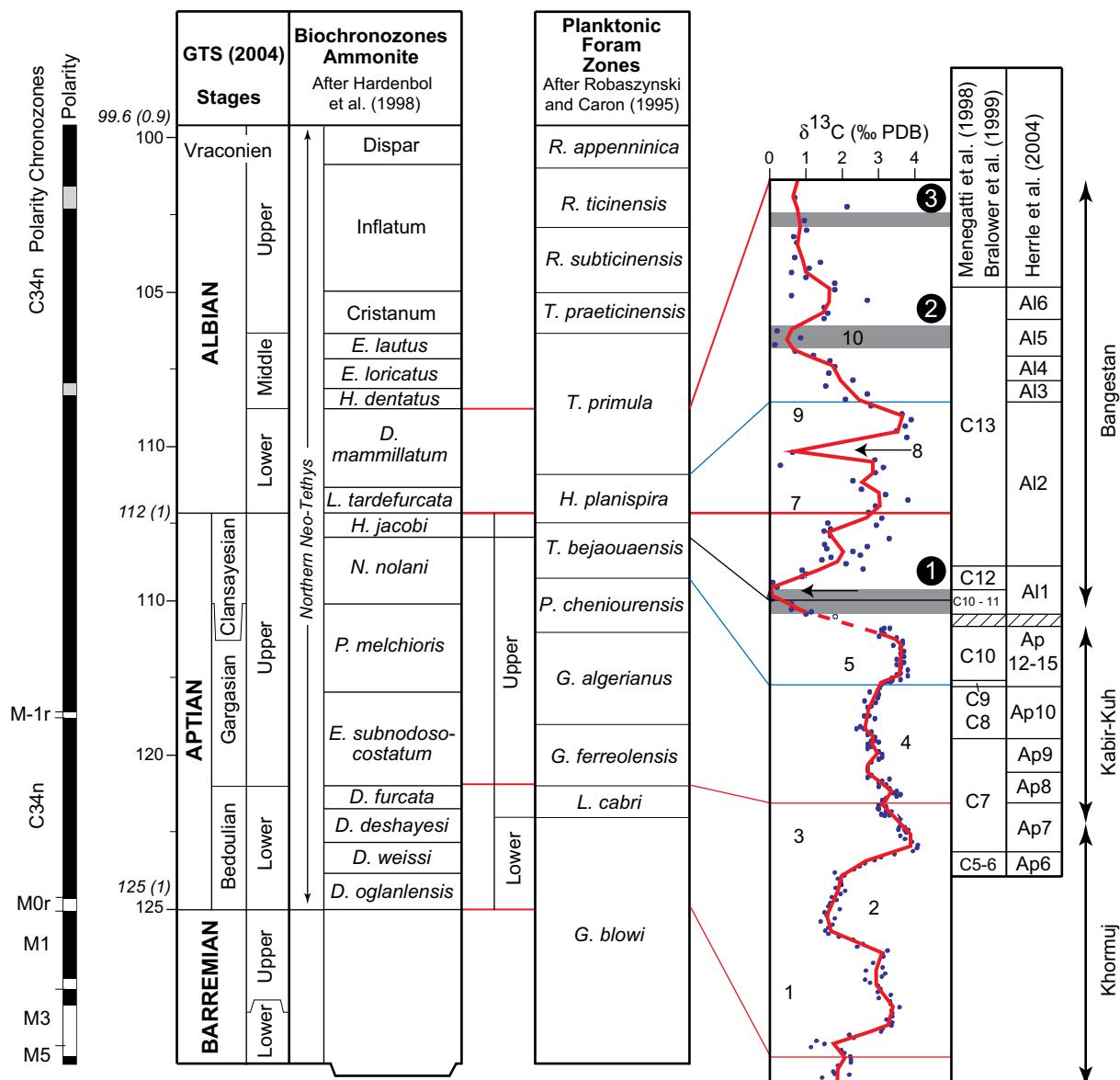


Figure 10: Composite Iranian carbon-isotope reference curve assembled with data from the Khormuj (platform), Kabir-Kuh (platform margin) and Bangestan (intra-shelf basin) sections. Ten characteristic shifts in the carbon-isotope curve are distinguished. Grey levels, numbered 1 to 3 (black circles), indicate organic-matter-rich levels; 1. Jacob and Kilian condensed, 2. Leenhardt, 3. no name. Absolute carbon-isotope values are given as indication only.

Figure 8). The overlying interval, barren in ammonites, is organic poor, except for one thin level towards its top which may tentatively be interpreted as a time equivalent of the Niveau Paquier (256 m, Enclosure I-1). Two levels with high concentrations of organic matter are found in the *D. mammillatum* ammonite zone (level 2 and 3; Enclosure I-1 and Figure 8). Level 3 is possibly an equivalent of the Niveau Leenhardt (Figure 8). The overall depositional context for these last organic-rich levels is characterised by an overall transgressive setting, and the presence of iron-rich deposits.

The Early Aptian OAE1a is relatively well constrained in time (e.g. Erba et al., 1999; Menegatti et al., 1998; despite the current debate on this topic in Moreno-Bedmar et al., 2009), and recognized around the World due to the characteristic shape of the $\delta^{13}\text{C}$ curve in a period of worldwide relative sea-level rise. The OAE1b, in contrast, is multiphase and less well constrained in time (Leckie et al., 2002). There are at least two factors that complicate the study of this event. Firstly, the low resolution of the planktonic foraminifera biozonation in this interval is due to the fact that the Aptian/Albian boundary does not coincide with a zone boundary but falls within the *H. planispira* zone, that together with the *T. primula* represent the biostratigraphic resolution of the Early and Middle Albian, a time span of approximately 7

My (e.g. Robaszynski and Caron, 1995; Hardenbol et al., 1998; Figure 9). Secondly, there is a difference in the sequence-stratigraphic timing of the deposition of OAE1a and OAE1b, with the former being deposited during maximum sea-level rise and the second during maximum lowstand and early transgression. Deposition during worldwide transgressions is naturally a favourable timing for preservation, while during periods of (long term) lowstand, preservation potential is low and likely to be scattered and incomplete. Indeed, Upper Aptian – Lower Albian sections are poorly represented in the geological record, and if present are often condensed, and found in isolated basins, such as documented in this study. The expansion of the latest Aptian to Early Albian interval with high sedimentation rates in the Kazhdumi Basin may explain a local dilution of the organic matter content, whereas the condensation in other places in the world may lead to its concentration and the better expression of the Niveau Paquier.

The following sequence of events can now be proposed for the Aptian – Lower Albian succession of southwest Iran:

- (a) the Early Aptian initiation of the intra-shelf Kazhdumi Basin occurred most likely in the *D. weissi* ammonite zone, and predated the OAE1a. During late transgression the deposition of condensed, organic-rich deposits took place in the intra-shelf basin (however, not in sufficient amounts to equate with the OAE 1a) whereas shallow carbonate platforms developed in the Fars and the High Zagros,
- (b) during the Late Aptian lowstand when the Kazhdumi Basin was virtually isolated, the deposition of organic-rich deposits occurred, which are interpreted as a condensed version of part of the OAE 1b set (Niveaux Jacob and Kilian),
- (c) during the latest Aptian sea-level rise (*H. jacobi* ammonite zone), the basinal faunal assemblage was characterised by high-diversity planktonic foraminifera and an ammonite assemblage rich in endemic species. Only part of the previously exposed platforms was flooded at this time (Enclosure I-2), which kept the basin relatively isolated,
- (d) during the latest Aptian - earliest Albian a faunal crisis occurred with the complete disappearance of ammonites and a planktonic foraminifera turn-over associated with a well-developed positive Carbon-isotope excursion (isotope segments 7-9 in Figure 9). The intra-shelf basin was still partially isolated,
- (e) during ongoing sea-level rise in the late Early Albian, more cosmopolitan ammonite faunas reappeared, and the planktonic foraminifera fauna recovered. The deposition of organic matter rich deposits occurred also at this time.

The ammonite-barren interval and planktonic foraminifera crisis-interval thus straddle the Aptian/Albian boundary and occur during an overall transgressive trend that commenced as early as the latest Aptian. Its onset, however, clearly postdates the OAE1b and happened before the deposition of the late Early Albian organic matter-rich interval (Niveau Leenhardt). Basin isolation can not have been the main controlling factor. Possible explanations for this faunal crisis include a eutrophication event (see above), a global change of seawater chemistry, and possibly climatic change in the aftermath of the Late Aptian cool period. Further work is clearly needed to investigate the exact cause of this crisis.

CONCLUSIONS

This paper focuses on the Aptian – Early Albian intra-shelf basinal deposits of the Kazhdumi Formation in the Dezful Embayment in southwest Iran. It presents an expanded Upper Aptian – Lower Albian interval with a combined dataset of a rich fossil content (ammonites, pelagic foraminifera, radiolarites), TOC and Carbon-isotope measurements. The integrated biostratigraphic and chemostratigraphic dataset resulted in a re-evaluation of the age of the Kazhdumi and Dariyan formations. The base of the Kazhdumi Formation is diachronous: it is of Early Aptian age (*D. weissi* to *D. deshayesi* ammonite zones) in the center of the intra-shelf basin, of late Early Albian age in Kuh-e-Gach and Kuh-e-Khormuj, and of Late Albian age in Kuh-e-Asaluyeh. The top of the Dariyan Formation is also diachronous: it is of late Early Aptian age in coastal Fars, and of Late Aptian age in Kuh-e-Fahliyan (*N. nolani* and *H. jacobi* ammonite zone). The Aptian/Albian boundary is placed in the Kuh-e-Bangestan section at the base of an interval characterised by the turnover of planktonic foraminifera, the absence of ammonites, and a pronounced positive $\delta^{13}\text{C}$ excursion.

A composite $\delta^{13}\text{C}$ isotope reference curve is proposed for southwest Iran, which is constrained by the good biostratigraphic control in both the shallow-water platforms (orbitolinids) and intra-shelf basinal deposits (ammonites and planktonic foraminifera). This well-dated curve has an expanded latest Aptian – Early Albian interval, with significant more detail than most currently published curves for the Neo-Tethys area for this particular interval. Five organic matter-rich layers are dated in the Kazhdumi Formation in Kuh-e-Bangestan: in the *H. jacobi* ammonite zone (max TOC 9%), two in the upper part of the *D. mammilatum* ammonite zone (max TOC 6% and 10%), one in the *H. dentatus* to *E. loricatus* ammonite zones (max TOC 10%), and one in the *D. cristatum* to *M. inflatum* ammonite zones (max TOC 15%).

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APPENDIX

Systematic palaeontology of Aptian and Albian ammonites from southwest Iran

Luc G. Bulot

INTRODUCTION

This palaeontological appendix discusses the taxa that are of biostratigraphic relevance for the dating of the outcrop sections in Kuh-e-Bangestan, Kuh-e-Fahliyan, Kuh-e-Khormuj, Kuh-e-Assaluyeh and Kuh-e-Gach, discussed above. Photoplates provide illustrations of some of the key species described below that support the biostratigraphic interpretation of the studied sections. The palaeontological notes that follow are by no means to be considered as definitive and many taxa are left in open nomenclature pending collection of further material and/or comparison with type material. Similarly synonymies are reduced to key specimens figured in the literature. Special attention was given to the genera and species of crucial interest for biostratigraphic dating and correlations. Unless otherwise mentioned the nomenclature retained herein is that of the Treatise of Invertebrate Palaeontology (Wright et al., 1996).

Unless otherwise mentioned all figures are natural size. The specimens and/or duplicates are deposited in the Museum of Natural History of Avignon (France). All pictures were taken by Jean-Louis Latil and the author. In synonymies, the mention of a v. before reference to a specific figure means that the original specimen or a plaster cast was studied by the author.

PART 1: SUPERFAMILY DESMOCERATOIDEA ZITTEL, 1895

Family Desmoceratidae Zittel, 1895 Subfamily Beudanticeratinae Breistroffer, 1953

Genus *Beudanticeras* Hitzel, 1902 *sensu* Casey, 1961a

Remarks: Kennedy (1994) showed that the type species *Beudanticeras beudanti* (Hitzel) is an Upper Albian ammonite (*D. cristatum* to *M. perinflatum* Zones). As already pointed out by Robert et al. (2001), most species assigned to *Beudanticeras* in the literature occur in the Lower and lower Middle Albian (Casey 1961a, Owen, 1988). *Beudanticeras* has never been reported from the Middle Albian above the *L. lyelli* Subzone and there is a significant stratigraphical gap in the distribution of the genus. As a consequence, a revision of *Beudanticeras* on phylogenetical grounds is urgently needed.

Beudanticeras n. sp. cf. *revoili* (Pervinquière, 1907)

- v. 1979 *Beudanticeras* («*Uhligella*») *rebouli* (Jacob), Martinez, p. 345-346, pl. 1, fig. 4a-c.
- v. 1982 *Beudanticeras* («*Uhligella*») *rebouli* (Jacob), Martinez, p. 79-80, pl. 6, fig. 6a-c.
- v. 2001 *Beudanticeras revoili* (Pervinquière), Robert et al., p. 56, fig. 2.

Material: Six pyritic nuclei – NIOC-LGB-BAN 75.9 to 75.14 (Kuh-e-Bangestan section).

Description: The individuals are up to 20 mm in diameter. Coiling is very involute, the umbilicus small (17–20% of diameter) with steep umbilical wall and narrowly rounded umbilical shoulder. The whorl section is compressed, with flattened, subparallel flanks, broadly rounded ventrolateral shoulders and a very feebly convex venter. Prorsiradiate constrictions are straight on the flanks, flexing forwards and concave on the outermost flank and ventrolateral shoulder, crossing the venter in a very feeble convexity. They are preceded by a collar rib, conspicuous on ventrolateral shoulders and venter. Intercalated ribs parallel the constrictions; they are most conspicuous on ventrolateral shoulder and venter.

Discussion: At similar size the topotype material from Tunisia collected by Latil (personnal communication, 2009) differs from the Iranian specimens by its smooth inner whorls, feeble ornamentation and slightly smaller umbilicus (14–18% of diameter in *B. revoili*). Our material is identical to the large collection made by Martinez (1979, 1982) and Robert et al. (2001) from the lowermost Albian of Spain. This form links *Zuercherella* Casey with *Beudanticeras* of the *revoili – newtoni* group.

Occurrence: In Tunisia, *B. revoili sensu stricto* occurs in the *D. mamillatum* Zone (Latil, 2005). The Spanish forms herein referred to these taxa were collected from the lowermost Albian (discussion in Robert et al., 2001). The Iranian specimens were collected from the Aptian/Albian transition Zone at Bangestan.

