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Integrated biostratigraphy across the Aalenian/Bajocian boundary of the Central High Atlas, Morocco

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Key words: Aalenian/Bajocian boundary, Central High Atlas, Morocco, integrated biostratigraphy.

Abstract. This work presents an integrated biostratigraphic study across the Aalenian/Bajocian boundary of the Central High Atlas of Morocco. The data that are the basis for this study were obtained from the region of Rich that is located in the center of the basin of the Moroccan High Atlas. This region presents a thick Aalenian–Bajocian succession with continuous marine sedimentation, which offers a rich and varied fauna whose analysis enables the compilation of an integrated biostratigraphy based on the different paleontological groups: ammonites, belemnites, brachiopods, bivalves, gastropods, calcareous nannofossils, foraminifera and ostracods.

INTRODUCTION

The Rich area, situated in the center of the basin of High Moroccan Atlas (Fig. 1), presents a thick Aalenian–Bajocian succession with continuous marine sedimentation, which offers rich and varied fossils. This section was proposed as the auxiliary stratotype of the Aalenian/Bajocian boundary in the Mediterranean Province (Sadki, 1994). An integrated biostratigraphic analysis of this section is presented here, detailing the distribution of the main paleontological groups: ammonites, belemnites, brachiopods, bivalves, gastropods, calcareous nannofossils, foraminifera and ostracods. The data presented here are from my personal research, or from work that I have done in collaboration with others or from data provided by researchers who have worked on the Aalenian and Bajocian of the central High Atlas. This integrated biostratigraphy enables us to establish parallel scales, to serve as a comparison tool, but also it is an element for dating when ammonites are rare or absent.

AMMONITES

The succession of ammonite faunas in the interval across the Aalenian/Bajocian boundary, shows (Fig. 2) six successive assemblages (Sadki, Elmi, 1991), sometimes dominated by the NW European graphoceratids, sometimes by Mediterranean Province taxa. Furthermore the abundance of the phylloceratids is similar to that of the hammatoceratids, and therefore shows the same trend as that of Mediterranean Province taxa. It appears that distribution of ammonites is dependent on tectonic basin-dynamics and on eustatic sea-level changes.

These different associations correspond to six biohorizons (Fig. 3) that characterize the transition between the Aalenian and the Bajocian in the Moroccan Central High Atlas (Sadki, 1994). The boundary between the two stages is marked by the first appearance of *Hyperlioceras* together with numerous Mediterranean elements.

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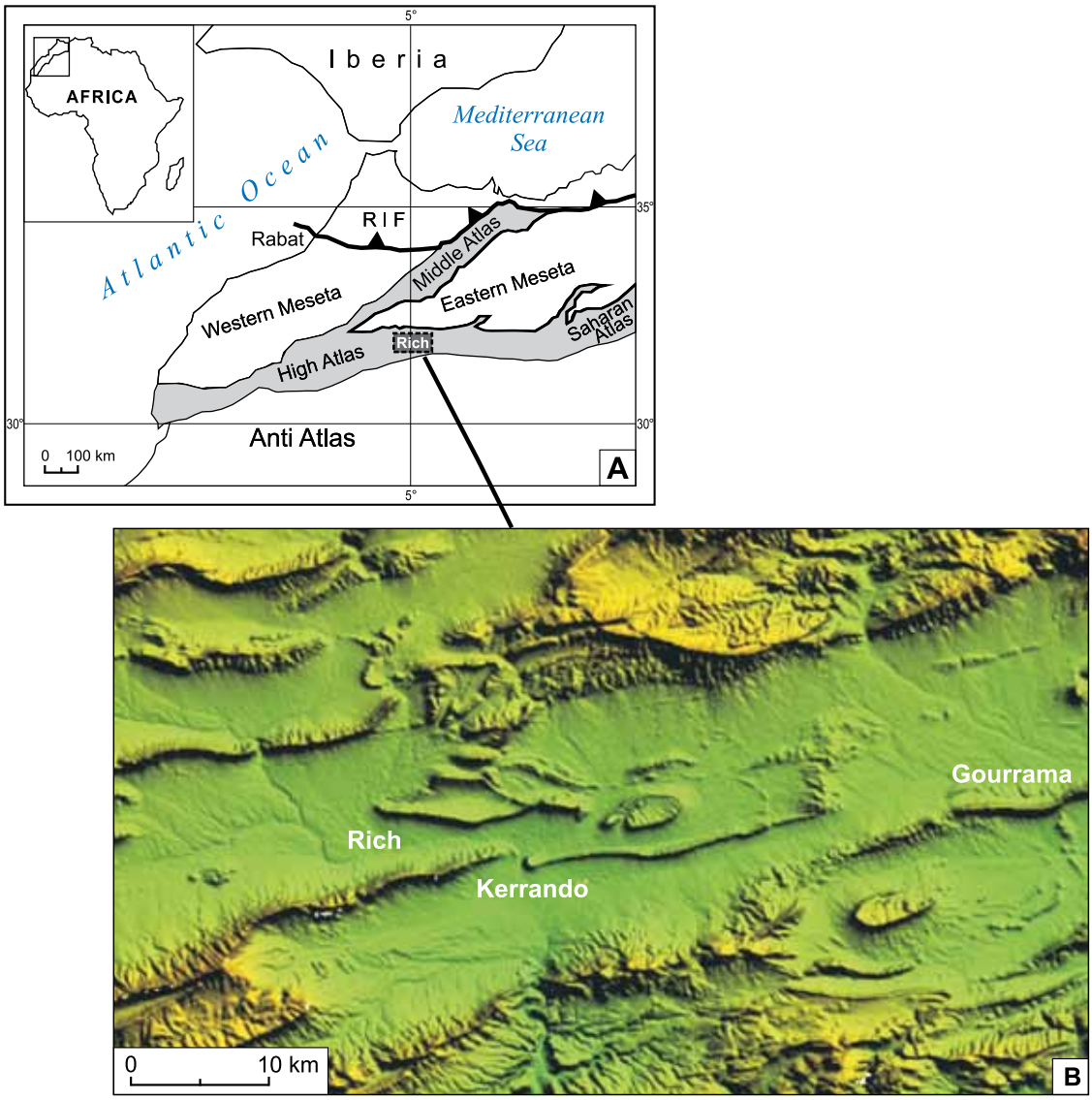

Fig. 1. A. Sketch map showing the Atlas range in the northen part of Morocco. B. Location of the studied area in the Central High Atlas

UPPER AALENIAN CONCAVUM ZONE

Concavum Subzone = (Horizons I and II)

Horizon I

Characteristic ammonites: This horizon is characterized by the presence of *Graphoceras concavum* Buckman, *Graphoceras (Ludwigella) cornu* Buckman and *G. (Ludwigella) rude* Buckman. The genera: *Pseudammatoceras*, *Planammatoceras*, *Euaptetoceras*, *Eudmetoceras*, *Haplopleuroceras*, *Ambersites*, *Bradfordia* and *Praeoppelia* are associated to these graphoceratids.

