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Lithostratigraphy, biostratigraphy and sedimentary dynamics of the Lower Cretaceous deposits on the northern side of the western High Atlas (Morocco)

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The analysis of a sedimentary succession on the northern side of the western High Atlas, from Essaouira to Amizmiz, has enabled us to identify, and describe, thirteen formations ranging in age from Tithonian to Clansayesian. The collection and determination of ammonite and echinoid faunas has allowed us to attribute a precise age to most of these units. Lower Cretaceous formations are organized into six main depositional sequences: Late Jurassic-Berriasian; Valanginian; Hauterivian-Barremian; Bedoulian; Gargasian; Clansayesian-Albian. This organization, the characteristics of the major discontinuities and the geometry of sedimentary succession allows recognition of the following events: a Late Berriasian distensive phase; a period of sea-level change and basin infilling during Valanginian, Hauterivian, Barremian and Bedoulian times under essentially eustatic control; an intra-Aptian tectonic phase; and a period of relative sea level rise and topographic levelling during Gargasian-Albian. This is essentially linked to the evolution of the North Atlantic ocean during the Early Cretaceous.

KEY WORDS: Lower Cretaceous; Lithostratigraphy; Biostratigraphy; Ammonites; Depositional sequences; Sedimentary evolution; High Atlas: Morocco.

1. Introduction

On the northern and northwestern foothills of the High Atlas, the regions of Essaouira, Imi N'Tanout and Amizmiz display a Lower Cretaceous succession deposited in the northern part of a basin, open to the west, with a depocentre located around one hundred kilometers towards the south, near Agadir. This basin, more commonly named the "Atlasic Gulf" (Choubert & Faure-Muret, 1962) allowed a connection between the Atlantic margin and the High Atlas mobile belt (Wurster & Stets, 1982). This Cretaceous succession has been studied during the last two decades as a part of a petroleum exploration programme. Duffaud *et al.* (1966) suggested a division of the Lower Cretaceous into several formations, dated using micro- and macro-paleontological data. More recently, different sections from this area have been described to further extend knowledge of the

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geological history of the Moroccan continental margin, with special emphasis on either the biostratigraphy (Wiedmann *et al.*, 1978) or the lithostratigraphy (Wurster & Stets, 1982). Within the framework of I.G.C.P. n°183 and "Action Intégree" n°86/210, we have undertaken a study of the Lower Cretaceous in this area to improve our knowledge of the different sedimentary successions by a study of the reference sections and a new interpretation of the lateral and vertical changes recorded in the light of recently developed stratigraphical models (Vail *et al.*, 1977) and newly acquired data on the history of passive margins. Following preliminary accounts of our work (Canérot *et al.*, *in press*; Rey *et al.*, 1986a, 1986b), we here present a lithostratigraphical description of the Lower Cretaceous successions.

2. Lithostratigraphic succession

The subdivision into formations and members principally comes from the examination and correlation of stratigraphic successions outcropping along five reference cross-sections (Fig. 1):

—*the Jbel Mradma section*, on the southern limb of the Oued Tidzi diapir-fold, 10 km NNE of Smimou and 1 km to the east of the hamlet of Mradma, on the southern bank of Oued Tidzi valley which is capped by the Jbel Mradma (or Jbel Tazzemourt) ridge;

—*the Oued Tlit section*, which is based on several small sections on the northern side of Jbel Amsitenne, 7 km ESE of Smimou, on the two sides of the Oued Tlit valley, near the Smimou to Imi N'Tlit road;

—*the Jel Talbourine section*, described from the northern limb of the Zem-Zem anticline, between the Dar Caïd Zem-Zem to Amskerkid road to the South and the Jbel Talbourine ridge to the North;

—*the Imi N'Tanout section*, a Lower Cretaceous succession which is well exposed on the southern side of Jbel Lemgo, 10 km WSW of Imi N'Tanout, to the North of the P40 road near Aït Bouçag and Tazought hamlets;

—*the Amizmiz section*, 2 km to the south of Amizmiz, on the right bank of Oued Anougal.

The lateral facies variations and a full description of the sedimentary successions in the Ichemrarn region and the Ameznez hills was also undertaken.

We wish to propose that the uppermost Jurassic-Lower Cretaceous succession in this area is divided into 13 formations (Figs 2 and 3) and these are now described.

2.1. Cap Tafelney Formation

This was first described by Taj-Eddine & Rey (1985). The *derivatio nominis* comes from Cap Tafelney, 45 km to the south of Essaouira, on the western end of the Amsittene ridge. The reference-section is located on the southern limb of the Jbel Amsittene anticline, on the eastern side of the P8 road, immediately to the North of the junction with the Cap Tafelney road (Lambert coordinates: x = 89; y = 69.5, Tamanar sheet).

This formation is composed of two members:

—member 1: "Bryozoan Limestones" (15 to 30 m), comprising bryozoan limestones, algal and foraminiferal mudstones, stromatolitic and algo-