PART 2: SUPERFAMILY SILESITOIDEA HYATT, 1900 NOM. TRANSL., VERMEULEN, 2007

Family Silesitidae Hyatt, 1900 *sensu* Wright et al. (1996)

Remarks: The family content has been the subject of many discussions (Obata, 1967; Kennedy et al., 1979; Matsumoto, 1988). As in the case of *Beudanticeras* there is a significant stratigraphical gap between the last Lower Aptian *Silesites* Uhlig and the first Upper Aptian Silesitidae *sensu* Wright et al. (1996). This point has been completely overlooked by Medina and Riccardi (2005) and in my opinion the phylogenetic relationships between the Upper Aptian and Lower Albian Silesitidae and the silesitoid morphologies expressed in Puzosiinae and Silesitoidinae Breistroffer are far less clear than stated by these authors. For those reasons exposed a conservative view of the Silesitidae is adopted herein.

Genus *Miyakoceras* Obata, 1967

Remarks: *Miyakoceras* is a poorly understood genus that was erected for a very limited number of specimens from the Miyako group of Japan (?uppermost Aptian). Relationship with other silesitoids taxa remains unknown. Outside Japan, a single extremely doubtful specimen was described from Colombia (Bogdanova and Hoedemaeker, 2004). Some specimens from Bangestan are tentatively assigned to *Miyakoceras*.

? *Miyakoceras* sp. nov.

Material: Three fragmentary pyritic nuclei – NIOC-LGB-BAN 75.6 to 75.8 (Kuh-e-Bangestan section).

Discussion: The Iranian specimens differ from all other silesitoid by their ornamentation style and will deserve specific, if not generic, differentiation when more material will become available. In some ways, our specimen compares with the *Miyakoceras tanohatense* but can be easily be distinguished by its sharper venter and higher whorl section. Constrictions are restricted to the inner whorls and quickly develop in flares.

Stratigraphic distribution: The Iranian specimens were collected from the Aptian/Albian transition Zone from the same bed that yielded *Platiknemiceras* aff. *bassei* Bataller and *Beudanticeras* n. sp. cf. *revoili*. In Japan (Obata, 1967), *Miyakoceras* was found from isolated localities and is considered to belong to the Late Aptian assemblage that includes *Epicheloniceras matsumotoi* (Obata), *Diadochoceras nododocostatiforme* (Shimizu) and *Hypacanthoplites subcornuerianus* (Shimizu).

PART 3: SUPERFAMILY ENGONOCERATOIDEA HYATT, 1900 NOM TRANSL. BASSE, 1952 EMEND (THIS PAPER)

Remarks: Until recently Engonoceratidae Hyatt were doubtfully considered as an offshoot of the Hoplitidea Douvillé (Wright et al., 1996), until they were transferred to the Pulchelliatoidea Douvillé by Robert and Bulot (2004) on the basis of morphological similarities with the Aptian genus *Mogharaeceras* Breistroffer. It is now established that *Mogharaeceras priscum* (Douvillé, 1916) (=

Subpulchellia oehlerti in Abu-Zied, 2008) is an Upper Barremian species and most likely an endemic offshoot of *Barremites* (Bulot and Vermeulen, in preparation) that cannot be retained as an ancestor to the Engonoceratidae.

Study of *Platiknemiceras* Casey and *Parengonoceras* Spath from the Aptian/Albian transition beds of Tunisia (Latil, 2005 and personal communication, 2009), Spain (Moreno et al., 2008) and Iran (see below) shows that there is no phylogenetic link with the primitive Hoplitoidea that evolved from the Desmoceratidae in the Boreal realm (see also Casey, 1999). As a consequence, inclusion of the engonoceratooids in Hoplitoidea must be rejected and Engonoceratoidea is reinstalled herein as a superfamily of itself. The origin of the superfamily remains unknown. As herein understood it is subdivided in two families: Engonoceratidae Hyatt emend., this paper and Knemiceratidae Hyatt emend., this paper.

Family Engonoceratidae Hyatt, 1900 emend. (This Paper)

Engonoceratidae is retained to group a lineage of genera that includes *Engonoceras* Neumayr and Uhlig, *Protengonoceras* Hyatt, *Metengonoceras* Hyatt and *Neolobites* Fisher. This family ranges from the upper Lower Albian into the Upper Cenomanian. Its geographic distribution is centered in the New World (Mexico, USA), but rare members spread toward north-western Europe in the Upper Albian (*Engonoceras iris* Spath).

Other reported occurrence of *Engonoceras* in the Andean basins (Robert and Bulot, 2004, with references) and peri-Tethyan basins (Basse, 1940; Latil, 1989; Bujtor, 1990; Abdallah and Memmi, 1994; Abdallah et al., 1995) are based of misinterpretations of the genus and will be discussed elsewhere (Bulot et al., in preparation). True Engonoceratidae are also documented in the Cenomanian of Western Europe by the spot occurrence of *Metengonoceras* and *Neolobites*. Discussion of the phylogenetic relationship between those taxa is far beyond the scope of the present paper.

The ornament of the oldest known *Engonoceras* (*E. elegans* Kennedy, Landmann & Cobban) recalls that of the coarsely ornamented “*Parengonoceras*” *roemeri* (Cragin) of the Glen Rose Formation, such as the specimen originally described as *Knemiceras nodosum* Scott, but the suture, with entire or near-entire saddles, is that of *Engonoceras*. This unique combination of ornament and suture suggests direct derivation of the Engonoceratidae from the Knemiceratidae by reduction of saddle complexity.

Family Knemiceratidae Hyatt, 1903 emend. (This Paper)

Remarks: Recent collections made in Egypt (Aly and Abdel-Gawad, 2001; Aly and Latil, unpublished data), Tunisia (Latil, 2005; Latil, unpublished data), Iran (described below) and Spain (Moreno et al., 2008), allow a better understanding of the early history of the Knemiceratidae. All evidences point out to a first occurrence of the Knemiceratidae in the Aptian/Albian transition beds. This early forms, provisionally attributed to *Platiknemiceras*, are scarce and show a very primitive morphology (Plate 1-1).

This early morphology is characteristic of the younger ontogenetic states of *Parengonoceras* Spath, *Knemiceras* Böhm, and *Glottoceras* Hyatt that strongly suggests evolution of the three genera from a common ancestor after geographic isolation in the Lower Albian (see discussion in Robert and Bulot, 2004). Preliminary analysis suggests that at the end of the *L. tardefucata* Zone or at the beginning of the *D. mamillatum* Zone, *Platiknemiceras* gave rise to *Knemiceras* in the Middle East (Iran, Egypt, Lebanon) and *Parengonoceras* in northern Africa (Tunisia, Algeria). A new step in evolution was marked by the spreading of *Parengonoceras* towards South America (Venezuela, Colombia, Peru) and individualization of *Glottoceras* during the *D. mamillatum* Zone.

As herein understood the Knemiceratidae represent a consistent phylogenetic group that spans the (?) uppermost Aptian to middle Upper Albian interval. Evolution of the family in the Upper Albian is more problematic. Taxonomic position of the ill defined genus *Hypengonoceras* Spath is unclear (see discussion in Klinger and Kennedy, 1989). This statement also applies to the *Knemiceras*-like and *Parengonoceras*-like taxa described from Venezuela (Renz 1970, 1982), the Iberic Peninsula (Geyer, 1995), Hungary (Bujtor,

Plate 1

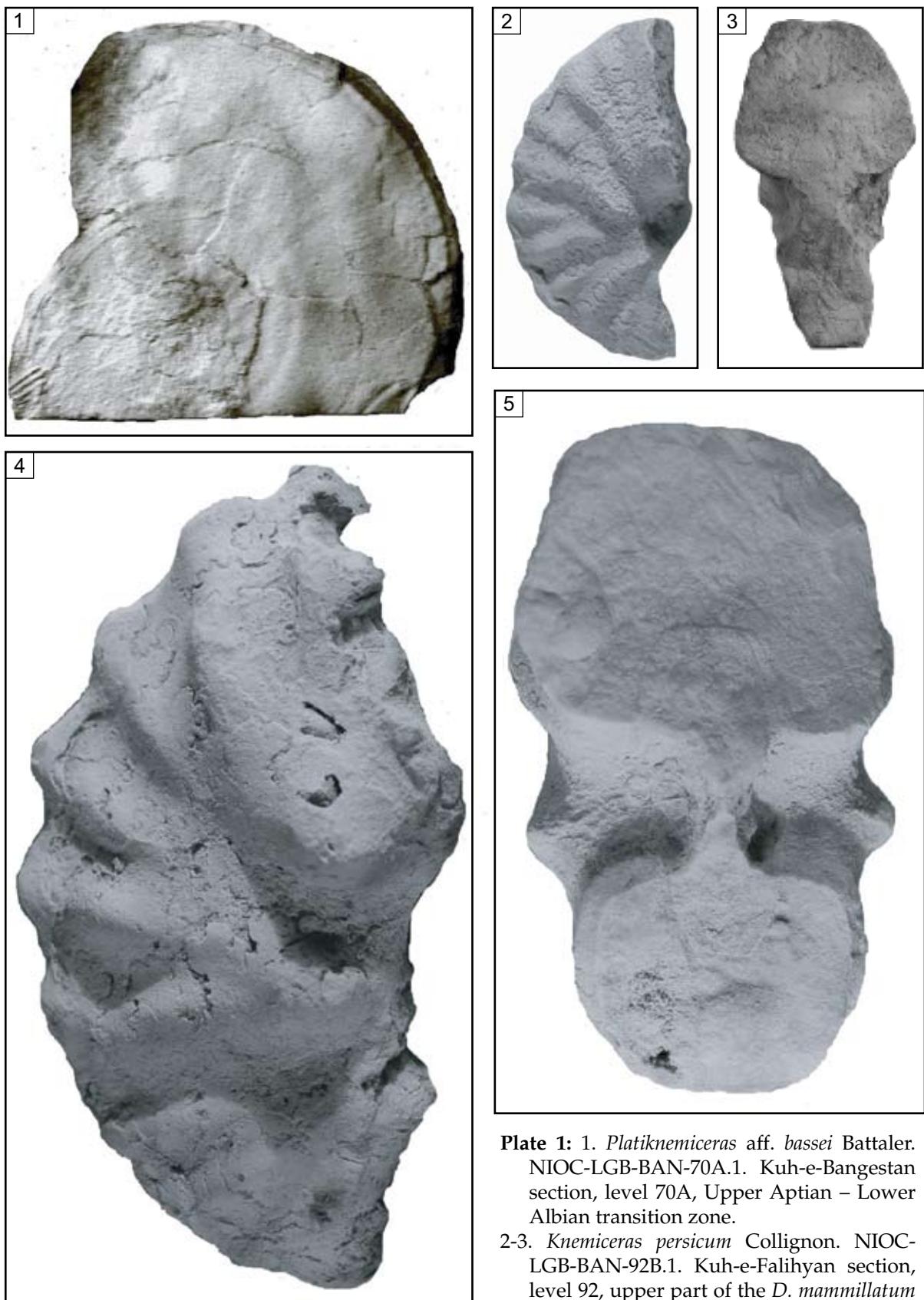


Plate 1: 1. *Platiknemiceras* aff. *bassei* Battaler. NIOC-LGB-BAN-70A.1. Kuh-e-Bangestan section, level 70A, Upper Aptian – Lower Albian transition zone.
2-3. *Knemiceras persicum* Collignon. NIOC-LGB-BAN-92B.1. Kuh-e-Falihyan section, level 92, upper part of the *D. mammillatum* Zone (Lower Albian).

4. *Knemiceras persicum* Collignon. NIOC-LGB-Gash-1.1. Gash section, level 1, upper part of the *D. mammillatum* Zone (Lower Albian).
5. *Knemiceras persicum* Collignon. NIOC-LGB-KEF-18.1. Kuh-e-Falihyan section, level 18 (= KEF 2-22), upper part of the *D. mammillatum* Zone (Lower Albian) [x 2].

1990) and South-East France (Latil, 1989). All these taxa merely represent the last step in evolution of the Knemiceratidae during the middle to upper Upper Albian. For the time being and pending a revision of these faunas they are maintained in the family Knemiceratidae as accepted herein.

Genus *Platiknemiceras* Battaler, 1954

Remarks: The type specimen of *Platiknemiceras bassei* Battaller is not associated with any other ammonites but a lowermost Albian age can be assigned to the species on the basis of new findings (Martinez et al., 1994; Moreno et al., 2008). *Platiknemiceras* is characterized by a discoidal phragmocone. Flanks show higher breadth on the compressed and vertical umbilical shoulder. The venter is flat to slightly concave up to a diameter of 4 mm. Ribs are well developed on the umbilical region but become inconspicuous on the flanks, where they are also flexuous. Ribs do not develop bullae outside the ventral shoulder. It should be noted that all known specimens are entirely septate and the adult growth stage are unknown. As herein accepted, *Platiknemiceras* is restricted to *P. bassei*, *P. hachourii* (Dubourdieu, 1953) and *P. flexuosum* Kennedy, Landmann and Cobban. Other species referred to the genus by Casey (1961b) should be transferred to *Knemiceras* such as *K. gracile* H. Douvillé, *K. subcomplicatum* Basse and *K. deserti* Mahmoud; or to *Glottoceras* such as *G. attenuatum* (Hyatt).

The problem of the relationship between *Platiknemiceras* and *Parengonoceras* is complex and linked to the revision of the Early Albian Knemiceratidae of Algeria and Tunisia described by Dubourdieu (1953). New collections made by Latil (2005 and personal communication, 2009) strongly suggests that *Platiknemiceras bassei* Battaller is closely allied to *Platiknemiceras hachourii* (Dubourdieu). The inner whorls of these two forms are also almost identical to those of *Parengonoceras mahmoudi* (Dubourdieu, 1953) and *P. algerianum* (Dubourdieu, 1953). This view is also supported by the aspect of the suture line. The type species of *Parengonoceras*, *Parengonoceras ebrayi* (de Loriol) was recently revised by Latil (2008) and also shows a *Platiknemiceras*-like early ontogenetic stage. This is also the case of *Parengonoceras caneroti* Collignon in Canérot and Colligon, (1981) from the lowermost Albian of North East Spain (Moreno et al., 2008). As a consequence *Platiknemiceras* is herein retained provisionally and may represent a junior subjective synonym of *Parengonoceras*.

Platiknemiceras aff. bassei Battaler, 1954 (Plate 1-1)

- v. aff. 1954 *Knemiceras* (*Platiknemiceras*) *bassei* Battaler, p. 174-175.
- v. aff. 1961 *Platiknemiceras bassei* Battaler, Casey, p. 355, fig. a-b.
- v. aff. 1994 *Platiknemiceras bassei* Battaler, Martinez et al., p. 350, pl. 3, fig. 4a-b.