Horizon II

Characteristic ammonites: This horizon contains rare graphoceratids, but however it is dominated by *Fontannesia*, *Eudmetoceras* and *Euaptetoceras*. The *Haplopleuroceras* are already present, and Haploceratacеae (*Bradfordia* and *Praestrigites*) are infrequent.

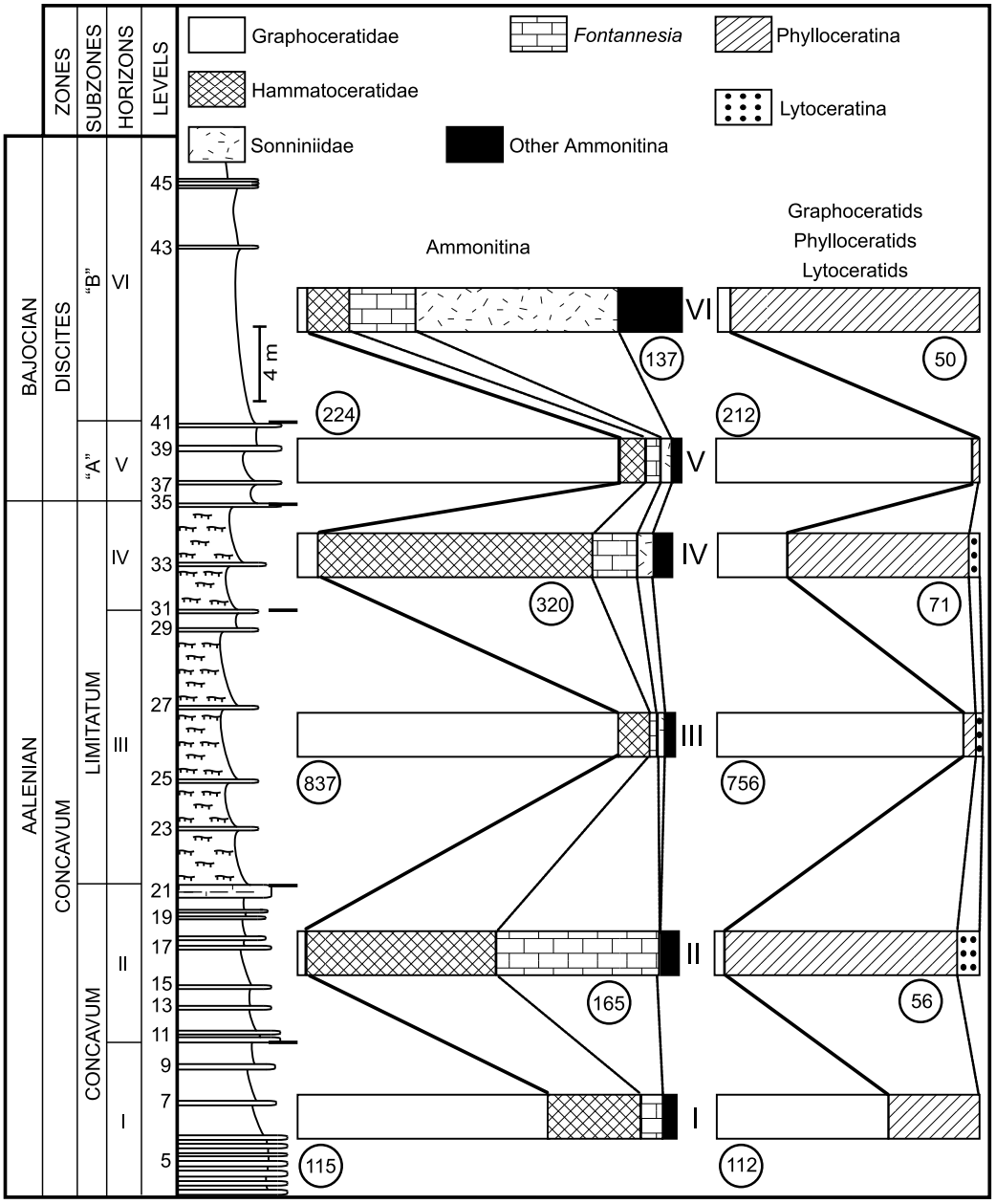

Fig. 2. Alternation between Phyllocertatidae-dominated and Graphoceratidae-dominated ammonoid communities in Aalenian–Bajocian marls of the deep Atlas Basin of Morocco (Sadki, Elmi, 1991)