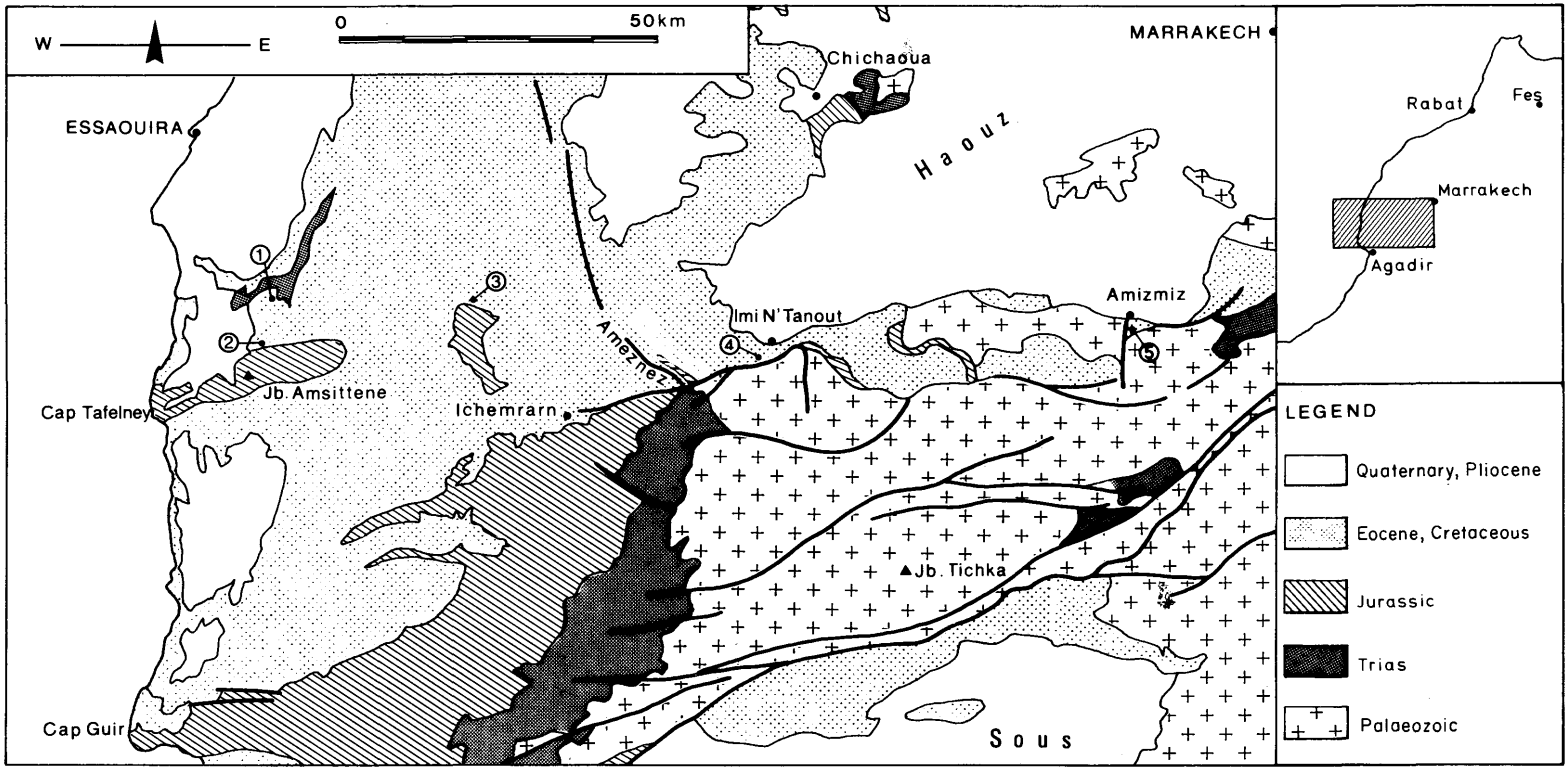

Figure 1. Geological map of the western High Atlas and the location of the main sections. 1, Jbel Mradma section 2, Oued Tlit section; 3, Jbel Talbourine section; 4, Imi N'Tanout section; 5, Amizmiz section.