Material: A single internal mould - NIOC-LGB-BAN 70A.1 and three pyritic nuclei - NIOC-LGB-BAN 75.2 to 75.4 (Kuh-e-Bangestan section).

Discussion: The larger specimen at our disposal matches quite well the holotype while the smaller pyritic nuclei compares with the younger ontogenetic stages illustrated by Martinez et al. (1994). It should be noted that specimen NIOC-LGB-BAN 75.2 shows ornamental features very close to the early ontogeny of *P. hachourii* illustrated by Dubourdieu (1953, pl. 2, fig. 15-18).

Stratigraphic distribution. In Spain, the typical form is known to occur in the lower Lower Albian (*L. tardefurcata* Zone and (?) lowermost *D. mammillatum* Zone) (Moreno et al., 2008). The Iranian specimens were collected from the Aptian/Albian transition Zone from the same bed that yielded *Beudanticeras* n. sp. cf. *revoili*.

Genus *Parengonoceras* Spath, 1924a

Parengonoceras sp.

- v. cf. 2008 *Parengonoceras caneroti* Battaler, Moreno et al., p. 1271, fig. 3d (sol).

Material: A single pyritic nuclei - NIOC-LGB-BAN 75.5 (Kuh-e-Bangestan section).

Discussion: This small pyritic specimen shows perumbilical swellings and associated bundles of ribs that fade on the flanks. The ventral area is highly distinctive and combines a marked sulcus and early development of ventrolateral clavi. In many ways this specimen matches the ornamental style of *Platiknemiceras caneroti* illustrated by Moreno et al. (2008, p. 1271, fig. 3d).

Stratigraphic distribution: The Spanish specimen was collected from the lower Lower Albian (*L. tardefurcata* Zone) (Moreno et al., 2008). The Iranian specimens were collected from the Aptian/Albian transition Zone from the same bed that yielded *Platiknemiceras* aff. *bassei* and *Beudanticeras* n. sp. cf. *revoili*.

Genus *Knemiceras* Böhm, 1898

Type species: *Ammonites syriacus* v. Buch, 1850, p. 20, pl. 6, figs 8-10, by original designation.

Comments: The genus *Knemiceras* is a crucial group for the stratigraphy of the Arabian Plate as it is most often the only ammonite to be found in the shallow water environments that characterize most of this region during Albian times. They have been a lot of dispute in the past about the content of the genus and the age of the various species and in many cases the problem remains unsolved (see discussions in Casey, 1961b; Geyer, 1995; Robert and Bulot, 2004).

This confusion is linked to: (1) a profusion of typological species without regards to intraspecific variation and polymorphism; (2) lack of detailed stratigraphic data. Moreover even when the stratigraphic distribution of the species is known the absence of accompanying fauna is a handicap.

The new collection at my disposal is therefore crucial to clarify some of the problems mentioned above as *Knemiceras* and stratigraphically significant species were collected from the same beds. Full revision of the fauna is far beyond the scope of the present paper but some comments on the taxonomy of the species identified are presented below.

***Knemiceras spathi* Mahmoud, 1955**

- 1955 *Knemiceras spathi* Mahmoud, p. 48-54, pl. 1, fig. 1-11, pl. 2, fig. 1, text-fig. 18-27.
1955 *Knemiceras spathi* var. *orientalis* Mahmoud, p. 54-55, pl. 2, fig. 2-7, text-fig. 28-29.
2001 *Knemiceras spathi* Mahmoud, Aly & Abdel-Gawad, p. 49, pl. 5, fig. 4-5, text-fig. 17.
2008 *Knemiceras deserti* Douvillé, Abu-Zied, p. 611, fig. 7a-c.
2008 *Knemiceras spathi* Mahmoud, Abu-Zied, p. 611, fig. 7d-g.

Type specimen: *Knemiceras spathi* Mahmoud, 1955 (p. 48-54, pl. 1, fig. 6a-c), designated herein.

Material: Four pyritic nuclei – NIOC-LGB-KEF 17.1-4 (Kuh-e-Falihyan section) and two internal calcareous moulds NIOC-LGB-BAN 92.1 and 92A-1 (Kuh-e-Bangestan section).

Discussion: There are two different morphotypes in our collection. Two inflated specimens (NIOC-LGB-KEF 17.2 and 3) match perfectly the juvenile specimens of *K. spathi* illustrated by Mahmoud (1955, pl. 1, fig. 2-3). The four others (NIOC-LGB-KEF 17.1 and 17.4, NIOC-LGB-BAN 92.1 and 92A-1) are identical to the juvenile specimens of *K. spathi* var. *orientalis* illustrated by Mahmoud (1955, pl. 1, fig. 3 and 5-6). As already pointed out by this author *K. spathi* var. *orientalis* differs from the nominal species by its less inflated whorl section and more delicate ornamental features.

The compressed morphotypes of *K. spathi* compare with *K. deserti* in whorl section but differs from that species by well developed ribs at an early ontogenetic stage. The most inflated morphotypes bear strong umbilical tubercles that recall *K. persicum*.

Stratigraphic distribution: At Bangestan, the species occurs in the main *Douvilleiceras* beds (BAN 92-92A) at a fairly low level in the *D. mammillatum* Zone. According to Moret & Mahmoud (1955), *K. spathi* occurs above *K. deserti*. Accompanying fauna includes *Uhligella* aff. *rebouli* (Jacob) and *Protanisoceras* aff. *raulinianum* (d'Orbigny), two species that are known to occur in the *D. mammillatum* Zone.

***Knemiceras persicum* Collignon, 1981** (Plate 1-2 to 1-5)

- 1981 *Knemiceras syriacum* (Von Buch); Collignon, p. 254, pl. 2, fig. 2 (*non* Von Buch).
1981 *Knemiceras (Iranoknemiceras) douvillei* Basse; Collignon, p. 258, pl. 4, fig. 1.
v. 1981 *Knemiceras (Iranoknemiceras) persicum* Collignon, p. 259, pl. 5, fig. 1.
v. 2006 *Knemiceras persicum* Collignon, Bulot, p. 51, fig. 2-1.

Type: The holotype, by the original designation of Collignon, 1981, p. 259 is no. 419-131 in the collections of the Compagnie Française de Petrole, figured by Collignon as his Plate 5, figs 1-3, and from Kazhdumi Formation of the Dahnou Anticline in Southwest Iran. It is deposited in the collections of the Université de Bourgogne, Dijon.

Material: 25 specimens. NIOC-LGB-BAN 114.1-5, NIOC-LGB-KEF 18.1-4, NIOC-LGB-KEF 19.1-2, NIOC-LGB-KEF 20A.1, NIOC-LGB-KEF 22.1-3, NIOC-GASH 01.1-2. NIOC-FVB-AN 411-412.1-6 ((Kuh-e-Bangestan, Kuh-e-Falihyan, Kuh-e-Anneh and Gash sections).

Discussion: The best specimens were collected from beds KEF 18, 20A, 22; GASH 01 and AN 411-412. NIOC-LGB-KEF 18.1 and 22.1 match respectively the type specimen figured by Collignon (1981, pl. 5, fig. 1-3) and *Knemiceras douvillei* Collignon *non* Basse (1981, pl. 4, fig. 1). A third specimen NIOC-LGB-KEF 20A.1 corresponds to the inner whorls and clearly shows that the subquadrate section is already realized at a whorl height of 7 mm. Less inflated forms such as NIOC-LGB-KEF 19.1 or 22.1 are identical to the specimen of *Knemiceras syriacum* Collignon *non* von Buch (1981, pl. 2, fig. 2). This seems to be the most common morphology in the population studied. The larger specimens such as NIOC-GASH 01.1 and NIOC-FVB-AN 411-412.1 are still septate at a diameter of 120 mm.

Stratigraphic distribution: Associated faunas in Iran indicates the upper Lower Albian (upper part of the *D. mammillatum* Zone) to lowermost Middle Albian (*H. dentatus* Zone, *L. lyelli* Subzone) age. The species is also known from the base of the Nahr Umr Formation in Oman (Bulot et al., in preparation).

***Knemiceras cf. persicum* Collignon, 1981** (Plates 2-1 and 2-2)

- 1981 *Knemiceras syriacum* (Von Buch); Collignon, p. 254, pl. 6, fig. 4.

Material: 1 specimen - NIOC-LGB-KOJ 03A (Khormuj section).

Comments: Both specimens are similar to *Knemiceras syriacum* Collignon *non* von Buch (1981, pl. 6, fig. 4). They differ from *K. persicum* by the absence of well developed umbilical tubercles and lack the pronounced ventro-lateral bullae that characterize the *K. syriacum* group. The global morphology is therefore a combination of *K. persicum* and *K. syriacum*. To some extent *Parengonoceras dufaurei* Collignon (1981, pl. 5, fig. 2) and *Parengonoceras prestati* Collignon (1981, pl. 6, fig. 3) seems to be allied to this form.

Stratigraphic distribution: The specimen was collected from the *Orbitolina* beds of the Khazdumi Formation at Khormuj. Similar morphologies occur with in the Nahr Umr Formation of Oman (Bulot et al., in preparation) and were collected above the typical *K. persicum* fauna. A Middle Albian age is assumed for this fauna.

***Knemiceras aff. kazhdumiense* Collignon, 1981**

- aff. 1981 *Knemiceras kazhdumiense* Collignon, p. 255, pl. 3, fig. 1.
v. 2006 *Knemiceras aff. dubertreti* Basse, Bulot, p. 51, fig. 2-2.
v. 2006 *Knemiceras dubertreti* Basse, Bulot, p. 51, fig. 2-3.

Type: The holotype, by the original designation, is from the Dahnou anticline (CFP 318 (3) – 111). The type specimen should be in the Dijon University collection and is believed to be lost.

Material: NIOC-FVB-AN 413.1, NIOC-FVB-AN 415.1-2, NIOC-FVB-AN 416.1.

Plate 2

Discussion: Typical *Knemiceras kazdumiense* are very rare in the collected fauna (Bulot et al., in preparation). Four specimens (NIOC-FVB-AN 413.2, NIOC-FVB-AN 415.1-2, NIOC-FVB-AN 416.1) compares fairly well in shape and ornamentation with the figured holotype. They also show superficial similarities with *K. dubertreti* Basse and further investigation are needed to establish the relationship between the two taxa. Comparison with new material from the Nahr Umr Formation of Oman show that *Knemiceras dubertreti* in Kennedy and Simmons (1991) is closer to our specimens than to the type material from Lebanon.

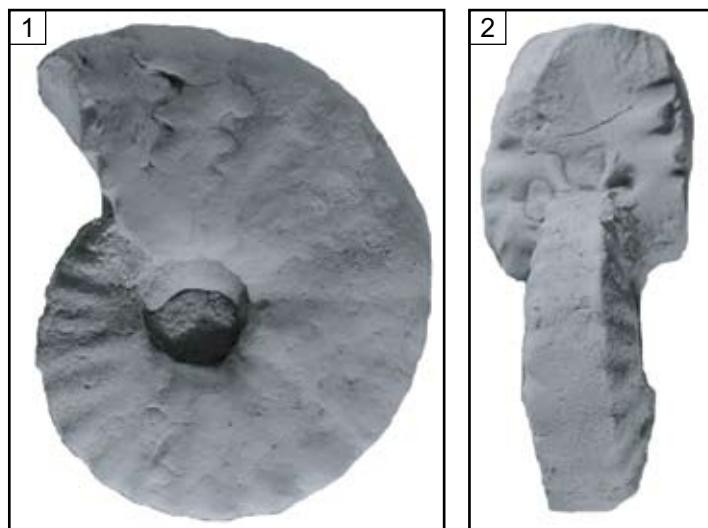


Plate 2: 1-2. *Knemiceras cf. persicum* Collignon. NIOC-LGB-KOJ-03A.1. Kuh-e-Khormuj section, level LGB 03, (lower?) Middle Albian.

Stratigraphic distribution: lower Middle to lower Upper Albian. Co-occurrence with *Mirapelia buarquianum* (White) in Bed AN 413 leaves no doubt anymore about its FO in the lower Middle Albian. Co-occurrence with *Knemiceras aff. iraniense* Collignon in Bed An 416 suggests that the species reaches the lower Upper Albian (see discussion below).

***Knemiceras aff. iraniense* Collignon, 1981** (Plates 3–1 to 3–4)

v. aff. 1981 *Knemiceras aff. iraniense* Collignon, p. 254, pl. 1, fig. 1, pl. 2, fig. 1.

Type: The holotype, by the original designation, is from the Gavbascht section (ELF 41792 – 104). The type specimen should be in the Dijon University collection and is believed to be lost.

Material: 20 well preserved specimens from Asaluyeh sections 1 and 2 and several fragments from Kuh-e-Anneh and Kuh-e-Falihyan.

Discussion: The faunas collected at Asaluyeh shows an important intraspecific variation. Compressed forms match the smaller specimen illustrated by Collignon (1981, pl. 2, fig. 1) and show body chamber at a small diameter.

Stratigraphic distribution: A late Middle to early Late Albian age is assumed for this species supported by its co-occurrence with *Venezoliceras* at Falihyan.

PART 4: SUPERFAMILY ACANTHOCERATOIDEA GROSSOUVRE, 1894

Family Prolyelliceratidae Latil, Robert and Bulot, 2010

Comments: Latil et al. (2010) have shown that all species previously referred to *Prolyelliceras* Spath, 1930 and *Ralphimlayites* Etayo Serna, 1979 do not have any phylogenetic relationship with Lyelliceratidae, e.g. the *Tegoceras* – *Lyelliceras* lineage established by Latil (1995) and Latil and Dommergues (1997).

Genus *Prolyelliceras* Spath, 1930 emend., Latil, Robert and Bulot, 2010

Prolyelliceras sp. nov. cf. *gevreyi* (Jacob, 1907)

- v. cf. 1860 *Ammonites Lyelli* Leymerie, Pictet and Campiche, p. 198, pl. 24, fig. 7 only.
- v. cf. 1907 *Acanthoceras gevreyi* Jacob, p. 37.
- v. cf. 1953 *Lyelliceras flandriini* Dubourdieu, p. 27, fig. 9, pl. 3, fig. 6-22.
- v. cf. 2010 *Prolyelliceras gevreyi* Jacob, Latil et al., fig. 1-3.