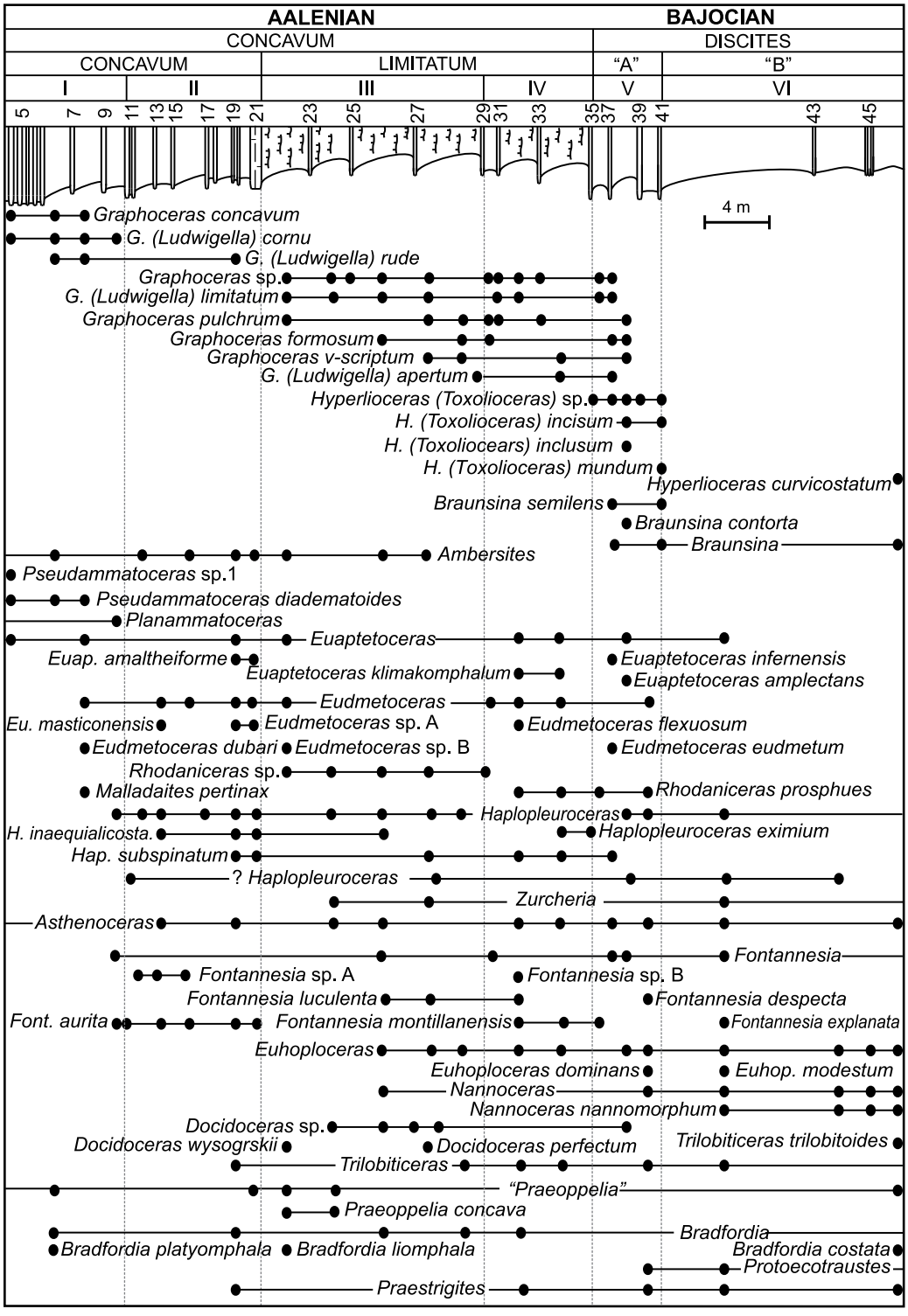

Fig. 3. Distribution of ammonites across the Aalenian/Bajocian boundary in the Central High Atlas (Sadki, 1994)

Limitatum Subzone = (Horizons III and IV)
Horizon III

Characteristic ammonites: This horizon has many graphoceratids and contains the first *Docidoceras* and the first sonniniids (*Euhoploceras* and *Nannoceras*). The other groups are represented by Hammatoceratinae, Erycitinae, Zurcheriinae (rare *Zurcheria*, and related forms of *Haplopleuroceras*), Grammoceratinae and Haploceratacеae.

Horizon IV

Characteristic ammonites: This horizon shows some *Graphoceras* belonging to species already encountered in the previous horizon. However, the most dominant taxa are represented by some *Euaptetoceras* and *Eudmetoceras*, but especially by *Rhodaniceras* gr. *prosphues* Buckman.

In this horizon, the *Haplopleuroceras* is also very abundant and *Asthenoceras* is rare. The other taxa are represented by sonniniids (*Euhoploceras*), otoitids (*Trilobiticeras* and *Docidoceras*), Haploceratacеae (*Bradfordia*, *Protoecotraustes* and *Praestrigites*).

LOWER BAJOCIAN DISCITES ZONE

Subzone “A” = (Horizon V)

Characteristic ammonites: The main feature of this subzone is the appearance of the first *Hyperlioceras*. Other taxa are represented by sonniniids, Hammatoceratinae (*Euaptetoceras amplectens* Buckman, *Eudmetoceras eudmetum* Buckman, *Rhodaniceras prosphues* Buckman), Zurcheriinae, Grammoceratinae, otoitids and Haploceratacеae.

Subzone “B” = (Horizon VI)

Characteristic ammonites: This subzone shows a total change in the composition of the ammonite assemblages. Graphoceratids are represented by a very few species of *Hyperlioceras* and *Braunsina*. Hammatoceratinae and Grammoceratinae are replaced by sonniniids which become very abundant. Otoitids are represented by *Trilobiticeras trilobitoides* Buckman, Haploceratacеae by *Bradfordia costata* Buckman, rare *Protoecotraustes* and *Praestrigites*.

BELEMNITES

Belemnites are very rare, sometimes absent, in the Concavum Zone and at the base of the Discites Zone. They become abundant and diverse at the top of the Discites Zone where *Holcobelus* is identified. It may be note that the belemnites of the Lower Bajocian of the Moroccan Atlas are being studied and will constitute the object of a future paper (R. Weis, D. Sadki and N. Marioti – in prep.).

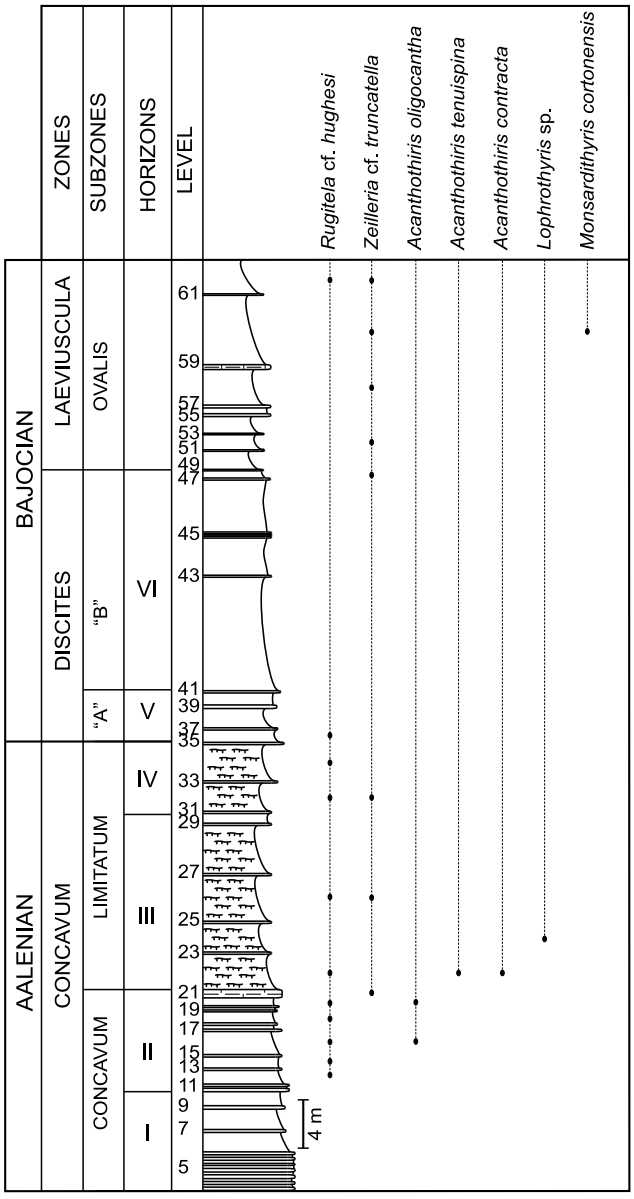

Fig. 4. Distribution of brachiopods across the Aalenian/Bajocian boundary in the Central High Atlas (Sadki, Almeras, 1992)

BRACHIOPODS

The Aalenian–Bajocian succession of the Rich area has yielded brachiopods, mainly zeilleriids sampled in the marly layers. The biostratigraphic succession (Sadki, Alméras, 1992) shows a faunal break between the Concavum and Discites zones (Fig. 4). Both zones are characterized by the predominance of zeilleriids that appear close to *Rugitela hughesi* (Davidson). This species is accompanied in the Concavum Zone by rare specimens of *Lophrothyris contracta* Buckman, *Acanthothiris oligocantha* Branco, *Acanthothiris tenuispina* Waagen and a specimen related to the genus *Loboidothyris* Buckman.

Apart from *Rugitela* cf. *hughesi*, also very rare in the basal part of the Bajocian, and a *Zeilleria* sp., no other brachiopods have been collected in the Discites Zone.