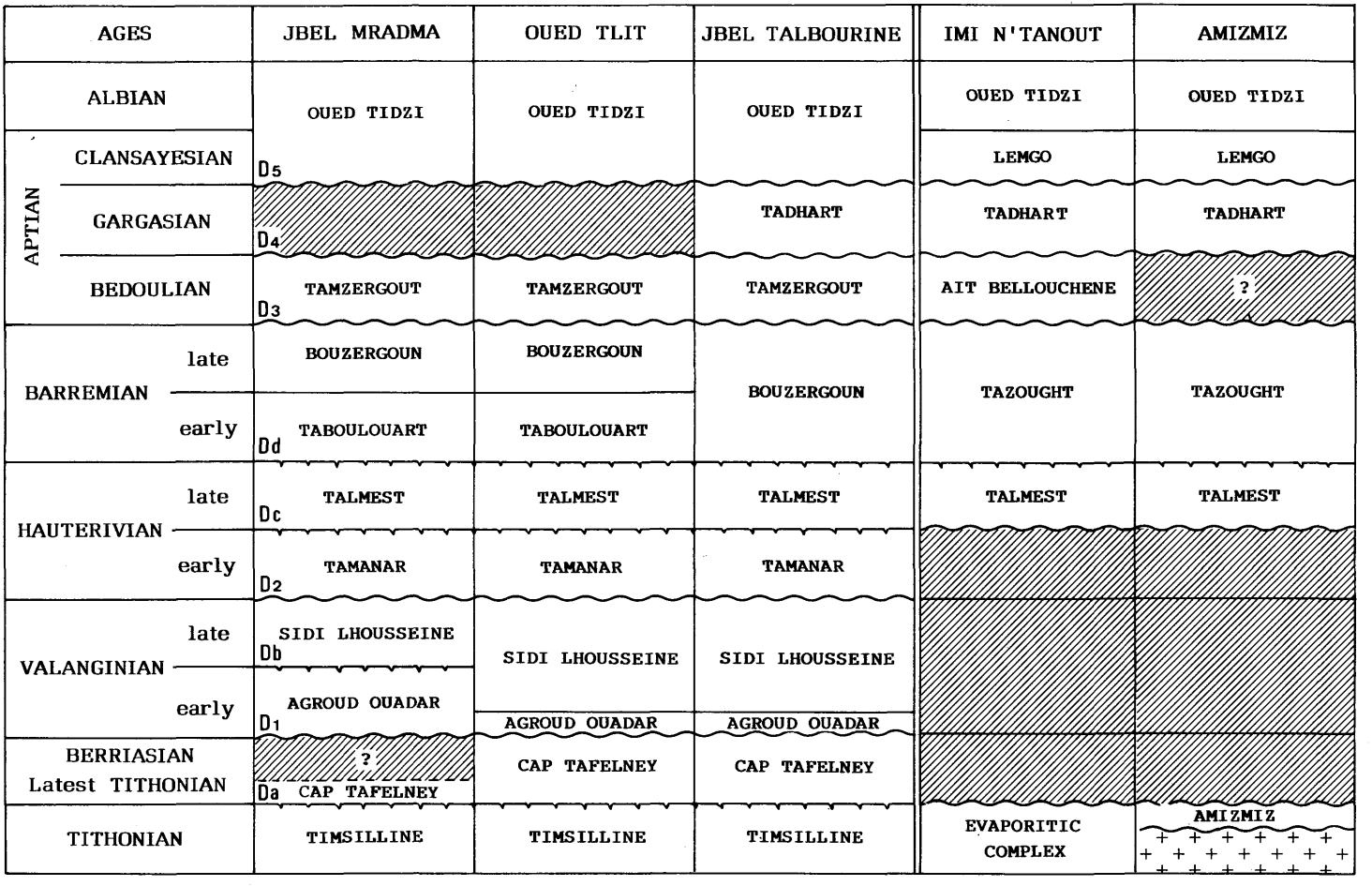

Figure 2. The lithostratigraphical units of the Lower Cretaceous in the Western High Atlas.

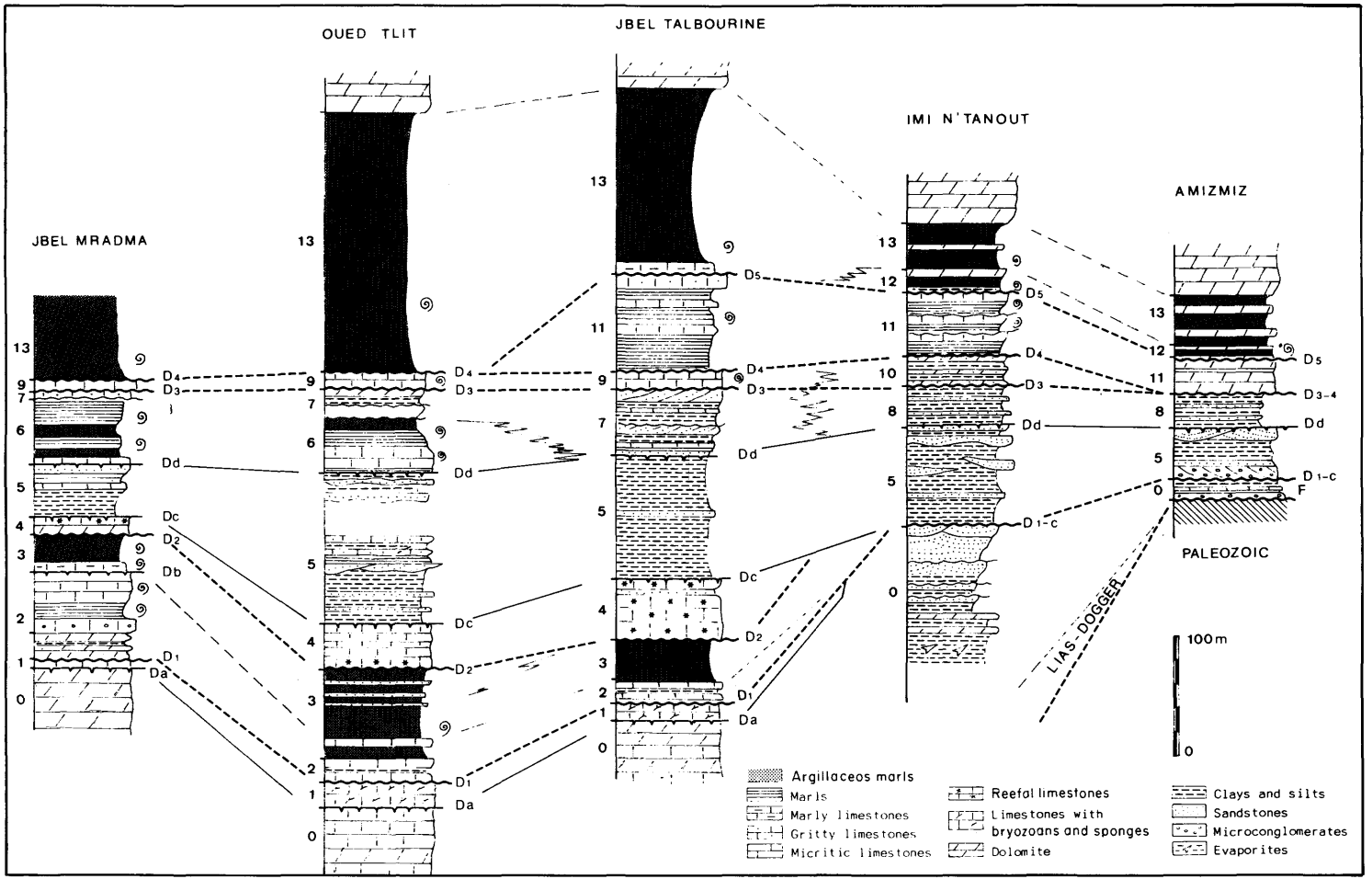

Figure 3. Lithostratigraphical and sedimentological correlation in the Lower Cretaceous strata of the western High Atlas. 0, Timsilline Formation; 1, Cap Tafelney Formation; 2, Agroud Ouadar Formation; 3, Sidi Lhousseine Formation; 4, Tamanar Formation; 5, Talmest Formation; 6, Taboulouart Formation; 7, Bouzergoun Formation; 8, Tazought Formation; 9, Tamzergout Formation; 10, Aït Bellouchene Formation: 11, Tadhart Formation; 12, Lemgo Formation; 13, Oued Tidzi Formation.