Plate 3

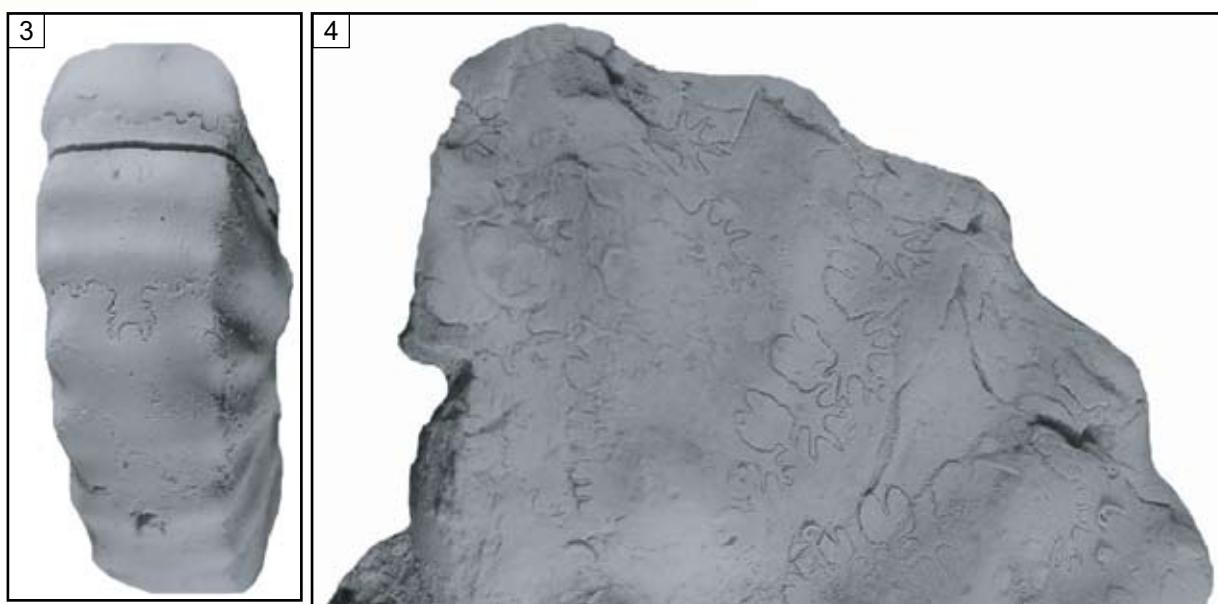
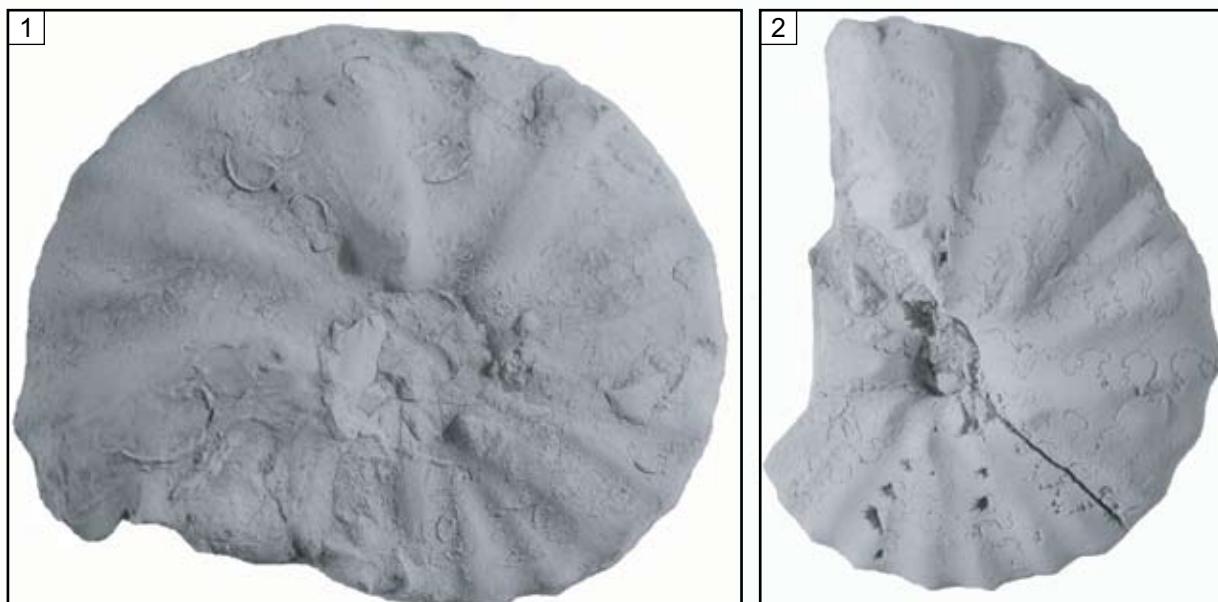


Plate 3: 1. *Knemiceras* aff. *iranense* (von Buch).
NIOC-LGB-AS-05.1.
Asaluyeh section 1, level
LGB 05, lower Upper
Albian (most likely *D.*
cristatum Zone) [x 1.5].

2-3. *Knemiceras* aff. *iranense*
(von Buch). NIOC-
LGB-AS-05.2. Asaluyeh
section 1, level LGB 05,
lower Upper Albian
(most likely *D. cristatum*
Zone) [x 1.5].

4. *Knemiceras* aff. *iranense*
(von Buch). NIOC-LGB-
AS-RS1.1. Asaluyeh
section 2, level RS 01,
lower Upper Albian
(most likely *D. cristatum*
Zone) [x 1.5].

Material: More than 30 crushed specimens (bed 67a and 67b – Kuh-e-Mish section).

Comments: Despite the poor preservation of most specimens, their abundance allows to reconstruct the ontogeny and variability of this taxa. The early and adult ontogenetic stages are identical to those of *P. gevreyi*. The middle growth stages are marked by a row of feeble tubercle slightly situated above the umbilical area that does not exist in *P. gevreyi*.

Stratigraphic distribution: In Tunisia, the range of *P. gevreyi* begins in the upper part of the *Leymeriella tardefurdata* Zone, and ends in the lower part of the *Douvilleiceras mammillatum* Zone. Because of its stratigraphic position just above the first occurrence of *Douvilleiceras* and below the first occurrence of *Knemiceras persicum*, the age of the Iranian new taxa is assumed to be Early Albian. Its precise position within the *D. mammillatum* Zone remains unknown.

Family Mojsisovicsiidae Hyatt, 1903

Remarks: The Mojsisovicsiidae were included as a subfamily in the Brancoceratidae by Wright et al. (1996). This view should be reconsidered in the light of recent discovery of early Mojsisovicsiidae and Brancoceratidae (Kennedy et al., 2000) in the *L. tardefurcata* Zone that suggest an early evolution of both families from a common ancestor. The oldest Mojsisovicsiidae belong to the genus *Mirapelia* Cooper. The family remains conspicuous until the upper Lower Albian boundary beds and is affected by a major adaptative radiation in the Middle Albian.

Genus *Oxytropidoceras* Stieler, 1920 emend. (This Paper).

Remarks: Cooper (1982) has pointed out the oversplitting of *Oxytropidoceras* in the literature and its phenotypic plasticity of shell form and ornament. The successive radiations of the genus *Oxytropidoceras* across the Lower-Middle and Middle-Upper Albian boundaries are moreover not well-constrained stratigraphically, geographically, and temporally. Cooper (1982) partly attempted a revision of the genus, mostly on the basis of literature and material from collections. This contribution is a first step, but brings forward more questions than answers. In this context, I prefer to use a typological taxonomic treatment of the genus.

As herein understood *Oxytropidoceras* is taken in a restrictive sense. Since all subgenera accepted by Wright et al. (1996) are parallel lineages that evolved separately (Young, 1996; Cooper, 1982), *Manuaniceras* Spath, *Venezoliceras* Spath (with *Tarfayites* Collignon and *Benavidesites* Cooper as synonyms), *Adkinsites* Spath, *Androiavitites* Collignon, *Laraiceras* Renz, *Mirapelia* Cooper and are herein considered as distinct genera. Therefore, *Oxytropidoceras* is restricted to the group of *Oxytropidoceras* (*O.*) *roissyanus* (d'Orbigny). This subgenus differs from *Mirapelia* Cooper by its finer and ribbing and frequent bifurcations at or above the umbilical edge. Beside the type species, other taxa included in the genus are *O.* (*O.*) *carbonarium* [and its synonyms *O.* (*O.*) *multifidum* (Steimann) and *O.* (*O.*) *cantianum* Spath], *O.* (*O.*) *supani* (Lasswitz), *O.* (*O.*) *parinense* Olsson, *O.* (*O.*) *hubbardi* Knetchel, *O.* (*O.*) *boesei* Knetchel, *O.* (*O.*) *uddeni* Young, *(O.) powelli* Young, *O.* (*O.*) *moorei* Young, *O.* (*O.*) *elaboratum* Young (and its subspecies) and *O.* (*O.*) *decsernae* Young.

Oxytropidoceratids are important elements of the upper Lower to lower Upper Albian faunas of South West Iran (fig. 3). This distribution confirms the importance of this genus for the biostratigraphy of the Albian with special reference to the southern margin of the Neo-Tethys Ocean. Unfortunately our understanding of the oxytropidoceratid stratigraphic distribution is still at a preliminary stage (Young, 1966; Cooper, 1982, Robert, 2002) and is handicapped by their spot occurrence in the standard successions of Western Europe (Owen, 1971; 1988). New data from Mexico (Latil, in preparation) and the Andean basins of Peru and Ecuador (Bulot, in preparation) may allow a better dating of some key species.

Oxytropidoceras carbonarium (Gabb, 1877) (Plate 4)

- 1877 *Ammonites carbonarius* Gabb, 1877, p. 269-270, pl. 38, fig. 2, 2a-b.
v. 1881 *Schloenbachia acutocarinata* var. *multifida*, Steinmann, p. 139, pl. 7, fig. 1, 1a-b.
1931 *Oxytropidoceras cantianum* Spath, p. 350-351, pl. 32, fig. 4-5.

- 1947 *Oxytropidoceras (Manuaniceras) carbonarium* (Gabb), Knechtel, p. 107, pl. 27, fig. 4, pl. 28, fig. 2, pl. 29, fig. 1.
- 1956 *Oxytropidoceras carbonarium* (Gabb), Benavides Cáceres, 1956, p. 457-458, pl. 49, fig. 6.
- 1966 *Manuaniceras peruvianum multifidum* (Steinmann), Young, 1966, p. 98, pl. 37, fig. 1-3, 6; pl. 38, fig. 4.
- 1966 *Manuaniceras carbonarium* (Gabb), Young, 1966, p. 99-103, pl. 7, fig. 4, 6; pl. 17, fig. 1-6, pl. 30 fig. 1, pl. 35, fig. 3.
- 1982 *Oxytropidoceras (Oxytropidoceras) carbonarium* (Gabb), Cooper, p. 287, fig. 14F-G (reproduction of the holotype *Oxytropidoceras cantianum* Spath).
- v. 1982 *Oxytropidoceras (Manuaniceras) peruvianum multifidum* (Steinmann), Renz, p. 55, pl. 16, fig. 1.
- v. 2002 *Oxytropidoceras (Oxytropidoceras) carbonarium* (Gabb), Robert et al., p. 271, fig. 10.

Material: Several crushed specimens mainly from level BAN 165A (Kuh-e-Bangestan section).

Remarks: The Iranian specimens fall within the range of variation of the species accepted in the synonymy and are very similar to the “*multifidum* morphotypes”. In agreement with Robert (2002), I consider that *O. peruvianum multifidum* is a junior subjective synonym of *O. carbonarium*. Direct observation of the holotype of the former and comparison with topotype material of the later has convinced me that the differences retained by Young (1966, p. 98-103) to distinguish the two taxa only reflects different preservations. A full revision of the Andean material from Peru and Ecuador is in progress.

Stratigraphic distribution: In Peru and Ecuador, the species is the index species of the upper part of the Middle Albian (Robert et al., 2002, fig. 3). According to Young (1966, p. 26), *Oxytropidoceras carbonarium* ranges from the late Mid-Albian into the early Late Albian of Texas and adjacent areas of Mexico (Chihuahua). In Venezuela, Renz (1982) reports *O. carbonarium* (= *O. peruvianum multifidum*) from an assemblage that characterize the lower part of the *M. inflatum* Zone. Occurrence in the United

Plate 4



Plate 4: *Oxytropidoceras carbonarium* (Gabb). NIOC-LGB-BAN-165A.1. Kuh-e-Bangestan section, level 165A, *D. cristatum* Zone (Upper Albian) [x 2].

Kingdom has been documented from the basal Upper Albian (*D. cristatum* Zone) by Spath (1931) and Owen (1971). The Iranian material was collected from the lower Upper Albian (*D. cristatum* Zone and lower part of the *M. inflatum* Zone).

Genus *Mirapelia* Cooper, 1982

Type species: *Ammonites mirapelianus* d'Orbigny, 1850, p. 124, by original designation.

Remarks: The subgenus was introduced for the coarsely ribbed species of *Oxytropidoceras* without bifurcation and intercalation of the simple ribs. In its original definition, this includes *M. mirapelianum*, *M. buarquianum*, *M. sergipense* (White), *M. evansi* (Spath), *M. packardi* (Anderson) and *M. douglasi* (Knetchel). New material from Peru (Robert, 2002) and Ecuador (Bulot, unpublished), suggests that *Ammonites peruvianus* v. Buch is to be placed in *Mirapelia* on the basis of its ontogeny and ornamental features.

Most recently, Kennedy et al. (2000) described a new species (*Mirapelia advena*) from the *L. tardefurcata* Zone of South East France that is the oldest representative of the genus. It has also been demonstrated that *M. alticarinata* (Spath) is an Early Albian species (Casey, 1978; Owen, 1988) and that *M. packardi* (Anderson) spans the Lower/Middle Albian boundary (Amédro and Robasynski, 2005). Therefore *Mirapelia* cannot be considered anymore as an exclusively Middle Albian to lower Upper Albian genus as originally stated by Cooper (1982). Discussion of the stratigraphic distribution of the Middle Albian species is to be found in Young (1966), Robert et al. (2001) and Tavares et al. (2006).

Mirapelia mirapelianum (d'Orbigny, 1850)

- v. 1850 *Ammonites mirapelianus* d'Orbigny, p. 302.
- v. 1982 *Oxytropidoceras (Mirapelia) mirapelianum* (d'Orbigny), Cooper, figs. 14D-E.
- 1997 *Oxytropidoceras (Mirapelia) mirapelianum* (d'Orbigny), Kennedy et al., p. 466, pl. 2, fig. 9; pl. 3, fig. 3, pl. 5, figs. 12-13, pl. 7, fig. 4, pl. 10, fig. 12, pl. 11, fig. 2.
- v. 2002 *Oxytropidoceras (Mirapelia) mirapelianum* (d'Orbigny), Robert, p. 183, pl. 34, fig. 4-5.
- v. non 2007 *Mirapelia mirapelianum* (d'Orbigny), Bulot, p. 51, fig. 2-6.