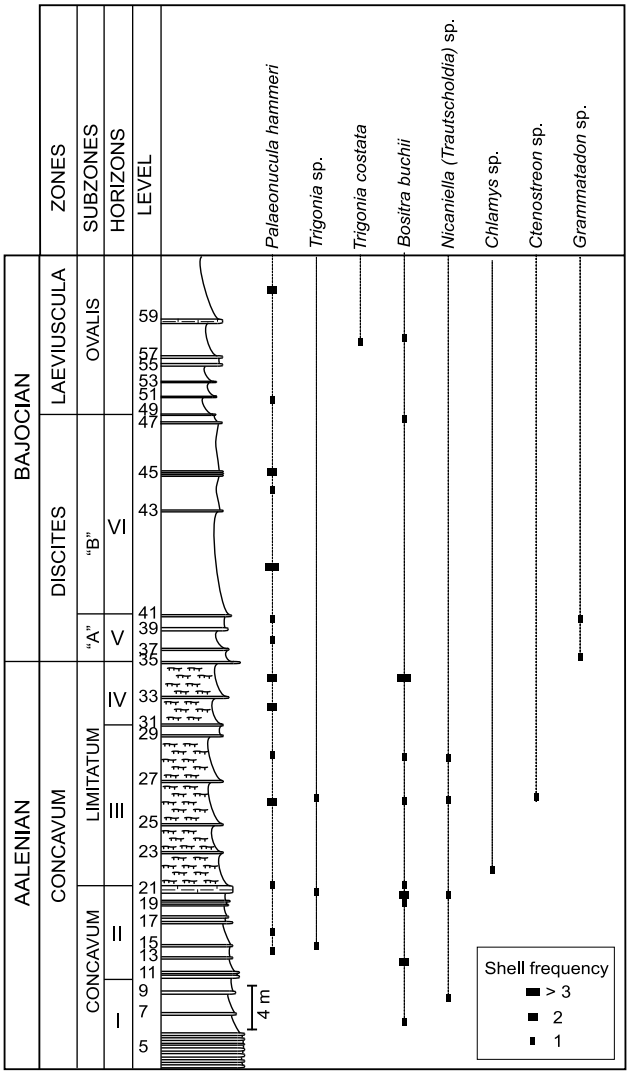

Fig. 5. Distribution of bivalves across the Aalenian/Bajocian boundary in the Central High Atlas

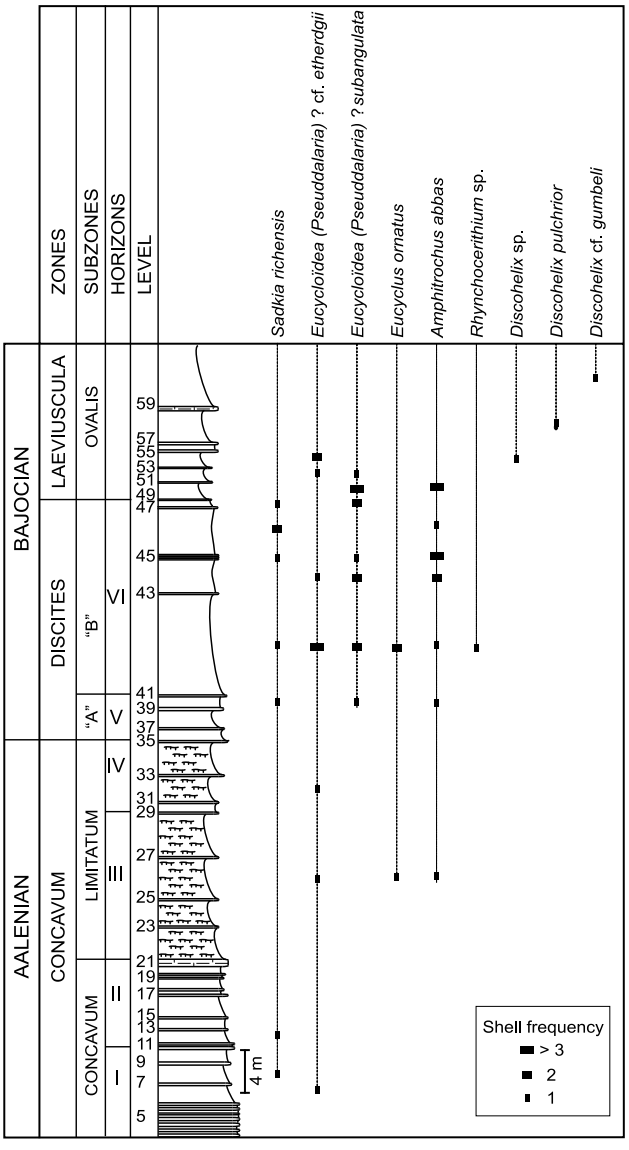

Fig. 6. Distribution of gastropods across the Aalenian/Bajocian boundary in the Central High Atlas (modified from Conti, Monari, 2001)

BIVALVES

The bivalve taxa which have been identified by Istvan Szente (University of Budapest, Hungaria) from the Rich section (Fig. 5) were mainly refered to *Palaeonucula*, indicating a soft substrate and poorly oxygenated water. Other burrowing forms such as *Trigonia*, *Astarte* and *Nicaniella* occur only sporadically, appearing mainly in the Concavum Zone together with the supposedly pseudo-planktonic *Bositra*. These are remarkably abundant at the top of the Concavum Zone. In the Discites Zone occur rare specimens of *Palaeneilo* sp. and *Grammatodon* sp.

GASTROPODS

The gastropods, analyzed by Conti and Monari (2001), show an inverse distribution to that of the bivalves (Fig. 6). Their density and diversity increase gradually as one rises in the series.

ZONES	CONCAVUM			DISCITES		
SUBZONES	LIMITATUM			"A"	"B"	
SAMPLES	KG72	KG73	KG74	KG75	KG76	KG77
Axopodorhabdus cylindratus	R	R	R		R	
Axopodorhabdus depravatus	C	M	M		M	
Biscutum auctum	F	R			R	
Biscutum dubium	M	M	F		F	
Biscutum intermedium	M	M			M	M
Biscutumn novum	R	R			M	R
Biscutumn pusillum	F	R				
Carinolithus magharensis	M	F	R		F	R
Crepidolithus crassus	R	F			F	
Cyclagelosphaera aff. *margerelii*	M	M	M		M	
Diductius constans	R				R	
Discorhabdus criotus	R	R	R		R	R
Discorhabdus striatus	F	F	F		F	F
Lotharingius hauffii	R	F	R		R	
Lotharingius lanceolatus	M	M			R	
Lotharingius sigillatus	R	R	R		R	R
Lotharingius veterenus	M	F			R	
Schizosphaera punctulata	R	F			F	R
Triscutum tiziense	R	R			R	
Watznaueria atlantis	F					
Watznaueria barnesae					F	R
Watznaueria britannica					R	
Watznaueria contracta	F	R			F	F
Watznaueria manivitae					R	
Watznaueria velata	F	R	F		F	R

Fig. 7. Selected calcareous nannofossil at the Aalenian/Bajocian boundary in the Rich Section (modified from de Kaenel, 1990)

The total abundance of coccoliths is as follows: C (common): 2 to 10 specimens for view; F (few): 1 specimen for 5–20 views; R (rare): 1 specimen for 20–50 views

In the Concavum Zone were identified: *Sadkia richensis* (Conti et Monari), *Eucycloidea* (*Pseudalaria*)? cf. *etheridgii* (Tawney), *Eucyclus ornatus* (Sowerby) and *Amphitrochus abbas* (Hudleston).