laminar limestones, associated within several regressive sequences. This unit lies on the carbonate Timsilline Formation (dolomites an limestones) from which it was not previously separated. This lower boundary is marked by a slight sedimentary discontinuity. The identified microfossils (*Pseudocyclammina lituus* (Yokohama), *Feurtillia frequens* Maync, *Mayncina bulgarica* Laug, Peybernès and Rey, *Trocholina* gr. *alpina-elongata, Lenticulina* sp., *Actinoporella podolica* Althman, *Salpingoporella annulata* Carrozi, *Clypeina jurassica* Favre, *Thaumatoporella parvovesiculifera* Raineri, *Lithocodium aggregatum* Elliott, *Cayeuxia piae* Frollo, and *Marinella lugeoni* Pfender) indicate an age in the Tithonian-Berriasian interval;

—member 2: "Calpionellid Limestones" (1 to 3 m), includes yellow beds of bioclastic and sandy-marly limestones. This member has its upper surface terminated by a major discontinuity. The calpionellid assemblage (identified by M. Durand-Delga) from the stratotype section includes *Calpionella alpina* Lorenz, *Crassicollaria* gr. *parvula* Remane, *Tintinnopsella* gr. *carpathica* Murgeascu and Filipescu.

The assemblage can be regarded as characterizing the latest Tithonian to earliest Berriasian interval. However, it is possible that this member is diachronous in its various outcrops and could terminate at various levels in the Berriasian.

The facies homogeneity of the Cap Tafelney Formation over all its depositional area is remarkable. However, on the boundary of the Oued Tidzi diapir (Jbel Mradma section), only member 1 is present (with Algal limestones) and reduced to a thickness of 0.50 m. This is possibly the result of vertical movements occuring at the Jurassic-Cretaceous boundary or at the end of Berriasian. To the east, between Ichemrarn and Imi N'Tanout (on the meridian of Ameznez hills), the Cap Tafelney Formation quickly disappears, pinching out under the Valanginian marls.

2.2. Agroud Ouadar Formation

This formation, created by Duffaud *et al.* (1966) consists of an alternating series of marly limestones and marls containing ammonites and echinoids. The maximum thickness (70 m) is found at Jbel Mradma where all the zones of the early Valanginian can be proved by the occurrence of echinoids (*Toxaster granosus* d'Orbigny, *Collyrites jaccardi* Desor) and by the presence of three ammonite assemblages:

—*Thurmanniceras* cf. *salientium* (Sayn) and *Olcostephanus* gr. *psilostomus* (Neumayr and Uhlig), pointing to the *otopeta* Zone, 45 m above the base of the formation;

—*Cymatoceras pseudoelegans* (d'Orbigny), *Spiticeras (Kilianiceras) gratianopolitense* Kilian, *Thurmanniceras* cf. *allobrogicum* (Kilian), *Sarasinella* gr. *trezanensis-longi* (Sayn), *Neocomites* gr. *neocomiensis* (d'Orbigny) corresponding to the *otopeta* Zone and probably the *pertransiens* Zone, at 55–60 m above the base;

—*Karakaschiceras inostransewi* (Karakasch) from the *campylotoxum* Zone, to the top of the formation and below a remarkable local discontinuity.

Elsewhere, the thickness of this unit is only 20 m.It is overlain without a break by the next formation and is probably restricted to the earliest Valanginian.

2.3. *Sidi Lhousseine Formation*

This unit was also erected by Duffaud *et al.* (1966) and is principally composed of green marls including some beds of marly limestones at the base and sandstones (with stream channels and slumps) at the top. The ammonites collected from Jbel Mradma indicate a late Valanginian age, with successively:

—a *verrucosum* Zone assemblage at the base (overlying the discontinuity capping the Agroud Ouadar Formation) with *Cymatoceras pseudoelegans, Kilianella (Luppovella)* gr. *superba* (Sayn), *Neocomites teschenensis* (Uhlig), *Karakaschiceras* cf. *biassalense* (Karakasch), *K. aff. brandesi* (Koenig), *Neohoploceras* cf. *provinciale* (Sayn), *Dobrodgeiceras ventrotuberculatum* Nikolov., *D.* aff. *wilfridi* (Karakasch), *Olcostephanus atherstoni* (Sharpe) and *O.* gr. *sayni-subfilosus*;

—an assemblage which might indicate the *callidiscus* Zone within the following 12 meters. This yields *Neocomites* gr. *neocomiensis, Teschenites* aff. *pachydicranus* (Thieuloy), *Olcostephanus densicostatus* (Wegner), *O. atherstoni* and *Bochianites neocomiensis* (d'Orbigny).

On the other hand, the layer found along the Oued Tlit section, 25 m above the boundary between the Agroud Ouadar and Sidi Lhousseine Formations corresponds to the *campylotoxum* Zone, indicating an early Valanginian age. This contains *Cymatoceras* aff. *neocomiense* (d'Orbigny), *Thurmanniceras campylotoxum* (Uhlig), *Kilianella* sp., *K. (Luppovella)* gr. *superba, Olcostephanus psilostomus lateumbiculatus* (Roch), *O.* gr. *atherstoni, Karakaschiceras biassalense* and *K.* aff. *pronecostatum* (Felix). The lower boundary of the Sidi Lhousseine Formation could be diachronous, becoming younger towards the north (Jbel Mradma section) when compared to the Oued Tilt section in the south. This unit represents the late Valanginian and, to the south and in the centre of the studied area, a part of the early Valanginian. It is overlain by a major sedimentary discontinuity. Its thickness varies from 27 m (Jbel Mradma) to 70 m (Oued Tlit).

The two Valanginian formations, Agroud Ouadar and Sidi Lhousseine, become more litoral (with dolomites and sandy limestones) to the east of Ichemrarn, then both very quickly disappear near Igourdane, probably by coastal on-lap.