Type specimen: NHMP-5758 in the d'Orbigny collection from Clar, France illustrated by Cooper (1982, figs. 14D-E) and Kennedy et al. (1997, pl. 5, figs. 12-13), designated herein.

Material: Several crushed specimens (mainly from beds BAN 115 and BAN 133 - Kuh-e-Bangestan section).

Remarks: *Mirapelia mirapelianum* was concisely revised by Kennedy et al. (1997, p. 466). Extensive illustration supports the understanding of the species by those authors and the material at my disposal falls within the range of variation accepted by Kennedy et al. (1997). Specimens from BAN 115 are too poorly preserved to fully assume identity with the nominative species and have been treated as *Mirapelia cf. mirapelianum*.

Stratigraphic distribution: When well dated *Mirapelia mirapelianum* is of lower Middle Albian age (*H. dentatus* Zone, *H. spathi* Subzone) (Owen, 1971; Kennedy et al., 1997). Nevertheless, in a more recent paper, Kennedy et al. (2000, p. 681) considers the species as upper Lower Albian without giving any evidence for this new assignment. Latil (2005) reports *M. cf. mirapelianum* from the upper Lower Albian of Tunisia. In Peru, the species belongs to the *P. ulrichi* Subzone of the *O. carbonarium* Zone (Robert, 2002). At Bangestan, typical *Mirapelia mirapelianum* occurs in the *H. dentatus* Zone above the beds with *Pseudobrancoceras*. Poorly preserved specimens that may belong to that species were collected from the uppermost part of the *D. mamillatum* Zone and lower *H. dentatus* Zone (*L. lyelli* Subzone).

Mirapelia buarquianum (White, 1887) sensu Cooper, 1982 (Plate 5-1)

- 1887 *Ammonites buarquianus* White, p. 222, pl. 24, fig. 3-4; pl. 25, fig. 7-8.
- 1982 *Oxytropidoceras (Mirapelia) buarquianum* (White), Cooper, p; 296, 302-303, figs. 3A-B, 6B, 10A-B, 15A-B, 19C-E, 22D-E, 23A-D, F-G, 24-25, 27. Robert
- v. 2007 *Mirapelia mirapelianum* (d'Orbigny), Bulot, p. 51, fig. 2-6.

Material: A single fragmentary specimen - NIOC-LGB-AN 413.1 (Kuh-e-Anneh section).

Comments: According to Cooper (1982), *M. buarquianum* and *M. mirapelianum* are closely related species and there is an insensible transition between them. Nevertheless, the ribs are more flexuous and flattened on the outer flanks of *M. mirapelianum*. Still according to Cooper, the taxa that belong to the same plexus as *M. buarquianum* include *M. douglasi* Knetchel and *M. salasi* (Young). This later form represents the more rigid and densely ribbed morphotype of the group. The Iranian specimen from the Kuh-e-Anneh is very similar to the *douglasi* morphotypes from Angola that are said to be transitional to *M. salasi* (Cooper, 1982, fig. 19D-E, fig. 22D-E).

Stratigraphic distribution: According to Tavares et al. (2007), *Mirapelia buarquianum* marks the base of the Middle Albian in Angola. In Texas, a similar position was given by Young (1966) while *M. douglasi* and *M. salasi* occur at a slightly younger level. In Peru, *M. douglasi* is reported from the lower Middle Albian (*O. carbonarium* Zone, *P. ulrichi* Subzone, Robert et al., 2002). The Iranian specimen was collected between the acme of *K. persicum* and *K. aff. iraniense*. Since all evidences point out to an upper Lower Albian age for the acme of *K. persicum*, an upper Middle Albian age is assumed for *M. buarquianum*.

Mirapelia sp. inc. (Plates 5-2)

Material: Several crushed specimens including – LGB-BAN-158.1 and 158.2 (beds 157 and 158 – Kuh-e-Bangestan section).

Comments: This species clearly belongs in the *mirapelianum* - *buarquianum* plexus but do not match any of the described species. The best specimens at my disposal differ from the other *Mirapelia* collected at Kuh-e-Bangestan by their very high keel and sigmoid club shaped ribs. Unfortunately, full ornamental development (adult stages) remains unknown.

Stratigraphic distribution: This species characterizes a high level in the Middle Albian.

Genus *Venezoliceras* Spath, 1925 sensu Renz, 1968

Remarks: The taxonomy of the genus *Venezoliceras* is still in a very preliminary state. True *Venezoliceras* morphology, as expressed in the *Venezoliceras venezolanum* group (including *Tarfayites*), is restricted to the upper part of the Middle Albian and lower part of the Upper Albian (Collignon, 1966; Young, 1966; Renz, 1968, 1982). As already pointed out by Young (1966) and Renz (1968, 1982), there is another group of *Venezoliceras* in which the early and middle ontogenetic stages are characterized by dense, bifurcating and non tuberculate ribs. Cooper (1982, p. 295) introduced the name *Benavidesites* for this group of species. In my opinion this group of species only links *Oxytropidoceras* and *Venezoliceras* and represents the root stock of the latter. It therefore does not deserve separation at the genus level.

Stratigraphic distribution: *Venezoliceras* are very abundant in the upper part of the Kuh-e-Bangestan section (see Figure 3, levels BAN 165A to BAN 183) where it characterizes a very distinct interval that includes the *D. cristatum* Zone and *M. pricei* Subzone of the *M. inflatum* Zone. Rare specimens from platform settings (Plate 5-3) allow to bracket the age of the youngest *Knemiceras* faunas with special reference to the *K. aff. iraniense*. The globally crushed preservation of the fauna handicaps identification at the species level but the fauna is dominated by specimens similar to *Venezoliceras karsteni* (Stieler) and *V. venezolanum* (Stieler) (Plates 5-4 and 6).

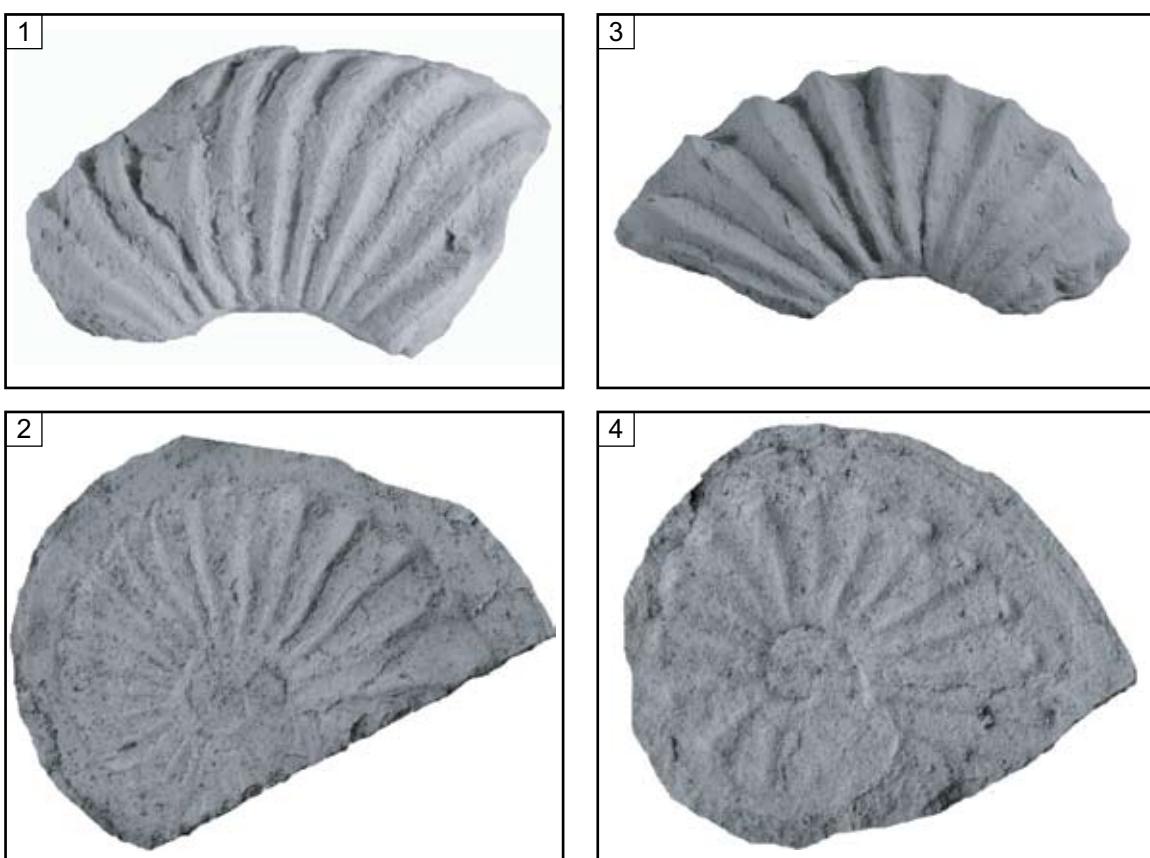
Genus *Mojsisoviczia* Steinmann, 1881

***Mojsisoviczia subdelaruei* Spath, 1931**

1931 *Diploceras subdelaruei* Spath, p. 355-357, pl. 33, fig. 6, 9, 10.

Material: A single specimen – LGB-BAN-147.1 (Kuh-e-Bangestan section).

Plate 5



- Plate 5:**
1. *Mirapelia buarquianum* (White) *sensu* Cooper. NIOC-LGB-AN-413.1. Kuh-e-Anneh section, level 413, lower Middle Albian (most likely *H. dentatus* Zone).
 2. *Mirapelia* sp. inc. NIOC-LGB-BAN-158.1. Kuh-e-Bangestan section, level 158A, upper Middle Albian [x 1.25].
 3. *Venezoliceras* sp. juv. gr. *venezolanum* (Stieler) *sensu* Renz. NIOC-LGB-KEF-23.1. Kuh-e-Falihyan section, level 23, lower Upper Albian (? *D. cristatum* or *M. pricei* Zones).
 4. *Venezoliceras* gr. *karsteni* (Stieler) *sensu* Renz. NIOC-LGB-BAN-182.1. Kuh-e-Bangestan section, level 165A, *M. pricei* Zone (Upper Albian).

Remarks: Despite its fairly poor preservation the Iranian specimen matches the holotype and paratype figured by Spath (1931, p. 355-357, pl. 33, fig. 9, 10).

Stratigraphic distribution: According to Owen (1971), *M. subdelaruei* is restricted to the *M. subdelaruei* Subzone of the *E. loricatus* Zone in the Anglo-Paris basin. No significant ammonite fauna was collected with the Iranian specimen that was found above the top of the *H. dentatus* Zone and below beds rich in *Mirapelia*.

Family Lyelliceratidae Spath, 1921
Subfamily Lyelliceratinae Spath, 1921
Genus *Lyelliceras* Spath, 1922

Comment: *Lyelliceras* is never abundant in the assemblages collected at Bangestan and most specimens are crushed and poorly preserved. With rare exceptions, it is most often impossible to access the ornamentation of the ventral area that allows distinction between *Lyelliceras pseudolyelli* and *L. lyelli*, therefore most specimens were referred to *Lyelliceras* gr. *lyelli*.

Plate 6



Plate 6: *Venezoliceras* sp. juv. gr. *venezolanum* (Stieler) *sensu* Renz. NIOC-LGB-BAN-165A.1. Kuh-e-Bangestan section, level 165A, *D. cristatum* Zone (Upper Albian) [x 2].

***Lyelliceras pseudolyelli* (Parona and Bonarelli, 1897)**

v. pars. 2008 *Lyelliceras pseudolyelli* (Parona & Bonarelli), Kennedy and Klinger, p. pl. 3, figs 12–16; pl. 4, figs 6, 10, 15, 16; Pl. 5, figs 12, 13; pl. 6, figs 5, 8–10; pl. 7, figs 3, 4, 6–8, 10–17; pl. 8, figs 14–15; Figs 6/1a,b; 8/1, 2; 9/1, 2, 3 (pars); 11H–K; 12A–F, J–O, S–U; 24A–GG; 25D–H, J–O, R–T; 27A,B; 28 (cum synonymy).

Material: Several crushed specimens mostly from level BAN 122 of the Kuh-e-Bangestan section.

Comments: Despite its fairly poor preservation the Iranian material matches very well the west European populations illustrated by Latil (1995) and Kennedy and Klinger (2008).

Stratigraphic distribution: In the Anglo-Paris Basin (France and United Kingdom), *Lyelliceras pseudolyelli* is known to span the Lower/Middle Albian boundary (Owen, 1971, 1988; Latil, 1995).

Identical occurrence was reported from Venezuela (Arnaud et al., 2002). The main Iranian fauna co-occur with *Pseudobrancoceras versicostatum* (Michelin), an association that indicates an early Mid-Albian age.

Genus *Pseudobrancoceras* Kennedy, 2004

Type species: *Ammonites versicostatus* Michelin, 1838, p. 101, pl. 12, fig. 10, by original designation.

Pseudobrancoceras versicostatum (Michelin, 1838)

- 1838 *Ammonites versicostatus* Michelin, p. 101, pl. 12, fig. 10.
1841 *Ammonites versicostatus* Michelin, d'Orbigny, p. 273, pl. 81, figs 1–3.
v. 1995 *Lyelliceras versicostatum* (Michelin), Latil, p. 367, pl. 3, figs 21–24; text-figs 29–30.
1995 *Brancoceras (Eubrancoceras) versicostatum* (Michelin), Seyed-Emami, p. 432, figs 3, 5.
v. pars 2004 *Pseudobrancoceras versicostatum* (Michelin), Kennedy, p. 252, pl. 1, figs 1–24; pl. 2,
figs 3–8; pl. 3, figs 1–9, 13–17; text-figs 1, d, e, f.
2008 *Pseudobrancoceras versicostatum* (Michelin), Kennedy and Klinger, p. 96–98, pl. 9, figs 1–35;
figs 29A–P

Material: The species is especially abundant in bed 122 of the Bangestan section.

Comments: Despite its fairly poor preservation comparison with the material illustrated Latil (1995), Kennedy (2004) and Kennedy and Klinger (2008) leaves no doubt about the identity of the Iranian material. It is interesting to note that the species was already described from central Iran by Seyed-Emami (1995).

Stratigraphic distribution: Occurrence in the Paris basin indicated the base of the Middle Albian (*H. dentatus* Zone, *L. lyelli* Subzone). As a consequence first occurrence of this species associated with *L. pseudolyelli* is taken to mark the base of the Middle Albian in the Bangestan section.