In the Discites Zone occur: *Sadkia richensis* (Conti et Monari), *Eucycloidea* (?*Pseudalaria*) cf. *etheridgii* (Tawney), *Eucycloidea* (?*Pseudalaria*) *subangulata* (Monster), *Eucyclus ornatus* (Sowerby), *Amphitrochus abbas* (Hudleston) and ?*Rhynchocerithium* sp.

CALCAREOUS NANNOFOSSILS

Several bio-horizons of calcareous nannofossils in the Aalenian/Bajocian boundary succession (Fig. 7, Pl. 1: 1–24) were identified by de Kaenel (1990) and were correlated with the ammonite zones established by Sadki *et al.* (1986). The most striking pattern of events is the great number of first occurrences in the vicinity of the Aalenian/Bajocian

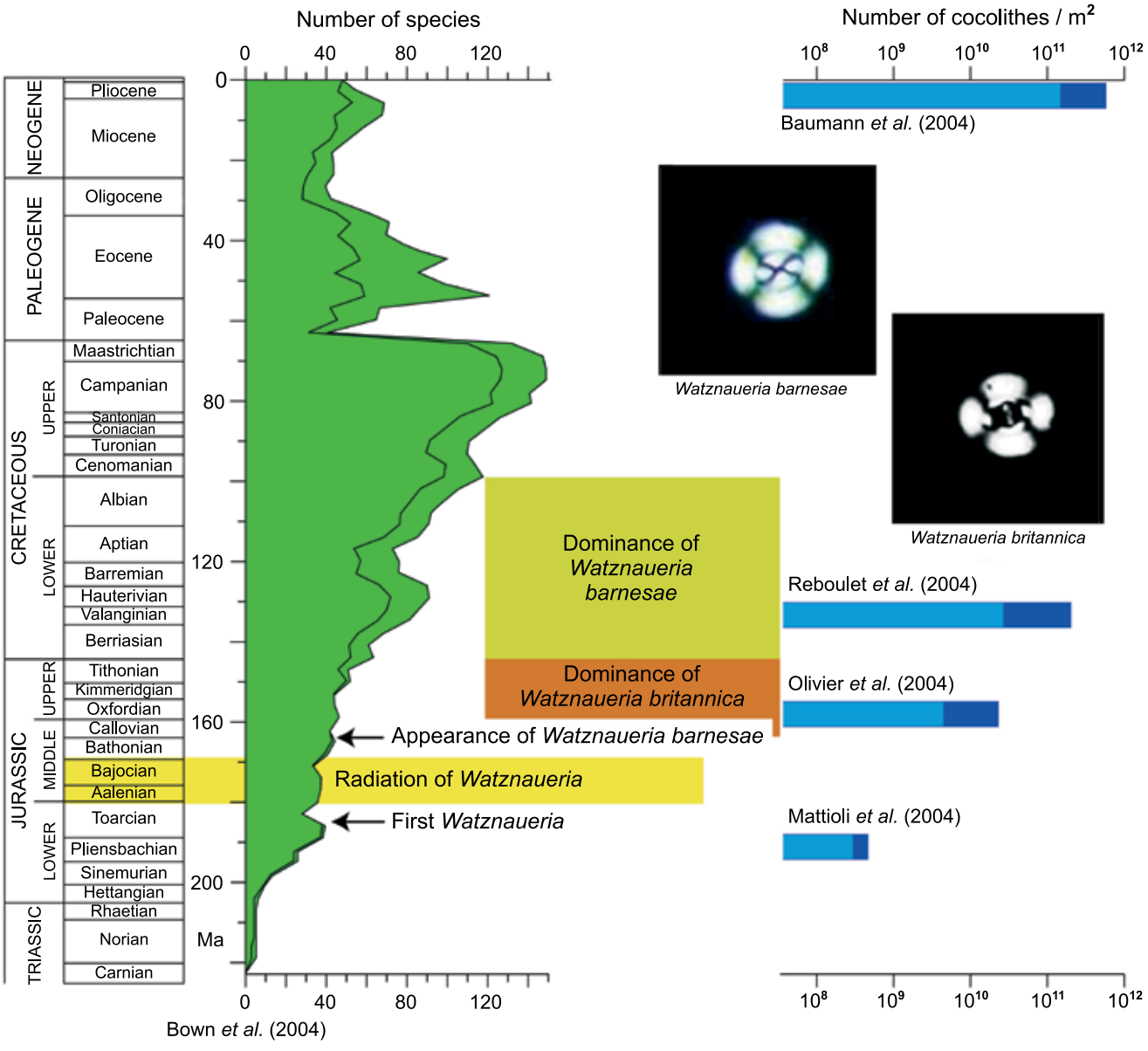

Fig. 8. Radiation curve of the coccolith genus *Watznaueria* (Bown *et al.*, 2004; Bour, 2005)

boundary. The new occurrences refer mainly to species of the genus *Watznaueria* (Fig. 8), which experienced a major diversification at that time (Bown *et al.*, 2004; Bour, 2005). Furthermore, in this interval, several new species of *Watznaueria* make their appearance: *W. contracta* (Bown et Cooper) and *W. velata* (Bown et Cooper) at the base of Concavum Zone, and *W. barnesae* (Black) and *W. britannica* (Stradner) in the Discites Zone. Some specimens of these nannofossils are described by de Kaenel and Bergen (1993).