2.4. *Tamanar Formation*

This formation (Duffaud *et al.*, 1966) of 35 to 50 m presents a reefal character. It is limited by two major discontinuities; the lower discontinuity having a ferruginous crust while the upper discontinuity has an erosive surface. Limestones, bearing joined *Madreporaria*, form massive beds alternating within cyclic sequences of marly and nodular limestones containing echinoids (*Codiopsis lorini* Cotteau, *C. meslei* Gauthier, *Salenia foliumquerci* Desor, *Hyposalenia stellulata* Cotteau, *Pseudocidaris clunifera* Agassiz) and brachiopods (*Lamellaerhynchia gillieroni* Pictet, *Loriolithyris melaitensis* Middlemiss). This fauna indicates that the Tamanar Formation corresponds to the lower part of the Hauterivian. Between Essaouria and Ichemrarn, the facies indicate a stable environment. Near this latter locality some clay/sand

lenses appear. To the east of Ichemrarn, the younger Talmest Formation directly overlies the Sidi Lhousseine Formation.

2.5. Talmest Formation

The Talmest Formation was first described by Duffaud *et al.* (1966). To the east, in the Amizmiz and Imi N'Tanout areas, it consists of red clays associated with sandy or conglomeratic sediments that form tabular beds with horizontal stratification or cross-bedded lenses. In the central area of Ichemrarn and Jbel Talbourine, red and green clays including thin sandy beds with horizontal stratification are dominant. To the west (Oued Tlit, Jbel Mradma) sandy limestones with oysters (particularly *Aetostreon couloni* Coquand), *Choffatella decipiens* Schlumberger, serpulids and bryozoans, appear within the red clays. The thickness generally increases from east to west (55 m at Amizmiz, 125 m at Oued Tlit). However, an important reduction of thickness can be recognized on the side of the Oued Tidzi diapir (Jbel Mradma section).

With unequivocal paleontological data, we include this formation within the upper part of Hauterivian, on the basis of its position between the Hauterivian Tamanar Formation and the Barremian Taboulouart Formation.

2.6. Taboulouart Formation

A unit created by Duffaud *et al.* (1966), the Taboulouart Formation only occurs in the more eastern outcrops where it consists of about 40 m of yellow or green marls and marly limestones (with brachiopods, echinoids and ammonites). In its lower part it is a wavy-bedded, bioclastic limestone with oysters. The important fossils are *Tetragramma autissiodorense* (Cotteau) and *Toxaster maurus* Lambert in the lowermost beds, then *Paraspiticeras percevali* (Uhlig), *Torcapella? barremensis* (Roch) and *Toxaster peroni* Lambert in the lower half, *Cymatoceras neocomiense* (d'Orbigny), *Pulchellia* (?) aff. *riedeli* (Burge), *Pulchellia (Nicklesia) didayi* (d'Orbigny), and *Toxaster peroni* in the upper half. This assemblage indicates an early Barremian age. The boundary between the Hauterivian and Barremian can be placed at the base of this formation.

2.7. Bouzergoun Formation

This unit, from F. Duffaud *et al.* (1966), includes margino-littoral deposits of thin sandstones with ripples and purplish-blue or green clays which are associated with thin calcareous beds with algal laminations, yellow cristalline dolomites and lumachelle limestones with large oblique stratification. To the west, its thickness varies from 5 m (Jbel Mradma) to 18 m (Oued Tlit). Overlying the Taboulouart Formation, it can be assigned to the upper part of the Barremian. In the Zem-Zem area (Jbel Talbourine section), it is thicker (55 m) and overlies the Talmest Formation and could correspond to the whole of the Barremian, with its lower part probably being the lateral equivalent of the Taboulouart Formation. It is replaced to the east by the Tazought Formation. In all its outcrops, the formation is terminated by a major discontinuity.

2.8. *Tazought Formation*

The name of this newly created unit (Rey *et al.*, 1986b) is taken from Tazought hamlet, situated at the foot of Jbel Lembo (Imi N'Tanout area). The reference section is on the southern side of Jbel Lemgo ridge, 350 m SE of the 1383 m spot height, 400 m NE of Tazought, Lambert coordinates: x = 162.6; y = 65.2 (Imi N'Tanout sheet).

The formation is largely composed of red and purplish-blue clays alternating with thin horizontal beds of silts, pink sandstones bearing *Rhizocorallium* and whitish limestones with gastropod and bivalve shell moulds. Attaining a thickness of 30 m, it is enclosed by two discontinuities of regional importance. It could be the lateral equivalent of the Bouzergoun Formation, having a higher energy-index and defined in the Zem-Zem Mountains. The Tazought Formation, containing the foraminifer *Choffatella decipiens* to the north of Inemern, can be assigned to the Barremian.

2.9. *Tamzergout Formation*

Within this Formation (Duffaud *et al.*, 1966) are included wavy-bedded marly limestones alternating with yellow marls and nodular marly limestones. The thickness varies from 6 m (Jbel Mradma) to 15 m (Oued Tlit, Jbel Talbourine). A thin, condensed horizon marks the base of the formation in the Oued Tlit section. It contains ammonites; *Dufrenoya* cf. *dufrenoyi* (d'Orbigny), *Cheloniceras* gr. *cornuelianum* (d'Orbigny), *Procheloniceras* cf. *stobieckii* (d'Orbigny) and *Neohibolites semicanaliculatus* (Blainv.). The younger beds in the Oued Tlit section contain *Procheloniceras* cf. *pachystephanum* (Uhlig), *Cheloniceras* gr. *seminodosum* (Sinzow), *Neohibolites semicanaliculatus, Toxaster villei* Gauthier and, in the Jbel Mradma section, *Procheloniceras* gr. *stobieckii-albrechtiaustriae*. Such assemblages can be regarded as characterizing the Bedoulian (= early Aptian). The formation is only present in the central and western part of the study area.