PART 5: SUPERFAMILY ANCYLOCERATOIDEA GILL, 1871 NOM. TRANSL. WRIGHT, 1957

Family Acrioceratidae Vermeulen, 2004

Remarks: Vermeulen (2004, 2006) has given evidences that *Acrioceras* Hyatt – *Dissimilites* Sarkar – *Toxoceratooides* Spath – *Tonohamites* Spath form a natural lineage of small tripartite heteromorph ammonites that first appear in the Hauterivian and evolves throughout Barremian and Aptian times. All representatives of the Acrioceratidae lineage were formerly placed in *Helycancylinae* Hyatt by Wright et al. (1996). Because the type specimen on which the genus *Helycancyulus* is based is a *nomen dubium* (see discussions in Anderson, 1938; Casey, 1961c; Aguirre Urreta, 1986), this view is herein rejected.

Genus *Tonohamites* Spath, 1924b emend. Casey, 1961b

Tonohamites aequicingulatus von Koenen, 1902 emend. Casey, 1961b (Plates 7-1 and 7-2)

1902. *Hamites aequicingulatus* von Koenen, p. 394, pl. 37, fig. 5a-c, 6a-e.
1902 *Hamites ? undosus* von Koenen, p. 393, pl. 35, fig. 13a-f.
1961 *Tonohamites aequicingulatus* von Koenen; Casey, p. 87, pl. 9, fig. 2a-b, 3a-b, text-fig. 32.
non 1962 *Tonohamites* sp. aff. *aequicingulatus* von Koenen; Collignon, p. 14, pl. 221, fig. 690.
non 1977 *Tonohamites aequicingulatus* von Koenen; Klinger & Kennedy, p. 322, fig. 38C, 66A-E, 88D.
? 1982 *Tonohamites* sp., Martinez, 142, pl. 24, fig. 6a-b, text-fig. 23.
? 1986 *Tonohamites aequicingulatus* von Koenen; Aguirre Urreta, p. 310, fig. 19D-F.

Type specimen: *Hamites aequicingulatus* von Koenen, 1902 (p. 394, pl. 37, fig. 5a-c), by subsequent designation of Casey (1961b, p. 87).

Material: A single well preserved specimen - NIOC-LGB- BAN 24.1 (Kuh-e-Bangestan section).

Description: Coiling labeceratid with long and narrow "eye". Whorls subcircular in section with flattening along the dorsum and along the venter. Costation hamitid-like, with narrow, rounded ribs separated by slightly larger interspace. Ribs lean forward as they pass straight over the dorsum. They scarcely diminish in strength over the dorsum. On the shaft, they broaden a little as they approach the venter which they cross at right-angles to the siphonal line. A pair of minute ventrolateral tubercles is present on each rib, but is lost before the beginning of the body chamber. Approaching the bend, the ribbing becomes more widely spaced and this feature is continued on the final limb. Here the ribs are slightly flexuous but still well marked on the venter.

Discussion: This is the most complete specimen ever found that can be assigned to the nominative species as all figured specimens are fragments of the shaft. It differs slightly from the specimens described in the literature by its coarser ornamental features. The early part of the shaft our specimen is almost identical to *Hamites? undosus* von Koenen, 1902 (pl. 35, fig. 13b-d). I therefore support Casey's view that *Hamites? undosus* is a junior subjective synonym of *Tonohamites aequicingulatus*. At a larger adult stage there is no significant differences with the fragments figured by Koenen (1902, pl. 37, fig. 6a-c). Nevertheless, it should be noted that the ancyloceratid coiling reconstruction proposed initially by Koenen is erroneous. The bending of the hook in *Tonohamites aequicingulatus* is identical to that of the other species with special reference to *Tonohamites limbatus* Casey and therefore the coiling is labeceratid. In my opinion, this latter species may only represent a densely ribbed morphotype of *Tonohamites limbatus* Casey.

The Upper Aptian specimens from Madagascar (Collignon, 1962) and South Africa (Klinger and Kennedy, 1977) differ from the Lower Aptian material from Europe and Iran by their less circular whorl section and stouter ornamental features near the venter. This is most clear for the ventrolateral tubercles that are clearly expressed on both sides of a narrow siphonal band. Fragments of a similar form were collected from the middle Upper Aptian of southeast France (Bulot in Dauphin, 2002, p. 140, fig. 13).

Plate 7

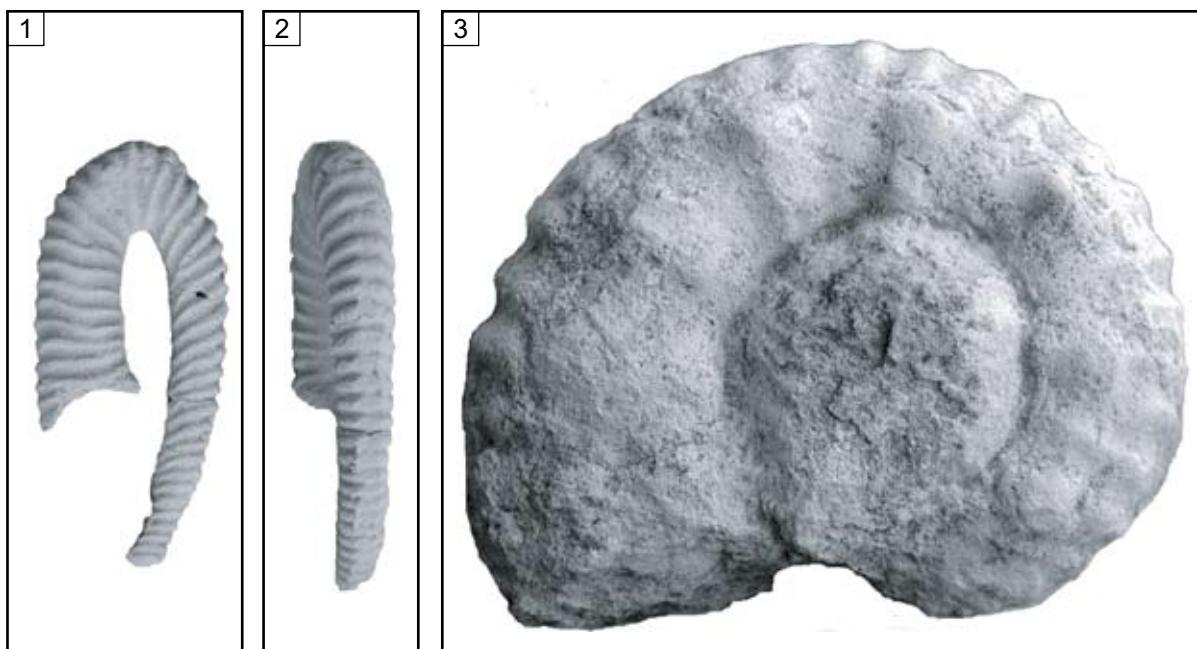


Plate 7: 1-2. *Tonohamites aequicingulatus* von Koenen emend. Casey. NIOC-LGB-BAN-24.1. Kuh-e-Bangestan section, level 24, *D. deshayesi* Zone, *D. grandis* Subzone (Lower Aptian).

3. *Epicheloniceras* aff. *migliorini* (Tavani). NIOC-LGB-KAB-14.1. Kabir-Kuh, level LBG-KAB14, *P. melchioris* Zone (Upper Aptian). The age of this monospecific assemblage is supported by pelagic forams (*G. ferreolensis* - *G. algeriana* assemblage collected from the underlying level).

Stratigraphic distribution: Upper Lower Aptian - *D. deshayesi* Zone (*D. grandis* Subzone) at Kuh-e-Bangestan. At the type locality the species was reported from the Lower Aptian with no more precision. In the UK (Isle of Wight), the specimens are from the *T. bowerbanki* Zone (*C. meyendorffi* Subzone) (Casey, 1961c, 1961d; Casey et al., 1998). If *Tonohamites limbatus* is included in the synonymy, the range of the species would also include the underlying *D. transitoria* Subzone of the *T. bowerbanki* Zone.

PART 6: SUPERFAMILY DOUVILLEICERATOIDEA PARONA AND BONARELLI, 1897 EMEND., VERMEULEN, 2006

Family Douvilleiceratidae Parona and Bonarelli, 1897

Remarks: As herein understood the Douvilleiceratidae is restricted to three subfamilies: Douvilleiceratinæ, Roloboceratinæ Casey and Astiericeratinæ Breistroffer *nom. transl.*, Bulot, herein. This later subfamily is monogenic and represents a micromorphic uncoiled offshoot directly derived from *Douvilleiceras* (Kennedy, 1986).

Subfamily Douvilleiceratinæ Parona and Bonarelli, 1897, emend., Bulot, herein (= Cheloniceratinæ Spath, 1923)

Remarks: Since all available evidence shows that *Spinocrioceras* Kemper, *Procheloniceras* Spath, *Cheloniceras* Hyatt, *Epicheloniceras* Casey, *Douvilleiceras* Grossouvre represent a single lineage, the subfamily Cheloniceratinæ is abandoned and considered as a subjective synonym of Douvilleiceratinæ. The genera *Vectisites* Casey, *Walpenites* Casey and *Vergunniceras* Thomel are micromorphic offshoots whose relationships are far from being clear but that derive from the *Cheloniceras* – *Epicheloniceras* plexus at various level of the lower Upper Aptian (Bulot in Dauphin, 2002). Pending further investigations they are maintained in Douvilleiceratinæ.

As already pointed out by Mikhailova (1963), Egoian (1965) and Kvantaliani (1971) *Diadochoceras* Hyatt that is most often considered as a Douvilleiceratidae (see Wright et al., 1996; Kennedy et al., 2000, among others) show typical Acanthohoplitidae juvenile stage and should therefore be excluded from the Douvilleiceratidae.

Genus *Cheloniceras* Hyatt, 1903

Remarks: The genus is fairly common in the studied sections but most specimens are too poorly preserved for specific identifications (crushed impression from the lower part of Kuh-e-Bangestan section). Large body chambers also occur on the surface of the hard ground surface BAN 24.

Stratigraphic distribution: *Cheloniceras* is strictly restricted to the upper part of the Lower Aptian in the Caucasus and Western Europe (Casey, 1961d; Bogdanova and Tovbina, 1995; Casey et al., 1998; Ropolo et al., 2000, 2008). Maximum of abundance was reported from the upper part of the *D. deshayesi* Zone and throughout the *D. furcata* Zone. This is supported by the Iranian findings.

Genus *Epicheloniceras* Casey, 1954

Remarks: *Epicheloniceras* is another of the Late Aptian genus that has been oversplit over the years. Most taxa were described from Western Europe and the Caucasus (Sinzow, 1906; Jacob & Tobler, 1906; Vasiliewskij, 1909; Kazansky, 1914; Nikchitch, 1915; Casey, 1962), but the genus is also widespread in other parts of the world such as Madagascar (Collignon, 1962), Mexico (Burkhardt, 1925; Humphrey, 1949) and Colombia (Etayo Serna, 1979; Sharikadzé et al., 2004). The genus is also known from Yemen (Howarth, 1998) and Somalia (Tavani, 1948) based on misidentification of *Cheloniceras* (see discussion below).

A first attempt was made by Dutour (2005) to reduce the number of taxa on the basis of pyritic material from the Vocontian domain of South East France. A more conservative view, closer to Casey (1961d) interpretation of the species, was followed by Ropolo et al. (2008) in their study of the faunas from the

key sections at La Bédoule (SE France). In both case, the authors failed to compare their material with the type specimens and this handicap their conclusions, with special reference to dimorphism.

Stratigraphic distribution. It is most often claimed that *Epicheloniceras* is strictly restricted to the lower Upper Aptian (*E. subnodosocostatum* Zone) in Western Europe (UK and Germany) and northern margin of the Neo-Tethys Ocean. This view has been altered by Ropolo et al. (2008) that clearly establish that *Epicheloniceras* co-occur with *Parahoplites* in the lower part of the *P. melchioris* Zone. Because *Eodouvilleiceras* is herein considered as synonym of *Douvilleiceras* and *Epicheloniceras* emended to include the *clansayense* group, the range of the genus now extends in the upper Upper Aptian (*H. jacobi* Zone).

Zagros occurrences. Poorly preserved specimens occur throughout the *E. subnodosocostatum* Zone at Kuh-e-Bangestan. They appear just above the highest occurrence of *Dufrenoyia* (level BAN 37). The last occurrence of the genus occurs 2 meters below the first occurrence of *Parahoplites* (level BAN 53). This range is very similar to the one documented in the Vocontian basin of southeast France (Bulot in Dauphin, 2002). Higher up in the succession *Epicheloniceras* of the *clansayense* group occurs in the Aptian-Albian transition zone (discussion below).

Epicheloniceras is far more common and better preserved in the Kazhdumi tongue at Kuh-e-Mish and Kuh-e-Fahliyan. In those sections, the material collected includes *E. gr. martinoides* (Casey), *E. gr. subnodosocostatum* (Sinzow) - *buxtorfi* (Jacob) and *E. gr. clansayense* (Jacob).

Most interesting is the large collection made at Kabir-Kuh (levels KK14 to 16). The range of morphologies includes specimens that compares with the cheloniceratids from Somalia described by Tavani (1948). One of these specimens is illustrated here (Plate 7-3) and is almost identical to the inner whorls of *Epicheloniceras migliorini* (Tavani). The age of forms (*P. melchioris* Zone) is supported by pelagic forams assemblage (*G. ferreolensis* - *G. algeriana*) collected from the underlying level.

Epicheloniceras gr. subnodosocostatum (Sinzow, 1906) - *buxtorfi* (Jacob and Tobler, 1906)

- v. 1906 *Douvilleiceras buxtorfi* Jacob & Tobler, p. 15, pl. 1, figs. 9-11.
- 1906 *Douvilleiceras subnodosocostatum* Sinzow, p. 175, pl. II, fig. 1-8.
- v. 1906 *Douvilleiceras subnodosocostatum* Sinzow, Jacob & Tobler, p. 14, fig. 4-6.
- 1915 *Douvilleiceras buxtorfi* Jacob & Tobler: Nikschitch, p. 45, pl. 6, figs. 8-10.
- v. 1962 *Cheloniceras (Epicheloniceras) buxtorfi* (Jacob & Tobler): Casey, p. 253, pl. 39, fig. 8, text-fig. 88l-p.
- v. 1971 *Cheloniceras (Epicheloniceras) buxtorfi* (Jacob & Tobler): Kemper, p. 367, pl. 27, fig. 1.

Material: All specimens were collected from Kuh-e-Mish (level 62 and 62A).