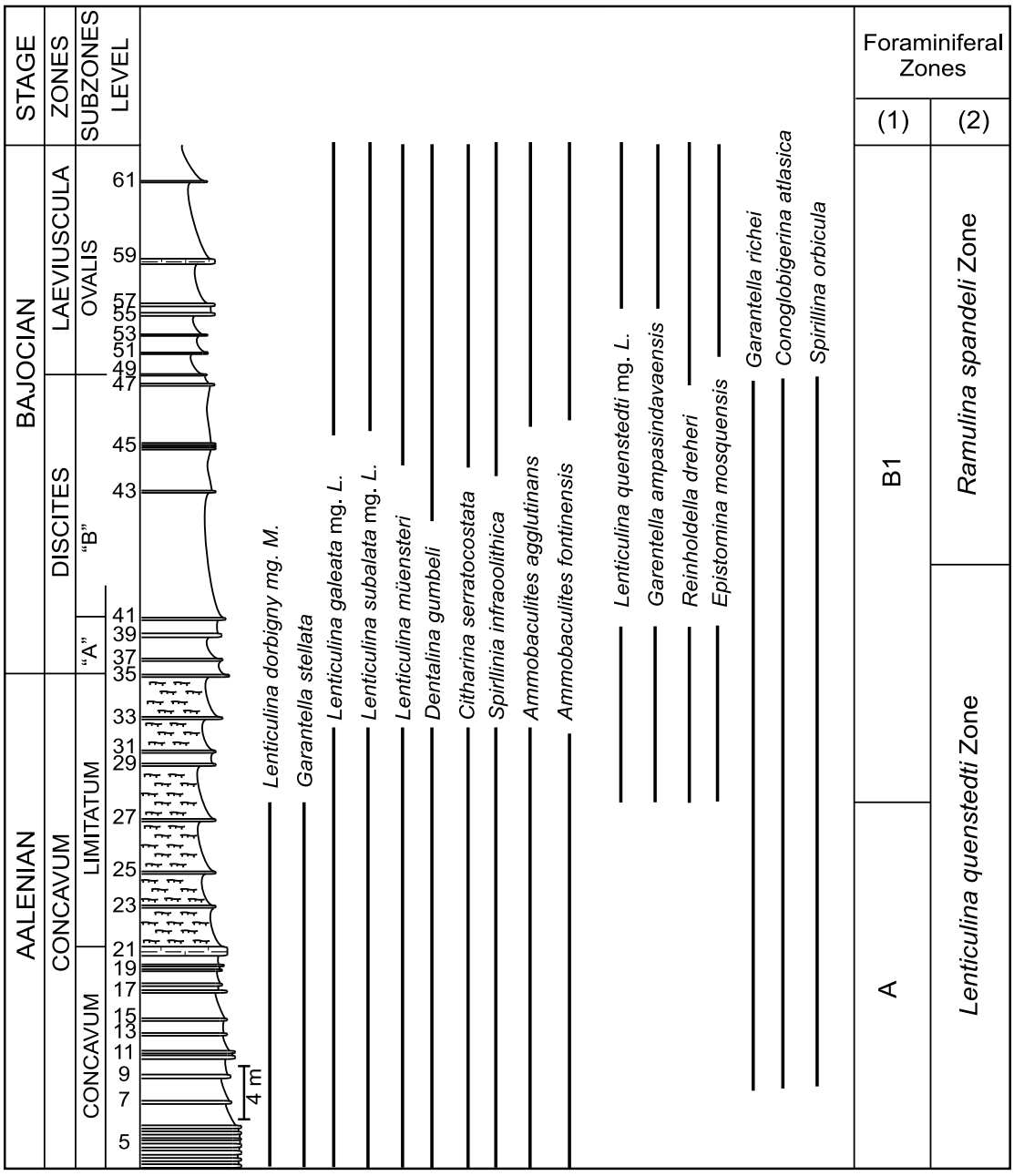

Fig. 9. Distribution of foraminifers across the Aalenian/Bajocian boundary in the Central High Atlas (modified after Amhoud, Boutakiout, 1994) and foraminiferal zones established for: (1) Central High Atlas (Amhoud, Boutakiout, 1994); (2) Lusitanian Basin (Canales, Henriques, 2013)

mg. – morphogenus

FORAMINIFERS AND OSTRACODS

Aalenian foraminifer and ostracod assemblages are generally similar to those known from the Toarcian. Their study has been done by Amhoud (Amhoud, Boutakiout, 1994; Amhoud, 1999) and El-Kamar (1997).

FORAMINIFERS

The major microfauna renewal at the Aalenian/Bajocian boundary (Fig. 9; Pl. 2: 1–18) is dominated by the disappearance of *Lenticulina dorbigny* (Roemer), *L. chicheryi* (Payard), *Nodosaria pulchra* (Franke) and the occurrence of *Lenticulina quenstedti* (Gümbel), *L. galeata* (Terquem), *Garantella stellata* Kaptarenko. Furthermore we can note that protoglobigerinids (*Conoglobigerina atlasica* El-Kamar) and ceratobuliminids [*Garantella richei* El-Kamar and *G. ampasindavaensis* (Epistalie et Sigal)] in association with nodosariids [*Lenticulina galeata* (Terquem) and *L. quenstedti* (Gümbel)] constitute an important event marking the Aalenian/Bajocian boundary (El-Kamar, 1997). This assemblage which marks the biozone B1 of the Discites Zone (Amhoud, Boutakiout, 1994), corresponds to the Ramulina spandeli Zone (Canales, Henriques, 2013) defined as formal unit integrating the biostratigraphic scale based on benthic foraminifers for the Aalenian/Bajocian boundary in Portugal (Silva *et al.*, 2014).

OSTRACODS

Ostracods abound with *Kinkelinella* gr. *sermoisensis* Apostolescu which disappears at the end of the Aalenian.

DISCUSSION AND CONCLUSION

This work, which represents an integrated study of thestratigraphic distribution of different palaeontological groups from the Aalenian/Bajocian boundary of the Central High Atlas of Morocco, shows that:

- The ammonite succession of the interval across the Aalenian/Bajocian boundary shows six successive assemblages (here interpreted as bio-horizons) sometimes dominated by NW European graphoceratids, sometimes by Mediterranean Province taxa. They enable good correlations.
- Belemnites are very rare in the Concavum and Discites zones. They become abundant and diverse later in the Laeviuscula Zone.
- Brachiopods are represented mainly by zeilleriids.
- Gastropods show an inverse distribution to that of bivalves.
- Foraminifers and ostracods, initially constituted by fossil assemblages generally known from the Toarcian, show an important renewal at the Aalenian/Bajocian boundary.
- Calcareous nannofossils show a change across the Aalenian/Bajocian boundary expressed by new occurrences of species of the genus *Watznaueria*.

These data show moreover that the Rich region (Central High Atlas) offers new data to define the boundary between the Aalenian and Bajocian in the Submediterranean Province. The fossil assemblages reflect a Mesogean character that is temporarily dominated by net Northwest European influences. They also have many affinities with assemblages of the Murtinheira Section (Western Portugal), defined as the Global Stratotype Section and Point (GSSP) for the Aalenian/Bajocian boundary (Henriques *et al.*, 1994; Pavia, Enay, 1997).

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PLATE 1

Micrographs showing some nannofossil taxa recorded accros the Aalenian/Bajocian boundary in the Rich section (all figured specimens are from de Kaenel, 1990)

Figs 1–4. *Diductius constans* Goy: **1** – crossed polars, KG76, Discites Zone (GA: 6.7) (pl. 5: 8), **2** – distal view, KG76, Discites Zone, ×6440 (GA: 5.3) (pl. 5: 5), **3** – distal view, KG72, Concavum Zone, ×7940 (GA: 4.7) (pl. 5: 6), **4** – distal view, KG76, Discites Zone, ×5020 (GA: 6.7) (pl. 5: 7)

Fig. 5. *Biscutum profundum* de Kaenel et Bergen: crossed polars, KG72, Concavum Zone (D: 4.4) (pl. 6: 26)

Figs 6, 7. *Discorhabdus occlusus* de Kaenel: **6** – distal view, KG76, Discites Zone, ×7040 (GA: 4.8) (pl. 7: 8), **7** – proximal view, KG76, Discites Zone, ×6440 (GA: 4.7) (pl. 7: 19)

Fig. 8. *Discorhabdus novus* (Goy in Goy, Noël et Busson) de Kaenel et Bergen: crossed polars, KG76, Discites Zone (pl. 7: 15)

Figs 9–11. *Palaeopontosphaera dubia* Noël, emend. de Kaenel et Bergen: **9** – crossed polars, KG72, Concavum Zone (GA: 2.3) (pl. 8: 16), **10** – distal view, KG72, Concavum Zone, ×9160 (GA: 4.2) (pl. 8: 21), **11** – distal view, KG72, Concavum Zone, ×11240 (GA: 2.6) (pl. 8: 25)