2.10. *Aït Bellouchene Formation*

The name of this recently described formation (Rey *et al.*, 1986b) comes from the Aït Bellouchene hamlet, situated at the foot of Jbel Lemgo (Imi N'Tanout area). The reference section corresponds to the southern side of Jbel Lemgo ridge, and more particularly to the outlier immediately to the west of Aït Bellouchene (Lambert coordinates: x = 163.7; y = 65.9, Imi N'Tanout sheet).

This formation includes several regressive depositional sequences of alternating wine-red clays, greenish marls, yellow dolomicrites and yellow sandy dolosparites with cross-stratification and numerous bivalve remains. The formation reaches a thickness of 28 m and is bounded by two hardgrounds. It would appear to be synchronous with the calcareous marls of the Tamzergout Formation and could be absent to the east, especially in Amizmiz.

2.11. *Tadhart Formation*

The Tadhart Formation is a newly recognised unit (Rey *et al.*, 1986a) outcropping near the Tadhart village, to the south of Jbel Talbourine (Ida Ou

Zem-Zem area). The reference section is located to the east of Tadhart, 900 m SE of Jbel Talbourine (Lambert coordinates: x = 123.8; y = 82.2, El Khemis des Meskalas sheet).

This formation was previously included within the younger Lemgo Formation. It contains whitish marls and yellow wavy-bedded micritic limestones. Marls and limestones are arranged within cyclic sedimentary sequences, associated themselves within several positive mesosequences showing normally graded limestone beds (three mesoquences in Imi N'Tanout). At the foot of Jbel Lemgo, the ammonite assemblage listed within the second mesosequence points to a Gargasian (= late Aptian) age; the fauna includes *Tropaeum (Epitropaeum)* sp., *Australiceras* sp., *Pseudoaustraliceras* sp., *Cheloniceras (Epicheloniceras)* sp., *Cheloniceras (Epicheloniceras)* cf. *subnodosocostatum* (Sinzow) and *Colombiceras* cf. *discoidalis* (Sinzow). Along this same section, the latest bed of the third mesosequence has a rich echinoid fauna including *Toxaster villei, Epiaster restrictus* Gauthier, *Discoides peroni* (Lambert), *Hyposalenia lardyi* Desor, *Hemidiadema rugosum* Agassiz and *Tetragramma dumasi* Lambert (determinations by A. Rocher). Occurring between two hard-grounds, the Tadhart Formation varies in thickness from 75 m (Jbel Talbourine) to 40 m (Amizmiz). To the east, at Amizmiz, limestones are replaced by yellow dolomites, with horizontal or cross-stratification, alternating with beige marls. The Formation does not occur in the Oued Tidzi area where Clansayesian (= uppermost Aptian) marls directly overlain Bedoulian limestones.

2.12. Lemgo Formation

This unit was proposed by Duffaud *et al.* (1966) and subsequently reinterpreted by Rey *et al.* (1986b). It is named after the Jbel Lemgo ridge, to the east of Imi N'Tanout. The reference section is situated on the southern side of this mountain, at the level of the 1328 m spot height, 1 km ESE of Aït Bellouchene (Lambert coordinates: x = 163.2; y = 65.9, Imi N'Tanout sheet).

We would prefer to restrict this formation to the green marls, yellow sandy marls and sandy dolomites that form a regressive mesosequence of Clansayesian. The unit reaches a thickness of 16.5 m in the Imi N'Tanout section where it begins with a condensed horizon containing *Diadochoceras nodosocostatum* (d'Orbigny), *Eodouvilleiceras clansayense* (Jacob), *Pseudoaustraliceras* gr. *ramososeptum* (Anthuea)—*pavlovi* (Wassiliewski), *Zuercherella* cf. *zuercheri* (Jacob and Tobler), *Uhligella* aff. *clansayensis* (Jacob), *U. toucasi* (Jacob), *Acanthophoplites* gr. *bigoureti* (Seunes), *Nodosophoplites* cf. *proprius* Egoyan, *N.* cf. *obscurus* Egoyan, *Nolaniceras* gr. *nolani* (Seunes), *N.* cf. *uhligi* (Anthuea), *Hypacanthoplites* gr. *nolanisimilis*—*mangyschlakensis, H.* cf. *anglicus audax* Casey. This rich assemblage characterizes the *jacobi* Zone and the *nolani* Subzone. Above this level are found three successive ammonite-rich layers:

—a lower layer with *Nolaniceras* cf. *rigidus* Breistoffer. and *Acanthohoplites* cf. *bergeroni* (Seunes);

—a middle layer with *Hypacanthoplites* aff. *sigmoidalis* Casey and *H. anglicus*;

—an upper layer with *Hypacanthoplites sigmoidalis* and *H.* gr. *jacobiplesiotypicus* (upper part of the *jacobi* Zone).

To the east, in the Amizmiz area, the thickness of the formation decreases (7 m). Within the highest beds are found *Cymatoceras neckerianum* (Pictet), *Acanthohoplites* cf. *seunesi* (Jacob), *Nolaniceras* aff. *uhligi* and *Hypacanthoplites* aff. *sigmoidalis*. To the west, the dolomitic beds disappear and the unit is not separable from the marls of the Oued Tidzi Formation.

2.13. Oued Tidzi Formation

This formation, created by Duffaud *et al.* (1966), comprises a complex of green marls bearing small pyritic ammonites and is intercalated with some beds of marly limestones or sandy dolomites. It is overlain, without a break, by dolomites belonging to the Kechoula Formation of Vraconian age. The thickness of the Oued Tidzi Formation progressively decreases from west to east (230 m at Oued Tlit to 38 m at Imi N'Tanout). A fossiliferous layer in the lowermost part of the marly complex just above the Bedoulian Tamzergout Formation was discovered along the P8 road, on the southern side of the Oued Tidzi valley, 5 km to the north of Smimou. This contains *Valdedorsella akuschaensis* (Anthuea), a stratigraphically diagnostic species indicating an uppermost Gargasian-Clansayesian age, and, 15 m above, *Hypacanthoplites* gr. *jacobi*, *Protetragonites* sp. juv., *Zuercherella* sp. juv. or *Uhligella* sp. juv., *Hypacanthoplites* sp. juv. and *Neohibolites* sp.; an assemblage assigned to Clansayesian.