Remarks: On the basis of pyritized nuclei, Dutour (2005) considered *Epicheloniceras buxtorfi* and *E. subnodosocostatum* as synonyms because of the morphological similarities between the two species. The first was thought to be the microconch, the second the macroconch of the same species. Given our present state of knowledge of *Epicheloniceras*, great care must be taken to determine if true dimorphism exists in Cheloniceratids. According to Ropolo et al. (2008) stratigraphic distribution do not support this synonymy because the range of *E. subnodosocostatum* differs from that of *E. buxtorfi*. These later authors also recognized morphologic dissimilarities between the two taxa. *E. buxtorfi* differs from *E. subnodosocostatum* in having a smaller number of intercalary ribs, a weaker sculpture and a different whorl section. For all these reasons an independent status was retained for the two species. Close examination of the material illustrated by those authors show that the discrepancies between the Dutour (2005) and Ropolo et al. (2008) also reflect different interpretation of *E. subnodosocostatum*. Pending a better understanding of this group of *Epicheloniceras*, I will treat *E. buxtorfi* and *E. subnodosocostatum* as closely related species.

Stratigraphic distribution: When well dated the *E. subnodosocostatum* - *buxtorfi* groups characterize the upper part of the *E. martini* Zone (Dutour, 2005 with references).

***Epicheloniceras cf. clansayense* (Jacob, 1905)**

- cf. 1905 *Douvilleiceras clansayense* Jacob, p. 413-415, pl. 13, fig. 4a-c.
non 1906 *Douvilleiceras clansayense* Jacob, Jacob and Tobler, p. 14, pl. 1, fig. 7-8.
non 1955 *Cheloniceras clansayense* (Jacob), Eristavi, p. 151, pl. 5, fig. 5.
cf. 1965 *Epicheloniceras clansayense* (Jacob), Egoian, p. 156-158, pl. 14, fig. 1a-c, 3a-c (sol).
cf. 1971 *Epicheloniceras clansayense* (Jacob), Kvantaliani, p. 108-110, pl. 16, fig. 3a-c.

Material: Several pyritic nuclei and fragments including – NIOC-LGB-BAN 75.15 to 18 and calcareous mould – NIOC-LGB-BAN 70.1 (Kuh-e-Bangestan section).

Remarks: Because *Eodouvilleiceras* Casey is a minor subjective synonym of *Douvilleiceras*, most upper Upper Aptian species formerly referred to *Eodouvilleiceras* by Casey (1961d, 1962), Egoian (1969), Obata (1969) and Sharikadzé et al. (2004) are herein transferred *Epicheloniceras*. These include *Epicheloniceras clansayense* (Jacob), *E. planum* (Rouchadzé), *E. badkhyzicum* Urmova, *E. extenuatum* Egoian, *E. aphanasievi* Egoian and *E. matsumotoi* (Obata). One can be tempted to treat those taxa as different morphotypes and growth stages of a single highly variable species. As an example, I am ready to accept the idea that *E. matsumotoi* and *E. aphanasievi* represent respectively the juvenile and adult stages of *E. clansayense*.

Nevertheless, in my opinion two other taxa should be kept distinct: 1) *E. badkhyzicum* whose early growth stages show a fairly primitive style of ornamentation; 2) *E. extenuatum* whose ornamentation links *Epicheloniceras* of the *clansayense* group with the primitive *Douvilleiceras*. The species listed above form a natural group that characterizes the upper Upper Aptian (*N. nolani* and *H. jacobi* Zones) and (?) basal Lower Albian.

Discussion: Despite their preservation state, the specimens at my disposal show more affinities with *E. clansayense* than with any other “species” of the group discussed above. Development of the tuberculation and density of the ribbing are similar to that of the juvenile ontogenetic stages illustrated by Egoian (1965). A large body chamber from Kuh-e-Mish (Bed 63) most likely also belongs here. Noteworthy is the specimen from Fahiyān that was collected 5 meters below the top of the Dariyan Formation.

Stratigraphic distribution: Little is known about the exact distribution of *E. clansayense* and allied species. A upper Upper Aptian age is usually given in the literature, but most specimens illustrated were collected from condensed levels that embraces the *P. melchioris* to *H. jacobi* Zones (Jacob, 1905; Egoian, 1965, 1969). It should also be noted that an lower Lower Albian age cannot be dismissed. Isolated specimens from the Vocontian domain were found in the *N. nolani* and *H. jacobi* Zzones (Bulot in Dauphin, 2002). The Iranian specimens were collected from the Aptian/Albian transition beds at Kuh-e-Bangestan. In the highest part of their range they co-occur with *Platiknemiceras* cf. *bassei* and *Beudanticeras* sp. nov. cf. *revoili*.

**Genus *Douvilleiceras* de Grossouvre, 1894
(= *Trinitoceras* Scott, 1940 ; = *Eodouvilleiceras* Casey, 1961)**

Remark: Following Vermeulen (2006), I herein consider that *Eodouvilleiceras* is a junior subjective synonym of *Douvilleiceras*. This opinion is based on the succession of ontogenetic stages on the type specimen of *Eodouvilleiceras horridum* that cannot be distinguished from the one observed in *Douvilleiceras*. *Eodouvilleiceras* that are transferred to *Douvilleiceras* include *Eodouvilleiceras pedrocarvajali* Etayo Serna and *E. trituberculatum* Sakharova. *Eodouvilleiceras* (?) *tequendamai* Etayo Serna lacks the doubling of the ventro-lateral tubercles and is most likely an *Epicheloniceras* of the *clansayense* group.

***Douvilleiceras* cf. *mammillatum* Schlotheim, 1813 var.**

***aequinodum* (Quenstedt, 1849) sensu Cooper, 1982** (Plates 8-1 to 8-4)

- cf. 1982 *Douvilleiceras mammillatum aequinodum* (Quenstedt, 1849), Cooper, p. 272-278, Figs 4A-B, 6C-G, 7D, G-I, 8A-B, 9A-C, E, 10C-D, F-H, 12A-B, 17A.

Plate 8

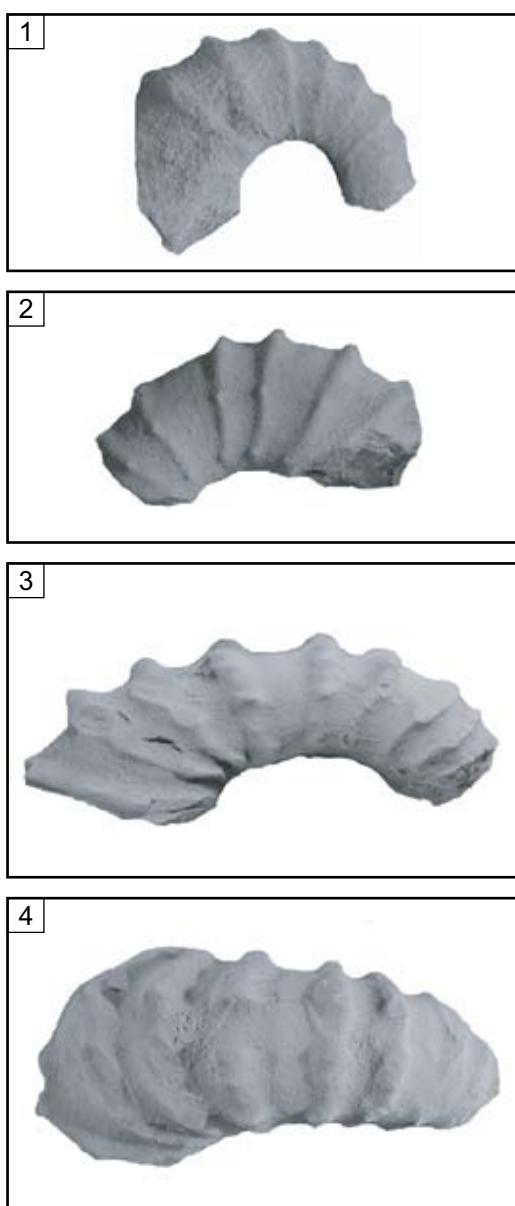


Plate 8: 1. *Douvilleiceras* aff. *mammillatum* Schlotheim var. *aquinodum* (Quenstedt) sensu Cooper. NIOC-LGB-BAN-92B.1. Kuh-e-Bangestan section, level 92B, *D. mammillatum* Zone (Lower Albian) [x 1.5].
 2. *Douvilleiceras* aff. *mammillatum* Schlotheim var. *aquinodum* (Quenstedt) sensu Cooper. NIOC-LGB-BAN-92B.2. Kuh-e-Bangestan section, level 92B, *D. mammillatum* Zone (Lower Albian) [x 1.5].
 3-4. *Douvilleiceras* aff. *mammillatum* Schlotheim var. *aquinodum* (Quenstedt) sensu Cooper. NIOC-LGB-BAN-92.1. Kuh-e-Bangestan section, level 92, *D. mammillatum* Zone (Lower Albian).

Material: NIOC-LGB-BAN 92.1 to 9 and NIOC-LGB-BAN 92B.1 to 10 (Kuh-e-Bangestan section).

Discussion: The collection from level 92 and 92B at Kuh-e-Bangestan includes all growth stages from the juvenile ornamentation to adults. The material is often distorted and fragmentary but it matches fairly well the specimens illustrated by Cooper (1982). Some specimens show a well develop lateral tubercle that recalls *D. variabile* Tavani in Cooper. Specimens that combine *D. variabile* and *D. mammillatum aequinodum* ornamental features were also illustrated by Cooper (1982) who suggested that further studies may show that both taxa are synonyms. Direct comparison with the material from Angola is needed to assume full identity of the Iranian forms.

Stratigraphic distribution: According to Owen (1988), *D. mammillatum aequinodum* ranges from the base of the *S. chalensis* Zone to the lower part of the *O. auritiformis* Zone in the UK. This correspond to the lower two third of the *D. mammillatum* Zone (middle Lower Albian). A similar range can be inferred for South Africa (Kennedy and Klinger, 2008) and Angola (Tavares et al., 2007).

PART 7: SUPERFAMILY DESHAYESITOIDEA STOYANOW, 1949

Family Deshayesitidae Stoyanow, 1949 Genus *Dufrenoyia* Kilian & Reboul, 1915

Remarks: The genus *Dufrenoyia* is restricted to the uppermost ammonite zone of the Lower Aptian (*D. furcata* Zone of the Mediterranean standard ammonite scale). There is no consensus between recent authors about the taxonomy of the genus at the species level (Martin, 2003; Ropolo and Gonnet, 2003; Dutour, 2005; Ropolo et al., 2006). *Dufrenoyia* is common in the Lower part of the Kuh-E-Bangestan section (level BAN26 to BAN37). Most specimens are crushed impressions that do not allow identification at the specific level (Plate 9-1).

Family Parahoplitidae Spath, 1922 Subfamily Acanthohoplitiniae Stoyanow, 1949 emend (This paper)

Preliminary remarks: Acanthoplitidae are a common element of the ammonite assemblage from the Zagros. Material was collected in intra-shelf basin (Kuh-e-Bangestan section) and platform settings (Kuh-e-Mish and Kuh-e-Fahliyan sections). Acanthohoplitiniae characterizes the uppermost Lower Aptian to lowermost Albian interval (Wright et al., 1996) and includes *Nolaniceras* Casey and

Hypacanthoplites Spath that have long been accepted as biostratigraphic markers of the standard Aptian ammonite scale.

According to Owen (in Ruffel and Owen, 1995), *Hypacanthoplites* derives from *Acanthohoplites* Sinzow as the ultimate member of a lineage that also includes *Colombiceras* Spath and *Parahoplites* Anthula. This same author considers that in accordance with the rules of precedence Acanthohoplitinae should be abandoned and all genera formerly grouped in this subfamily should be included in the family Parahoplitidae Spath.

In my opinion the phylogeny proposed by Owen is not supported by the ammonite succession or by the ontogeny of the proposed lineage. All evidences obtained from the ammonite successions of the Vocontian basin (Bulot in Dauphin, 2002; Dutour, 2005) show that:

1. There is a progressive morphological transition between *Gargasiceras* Spath and *Colombiceras*, and both taxa are not always easy to distinguish;
2. *Acanthohoplites* derives from *Colombiceras* well before the first occurrence of *Parahoplites*;
3. The nature of the relationship between *Parahoplites* and *Colombiceras* has never been sustained, even if *Egoianiceras* Avram could represent an intermediate morphology;
4. The generic or sub-generic status of *Nolaniceras* and the way it derives from *Acanthohoplites* s. str. is still unclear such as its potential synonymy with *Protacanthoplites* Tovbina (discussion in Casey, 1999);
5. *Diadochoceras* and the closely allied, if not synonym, *Nodosohoplites* are offshoots of *Acanthohoplites* and by no mean Cheloniceratinae as most often claimed in the literature (discussion in Mikhailova, 1963).

Moreover, many other genera retained as Acanthohoplitinae by Wright et al. (1996) are still poorly understood. This is the case of *Rhytidoplites* Scott; *Penaceras* Cantu-Chapa; *Riedelites* Etayo Serna and *Chaschupseceras* Kvantaliani & Sharikazé. Synonymies and stratigraphic range of those taxa are in need of revision. Two other genera have been overlooked by Wright et al. (1996). These are *Immunitoceras* Stoyanow and *Oshimaceras* Obata & Futakami; the former considered as a junior synonym of *Nolaniceras* or *Hypacanthoplites* in recent literature (Casey, 1965; Lucas, 2000), the later as close to *Parahoplites* by its authors. Another problem lies in the classification of *Neodeshayesites* Casey that is generally considered as a late member of the Deshayesitinae Stoyanow, 1949 (Wright et al., 1996, p. 272; Bogdanova and Mikhailova, 2004, fig. 3; Bogdanova and Hoedemaeker, 2004, p. 185-186). Robert and Bulot (2005, p. 611) did show that this view is erroneous and that *Neodeshayesites* is a New World derivative of *Hypacanthoplites* sensu lato. As a consequence and pending a comprehensive revision of the genera listed above, I retain Acanthohoplitinae as a distinct subfamily.