Fig. 12. *Helenea incompta* (Bown et Cooper) comb. nov.: distal view (specimen without center), KG72, Concavum Zone, ×7500 (GA: 4.9) (pl. 10: 25)

Fig. 13. *Axopodorhabdus cylindratus* (Noël) Wind et Wise in Wise and Wind: crossed polars, KG72, Concavum Zone (GA: 5.2) (pl. 9: 24)

Figs 14–15. *Ethmorhabdus gruenii* Bergen: **14** – proximal view, KG72, Concavum Zone, ×6440 (GA: 5.3) (pl. 10: 9), **15** – proximal view, KG76, Discites Zone, ×6440 (GA: 5.6) (pl. 10: 10)

Fig. 16. *Triscutum tiziense* de Kaenel et Bergen: crossed polars, KG76, Discites Zone (GA: 10.8) (pl. 12: 19)

Figs 17, 18. *Triscutum sullivanii* de Kaenel et Bergen: **17** – crossed polars, KG76, Discites Zone (GA: 8.0) (pl. 12: 12), **18** – distal view, KG76, Discites Zone, ×4660 (GA: 7.5) (pl. 12: 17)

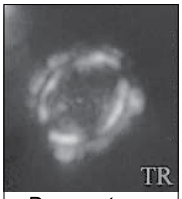
Fig. 19. *Lotharingius contractus* Bown et Cooper: distal view, sample KG76, Discites Zone, ×5380 (GA: 5.8) (pl. 14: 30)

Figs 20, 21. *Lotharingius velatus* Bown et Cooper: **20** – proximal view, KG72, Concavum Zone, ×5580 (GA: 6.1) (pl. 14: 31), **21** – crossed polars, KG72, Concavum Zone (GA: 6.4) (pl. 14: 21)

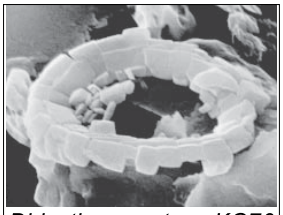
Fig. 22. *Watznaueria atlantidis* de Kaenel: crossed polars, KG76, Discites Zone (GA: 7.6) (pl. 15: 22),

Fig. 23. *Ellipsagelosphaera britannica* (Stradner) Perch-Nielsen: crossed polars, sample KG76, Discites Zone (GA: 8.4) (pl. 16: 19)

Fig. 24. *Ellipsagelosphaera frequens* Noël: distal view, KG76, Discites Zone, ×5380 (GA: 6.3) (pl. 15: 30)



D. constans KG76 1



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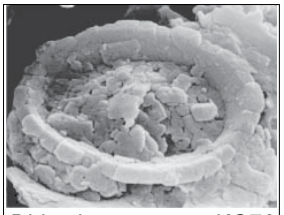

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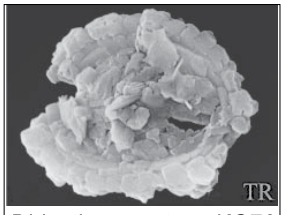
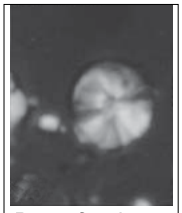
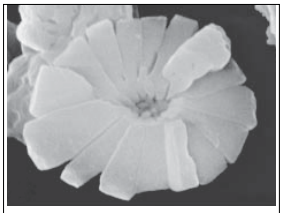


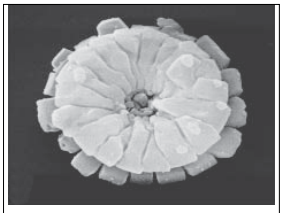
Diductius constans KG76 4



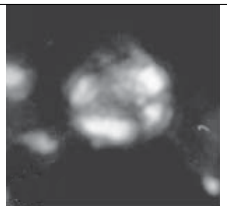
B. profondum KG72 5



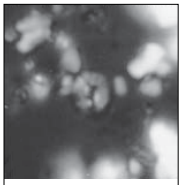
Discor. occlusus KG76 6



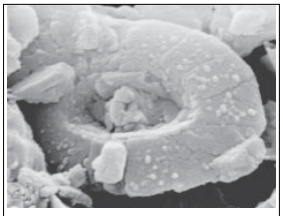
Discor. occlusus KG76 7



Discor. novus KG76 8



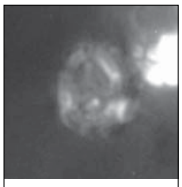
Palaeo. dubia KG72 9



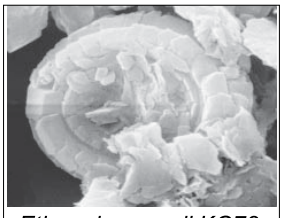
Palaeopont. dubia KG72 10

Palaeopont. dubia KG72 11

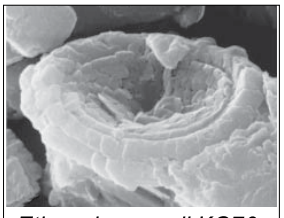
Helenea incompta KG 72 12



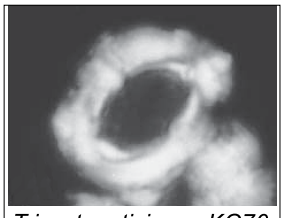
Ax. cylindratus KG72 13



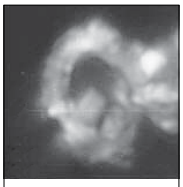
Ethmorh. gruenii KG72 14



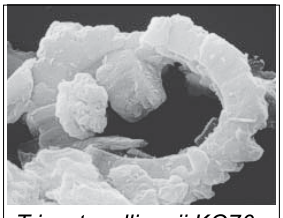
Ethmorh. gruenii KG76 15



Triscutum tiziense KG76 16

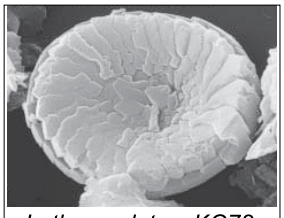


Tris. sullivanii KG76 17

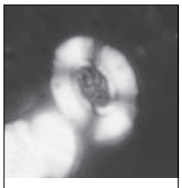


Triscut. sullivanii KG76 18

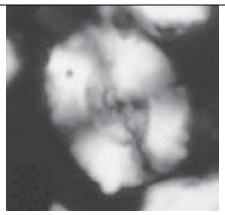
Loth. contractus KG76 19



Lothar. velatus KG72 20

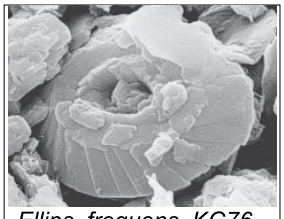


Loth. velatus KG72 21



Watzna. atlantidis KG76 22

Ellips. britannica KG76 23



Ellips. frequens KG76 24

PLATE 2

Upper Aalenian and Lower Bajocian selected foraminifers recorded at some sections in the central High Atlas (after El-Kamar, 1997 and Amhoud, 1999)