In the Oued Tidzi section, *Oxytropidoceras roissyanum* (d'Orbigny) of middle Albian age was recently found 50 m above the base of the formation. We can thus estimate that, in the central and western part of the studied area, the Oued Tidzi Formation embraces the Clansayesian to Albian interval. In the eastern area (Imi N'Tanout and Amizmiz), this unit, which overlies the Clansayesian Lemgo Formation could be of Albian age, following the discovery at the base of small pyritic ammonites similar to *Beudanticeras dupinianum* var. *africana* (Pervinquières).

3. Organisation of the succession

Uppermost Jurassic and Lower Creceous sediments are organized into seven depositional sequences (corresponding to regional cycles of third order relative sea-level, in the terminology of Vail *et al.*, 1977) separated by five major discontinuities (Figs 4 and 5).

The latest Jurassic and Berriasian platform opening sequence (SI) corresponds to the transition from lagoon (Timsilline Formation) to outer carbonate-rich subtidal to intertidal environments, with discontinuous and restricted sedimentation (Cap Tafelney Formation). The rapid opening is marked by an hiatus (discontinuity D*a*). In the Imi N'Tanout area, the upper part of the succession is truncated either by erosion or non-deposition of the Cap Tafelney Formation. However, a tendency towards sea level rise is seen by the lagoonal-marine transgression during the Tithonian onto the Hercynian basement of the Amizmiz area (Amizmiz Formation).

The Berriasian-Valanginian boundary discontinuity (D1) shows a sudden deepening of the depositional surface to the west of the Ameznez faults, probably associated with a marked fall of global sea lefel. The totally calcareous late Tithonian-Berriasian sedimentation is then replaced by mainly terrigenous sedimentation. This relative sinking phase of the Western

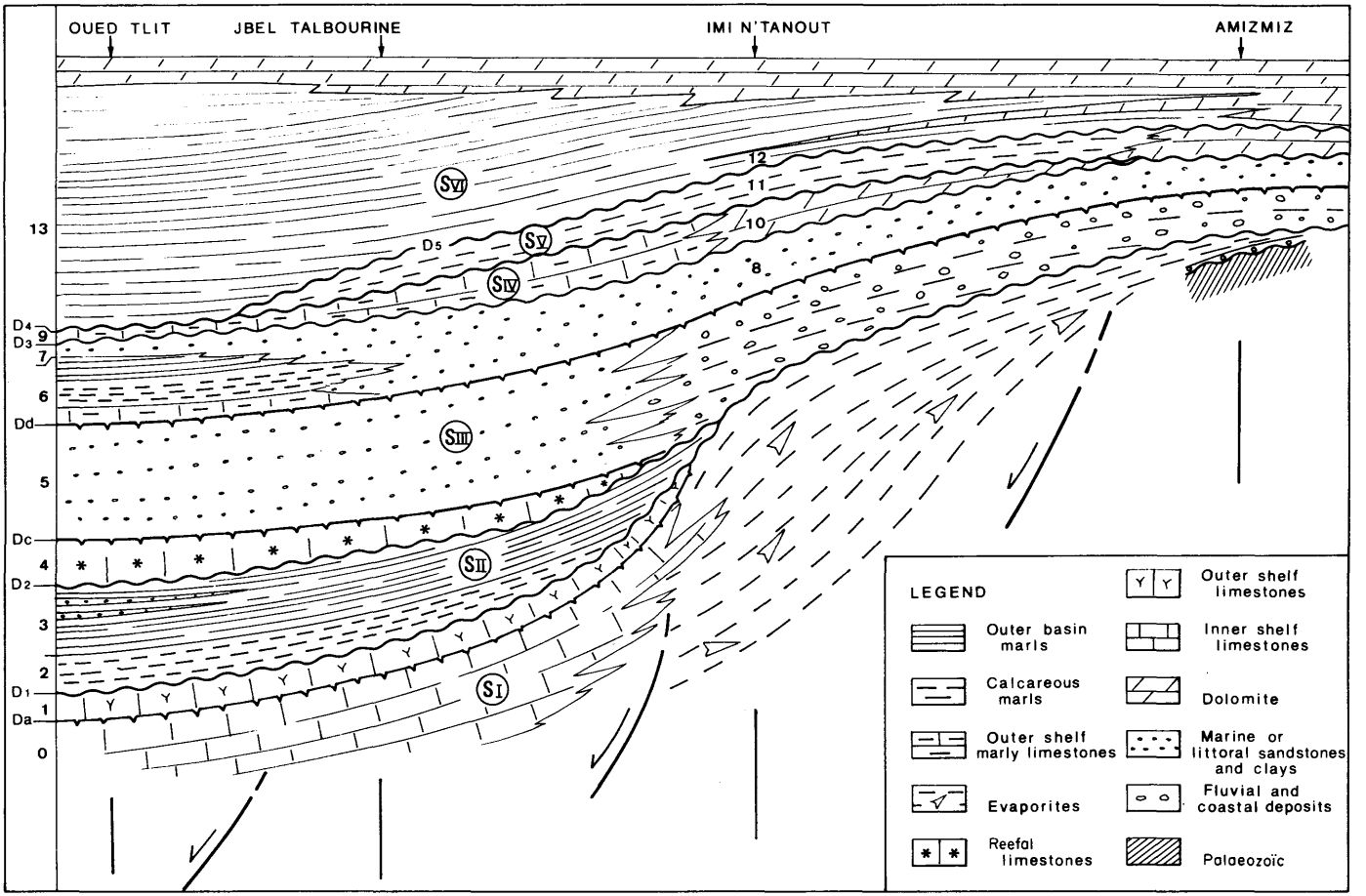

Figure 4. The geometrical relationships between the sedimentary bodies in the Lower Cretaceous of the Western High Atlas. The arabic numerals designate the formations (see legend of the Figure 3). For the description of the depositional sequences (SI and SVI) and discontinuities (D1 to D5; Da to Dd), see text.