Genus *Nolaniceras* Casey, 1961c

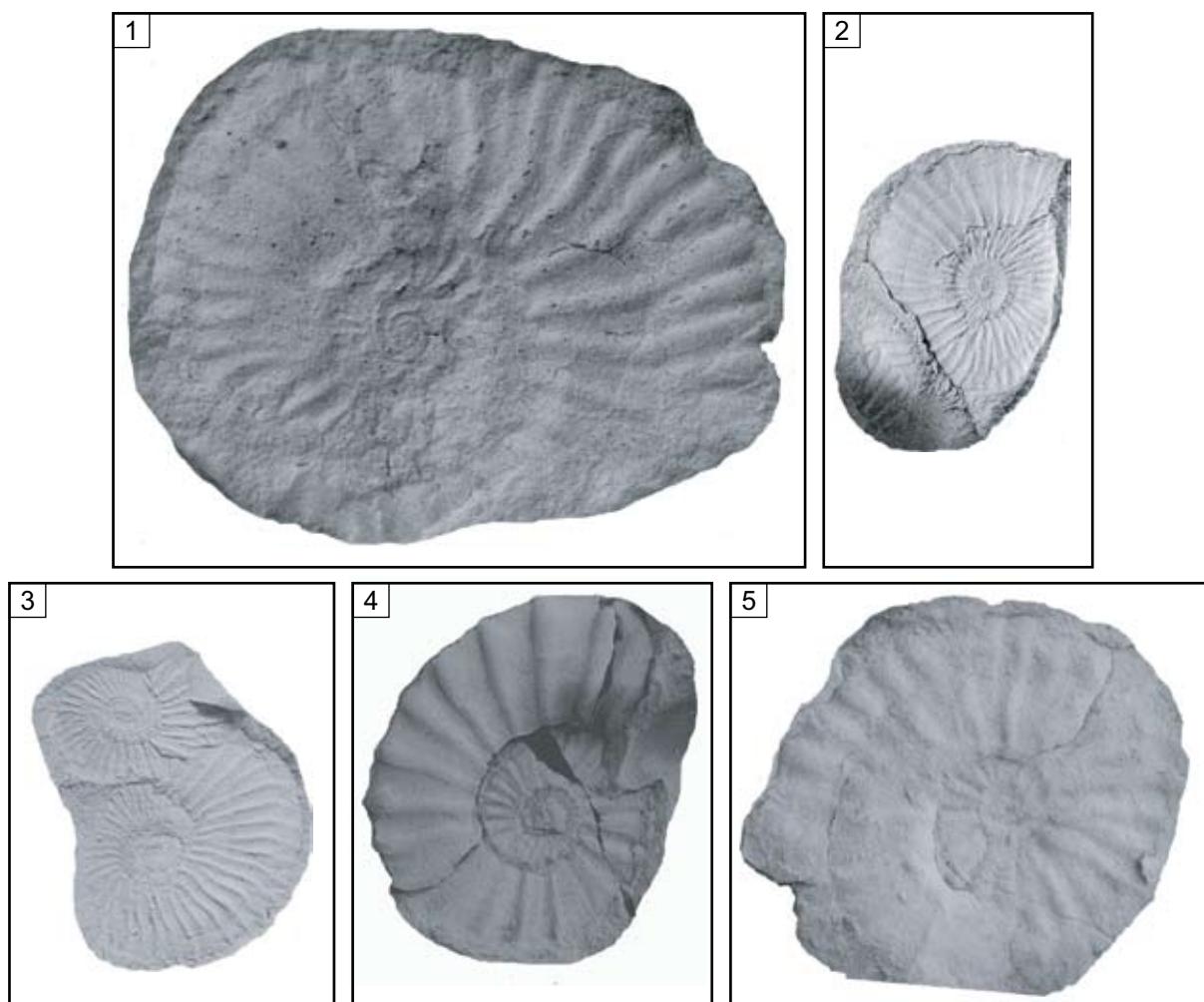
Comments: Russian authors most often consider *Nolaniceras* as a junior synonym of *Acanthohoplites*. In my opinion, even if *Nolaniceras* is derived from *Acanthohoplites* it shows sufficient distinctive features to be separated at the genus level. *Nolaniceras* is an important biostratigraphic marker that comprises a group of species that lie in direct line of ancestry to the compressed, finely ribbed group of "*Hypacanthohoplites*" *nolaniformis* Glazunova - "*H.*" *nolanisimilis* Breistroffer. Its general morphology is similar to compressed "*Hypacanthohoplites*", with close, flexuous ribbing, but venter rounded, with only a trace of flattening in the young and no tubercles at the margin at any stage. Lateral tubercles represented only by microscopic pustules in early youth.

Nolaniceras nolani (Seunes, 1887) (Plates 9-2 and 9-3)

- 1887 *Hoplites nolani* Seunes, p. 564, pl. 13, fig. 4a-b.
1965 *Nolaniceras nolani* (Seunes), Casey, p. 457, text-fig. 171.
2004 *Acanthohoplites nolani* (Seunes), Sharikadzé et al., p. 401, pl. 85, fig. 2.

Type species: *Hoplites nolani* Seunes, 1887, p. 564, pl. 13, fig. 4a-b, by monotypy.

Plate 9



- Plate 9:**
1. *Dufrenoyia* gr. *furcata* (Sowerby). NIOC-LGB-BAN-26.1. Kuh-e-Bangestan section, level 26, *D. furcata* Zone (Lower Aptian). Rubber mould.
 2. *Nolaniceras nolani* (Seunes). NIOC-LGB-BAN-59.1. Kuh-e-Bangestan section, level 59, *N. nolani* Zone (Upper Aptian).
 3. *Nolaniceras nolani* (Seunes). NIOC-LGB-BAN-59.2. Kuh-e-Bangestan section, level 59, *N. nolani* Zone (Upper Aptian).
 4. Acanthohoplites gen. nov. sp. nov. NIOC-LGB-BAN-73.2. Kuh-e-Bangestan section, level 73, Upper Aptian – Lower Albian transition zone.
 5. *Parahoplites melchioris* Anthula. NIOC-LGB-BAN-53T.1. Kuh-e-Bangestan section, level 53T, *P. melchioris* Zone (Upper Aptian). Another specimen of "Acanthohoplites" aff. *subangulicostatus* (Sinzow) sensu Druschitz & Kudryutzeva was found in the same bed.

Material: About 80 specimens from bed BAN 59 to BAN 60B. Hundreds of specimens can be collected from that interval of black shales. Each layer is covered by ammonites. Sample NIOC-BAN 59.1 shows 16 specimens on a surface of about 10 square centimetres.

Discussion: According to Casey (1965, p. 457), and after examination of the type and large series of topotypes, the species exhibits considerable variation in density of ribbing and in the inflection of the ribbing on the venter. Despite the preservation as crushed internal mould, I have no doubt that the Iranian material falls in the range of variation of *Nolaniceras nolani*.

Stratigraphic distribution: *Nolaniceras nolani* is the index species of the Upper Aptian *N. nolani* Zone but its exact range in the zone remains unknown. At Kuh-e-Bangestan, it shortly overlaps with *Parahoplites* (level BAN 59) and its last occurrence lies 3 meters before the entry of "*Hypacanthoplites*" (level BAN 61).

Genus *Hypacanthoplites* Spath, 1923

Type species: *Acanthoceras milletianum* (d'Orbigny) var. *plesiotypicum* Fritel, 1906, by original designation

Remarks: The genus *Hypacanthoplites* has been widely quoted from the uppermost Aptian and lowermost Lower Albian all over the world and is considered by most authors as a cosmopolitan genus. Nevertheless, no revision of the genus is available and in many ways *Hypacanthoplites* is a "dust bin taxa" used for any species that show morphological similarities to the species originally described from the Hannover area of the Lower Saxony Basin (North Germany) by Fritel (1906) and Collet (1907); i.e. the groups of *Hypacanthoplites plesiotypicus* (Fritel), *H. nodosostatus* (Fritel) and *Hypacanthoplites elegans* (Fritel).

It should first be noted that the type species of *Hypacanthoplites* is *Acanthoceras milletianum* d'Orbigny sp. var. *plesiotypica* Fritel (1906, p. 245, 246, text-fig. 2), by original designation of Spath (1923, p. 64), now treated as a species of itself. Fritel's original specimen is believed lost and Casey (1965, p. 424) designated as neotype one of the syntypes of *Parahoplites jacobi* Collet.

A first problem lies in the designation of the neotype. Despite the poor quality of the original illustration by Fritel, it is clear to me that the specimen selected as neotype by Casey does not match the description and the illustration of *Acanthoceras milletianum* var. *plesiotypica*. In my opinion, the original of *Hypacanthoplites plesiotypicus* is far more closely related to the *H. clavatus* (Fritel), *H. nodosostatus* (Fritel), *H. sarasani* (Collet) complex than to *H. plesiotypicus* Casey non Fritel and to *H. jacobi* (Collet).

This taxonomic point has a major impact on the concept of *Hypacanthoplites* since it suggests that the key morphological feature of the genus (aside the flat enter at early growth stage) is the occurrence and persistence of tubercles on the middle of the flanks.

Relict lateral tubercles do occur in *H. plesiotypicus* Casey non (Collet) and *H. jacobi*, but do not exists anymore in such species as *H. anglicus* (Casey), *H. trivialis* and *H. milletianoides*. It therefore seems that two different groups evolved in the uppermost Aptian from a common ancestor: (1) strongly tuberculated group that includes *H. plesiotypicus* s. str., *H. clavatus*, *H. nodosostatus* and *H. sarasani* (Collet); and (2) feebly tuberculated to non tuberculated lineage that includes *H. jacobi*, *H. anglicus* and *H. trivialis*.

As already pointed out by Kennedy et al. (2000), the Upper Aptian and Lower Albian *Hypacanthoplites* have suffered from the introduction of an extensive number of specific and subspecific names for individuals that differ in minor detail only, and are in many cases merely nuclei of large individuals. This approach is exemplified by the work of Casey (1965).

The full resolution of the synonymies of many of these taxa requires a careful revision of the abundant material from the Hannover area in Germany. Kennedy et al. (2000) regards the *Hypacanthoplites elegans* (Fritel), *H. hanoverensis* (Collet), *H. spathi* (Dutertre) complex as a single species, treats the *H. clavatus* (Fritel), *H. nodosostatus* (Fritel), *H. sarasani* (Collet) complex also as a single species. *H. plesiotypicus* Casey non (Fritel) and *H. jacobi* (Collet, 1907) are regarded as synonyms.

Even if these opinions lack detailed biostratigraphic support and that the exact range of all typological species is still unknown in the sections of North Germany, preliminary analysis of the large collections made by Kemper and Wiedenroth and now stored and the GDR in Hanover provisionally supports the view expressed by Kennedy et al. (2000).

Another interesting taxonomic problem lies in the existence of size dimorphism in the populations of *Hypacanthoplites* from North Germany. This was already exemplified and suggested by Kemper (1982) and confirmed since by Kennedy et al. (2000). Large specimens, with a diameter up to 300 mm, are not uncommon and merely belong to *H. elegans* and its allied species.

Relationship with the faunas from the former USSR republics is even far less clear and the systematic position of such species as "*Hypacanthohoplites*" *nolaniformis* and its allied should be questioned. As a consequence of the taxonomic problems exposed above, the content of the genus *Hypacanthohoplites* should be completely reconsidered. This implies the revision of the faunas of the uppermost Aptian and Lower Albian of Caucasus and Mangschak but also SE France, North Africa and the New World with special reference to the taxa described from Algeria, Tunisia, Mexico and the USA.

Zagros occurrence: Finely ribbed "*Hypacanthohoplites*" that seems to belong to the "*H.*" *nolaniformis* – *nolanisimilis* plexus are not uncommon at Kuh-e-Bangestan. The more typical specimens occur in bed BAN 62. Through the BAN66 – BAN70 interval, evolution is marked by the progressive loss of secondary ribs toward a new morphology that is fully expressed in bed BAN73. This new morphology is somehow homeomorphic of early Brancoceratidae but early whorls clearly show that the species belong to a new genus of Acanthohoplitinae that is so far endemic to the studied area (Plates 9-4 and 9-5).

Subfamily Parahoplitinae Spath, 1922 Genus *Parahoplites* Anthula, 1899

Parahoplites melchioris Anthula, 1899 (Plate 9-6)

Material: 10 specimens from bed BAN 53 to BAN 55. Tens of specimens could be collected from that interval of black shales. Each layer is covered by ammonites.

Discussion: Sample NIOC-BAN 53T.1 illustrated here shows the typical form. Despite the preservation the specimens shows the regular alternation of primary and intercalated ribs that characterize Anthula's syntypes. When properly exposed the venter shows the bending forward chevron that characterize the genus.

Stratigraphic distribution: In Western Europe, *P. melchioris* is restricted to the lower part of the zone it names. This also applies to the Kuh-e-Bangestan section. The *Parahoplites* from the upper part of the zone (level BAN 58 to 58C) belong to a different species that need further investigation before identification.

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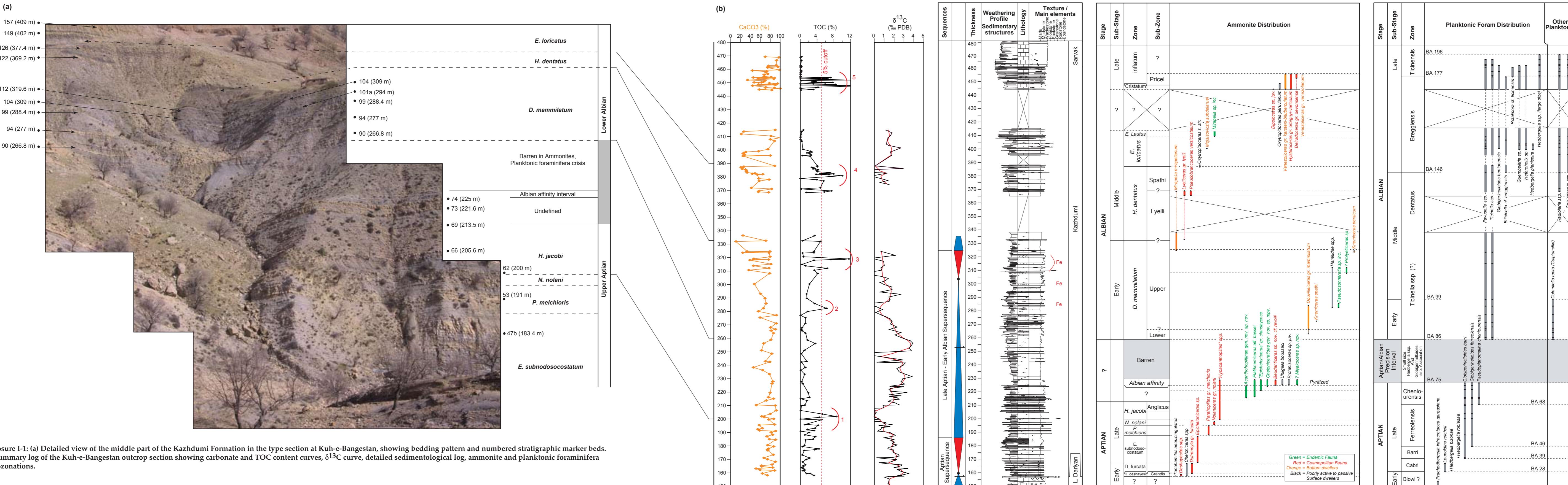


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ENCLOSURE I-1: KAZHDUMI FORMATION INTRA-SHELF BASINAL FACIES EXPOSED IN KUH-E-BANGESTAN



ENCLOSURE I-2: CARBON-ISOTOPE STRATIGRAPHY AND DEPOSITIONAL SEQUENCES IN PLATFORM TO BASIN CORRELATION