Fig. 1. *Ammobaculites agglutinans* (d'Orbigny), ×170, Lower Bajocian, Kerrando-Gourrama (Amhoud, 1999, pl. 10: 9)

Fig. 2. *Reophax horridus* (Schwager), ×150, Lower Bajocian, Kerrando-Gourrama (Amhoud, 1999, pl. 10: 6)

Fig. 3. *Conoglobigerina atlasica* El-Kamar, ×800, Lower Bajocian, Tizi n'Zou (El-Kamar, 1997, pl. 6: 5)

Fig. 4. *Conoglobigerina atlasica* El-Kamar, ×500, Upper Aalenian–Lower Bajocian, Rich (El-Kamar, 1997, pl. 6: 6)

Fig. 5. *Dentalina bicornis* Terquem, ×100, Lower Bajocian, Kerrando-Gourrama (Amhoud, 1999, pl. 15: 1)

Fig. 6. *Dentalina gümbeli* Schwager, ×120, Lower Bajocian, Bou Dahar (Amhoud, 1999, pl. 15: 6)

Fig. 7. *Ichtyolaria lignaria* (Terquem), ×83, Lower Bajocian, Kerrando-Gourrama (Amhoud, 1999, pl. 15: 22)

Fig. 8. *Lenticulina galeata* (Terquem) mg. *Lenticulina*, ×110, Lower Bajocian, Kerrando-Gourrama (Amhoud, 1999, pl. 19: 5)

Fig. 9. *Lenticulina münsteri* (Roemer) mg. *Lenticulina*, ×60, Lower Bajocian, Bou Dahar (Amhoud, 1999, pl. 16: 17)

Fig. 10. *Lenticulina polygonata* (Franke) mg. *Lenticulina*, ×50, Lower Bajocian, Bou Dahar (Amhoud, 1999, pl. 18: 11)

Fig. 11. *Lenticulina quenstedti* (Gümbel) mg. *Lenticulina*, ×130, Lower Bajocian, Kerrando-Gourrama (Amhoud, 1999, pl. 19: 6)

Fig. 12. *Lenticulina cephalotes* (Reuss) mg. *Marginulinopsis*, ×100, Lower Bajocian, Bou Dahar (Amhoud, 1999, pl. 17: 6)

Fig. 13. *Lingulina dentaliniformis* Terquem, ×300, Aalenian, Kerrando (Amhoud, 1999, pl. 21: 1)

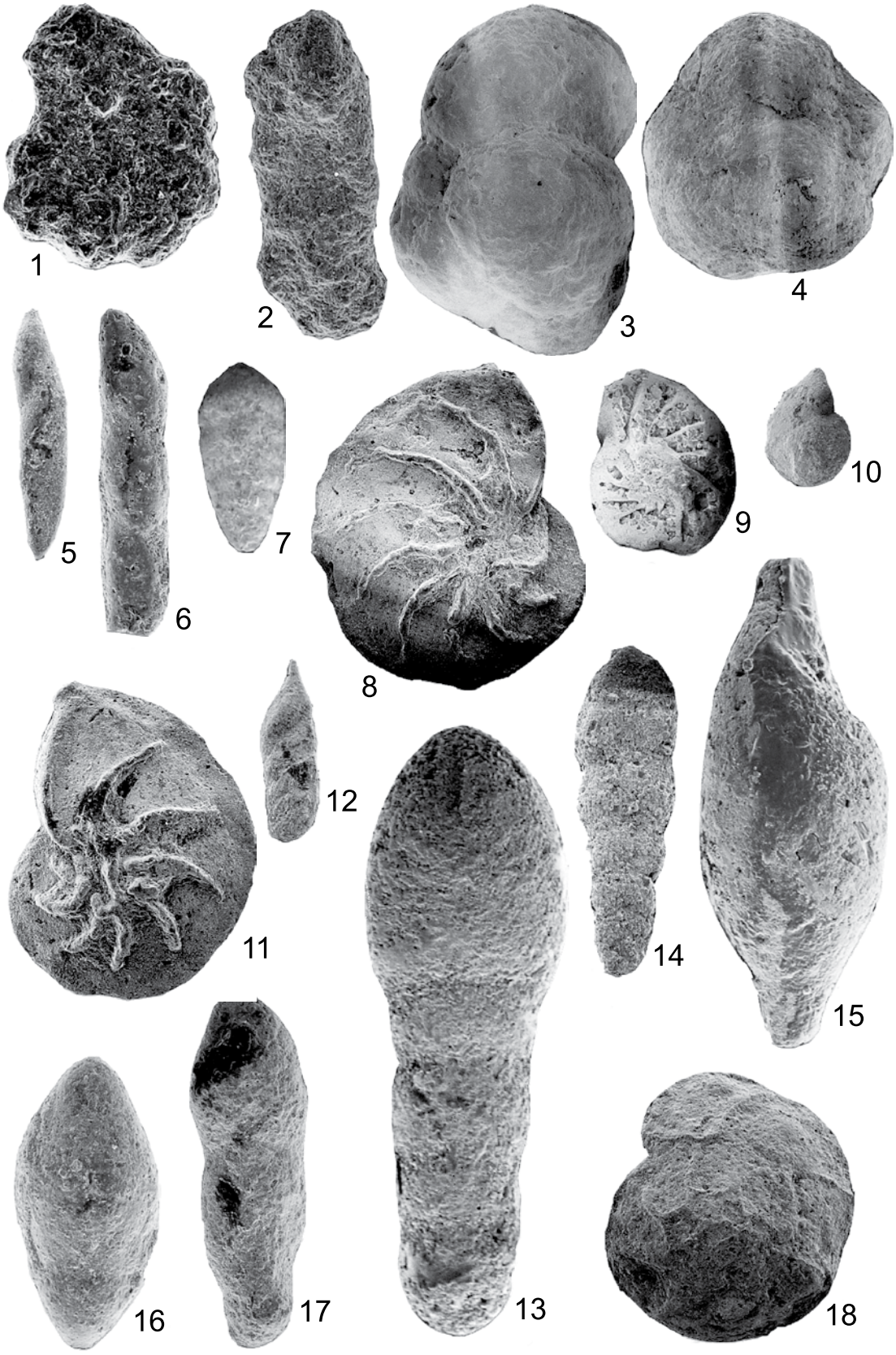
Fig. 14. *Lingulina nodosaria* (Terquem), ×170, Lower Bajocian, Kerrando-Gourrama (Amhoud, 1999, pl. 21: 6)

Fig. 15. *Nodosaria regularis* (Terquem), ×500, Lower Bajocian, Bou Dahar (Amhoud, 1999, pl. 21: 27)

Fig. 16. *Eoguttulina bilocularis* (Terquem), ×100, Lower Bajocian, Bou Dahar (Amhoud, 1999, pl. 23: 1)

Fig. 17. *Eoguttulina polygona* (Terquem), ×80, Lower Bajocian, Bou Dahar (Amhoud, 1999, pl. 23: 10)

Fig. 18. *Garantella stella* Kaptarenko, ×100, Lower Bajocian, Bou Dahar (Amhoud, 1999, pl. 24: 10)



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