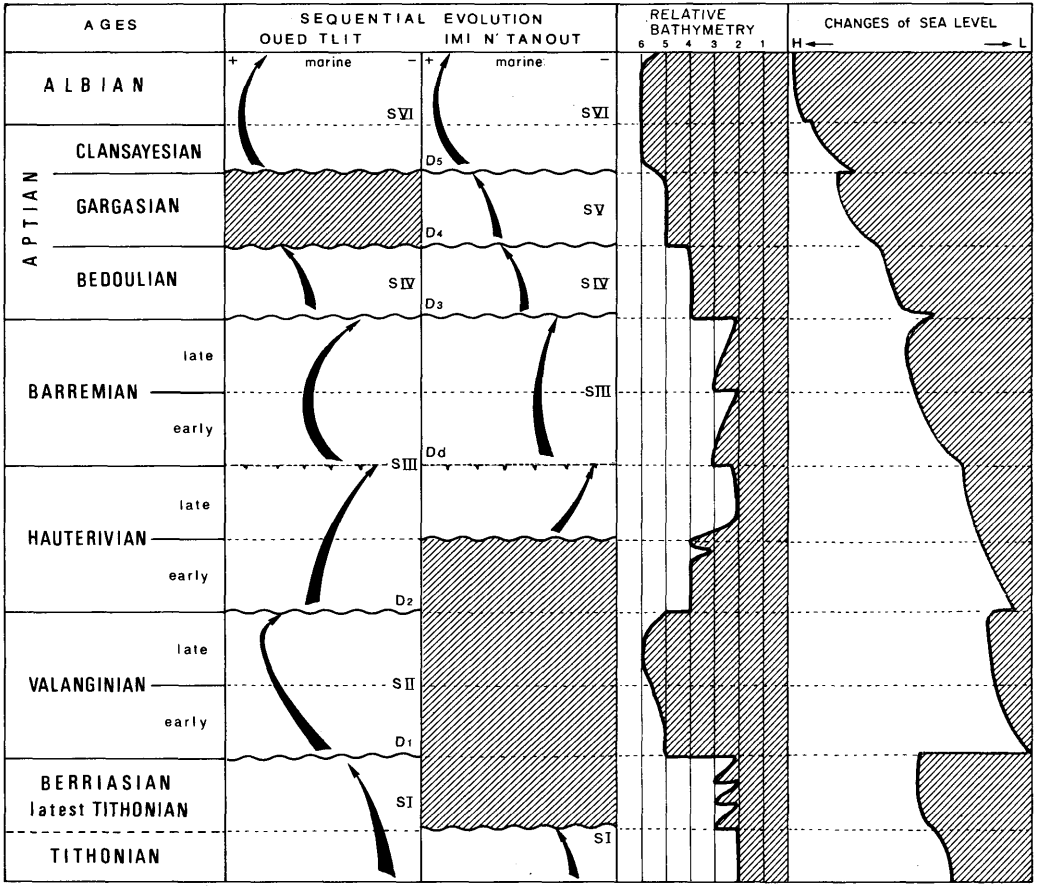

Figure 5. Sequential evolution, bathymetry and sea-level changes in the Lower Cretaceous of the Western High Atlas. The bathymetry refers to the Jbel Talbourine series; 1, fluvial deposits; 2, margino-littoral deposits; 3, infra-littoral deposits from inner shelf or open platform; 4, shoal or middle-platform deposits; 5, outer shelf deposits; 6, basin deposits.

High Atlasic area could have been preceded, or accompanied, by positive vertical movements in the diapiric zone of Oued Tidzi (Jbel Mradma section) similar to those known on the passive margin of Portuguese Estremadura (Rey, 1972).

The Valanginian sequence (SII) shows the increase of sea level in an external basin, to the west of Igourdane and the Ameznez faults. The superposition of the Agroud Ouadar and Sidi Lhousseine Formations, with a diachronous boundary shows a generally slow, but occasionally sudden, increase in bathymetry (the local discontinuity D*b* at the boundary between Lower and Upper Valanginian on the margins of the Oued Tidzi diapir-fold).

The Valanginian-Hauterivian boundary discontinuity (D2) shows a relative and sudden sea-level fall with the superposition of reefal platform limestones on Valanginian basinal marls in the central and western parts of the area.

The Hauterivian-Barremian sequence (SIII) is composed of two mesosequences; the first one, the Hauterivian mesosequence, tending to be regressive (reefal Tamanar Formation-lagoonal or fluviatile Talmest Formation). It coincides with a coastal on-lap towards the back of the Atlastic Gulf. We can therefore suppose that it was generated by a sea-level rise that caused an important terrigenous influx. The second, Barremian mesosequence, is cyclic (outer platform Taboulouart Formation-lagoonal or coastal Bouzergoun and Tazought Formations) and marks a new sea level rise with gradually increasing terrigenous deposition. The D*c* discontinuity at the top of the Tamanar Formation marks the sudden arrival of detrital sediments, with gullying, when lagoonal waters invaded the Imi N'Tanout and Amizmiz area. The D*d* discontinuity separating the two mesosequences corresponds to a sudden increase in the water column.

The Lower Bedoulian discontinuity (D3) marks a rapid sea level rise, with the creation of an outer shell carbonate environment all over the region of Essaouira and the Zem-Zem Mountains and the creation of a marine environment to the east of the Ameznez faults, in the Imi N'Tanout area.

The Bedoulian sequence (SIV) is mainly calcareous to the west (Tamzergout Formation) and dolomitic to the east (Aït Bellouchene Formation), and represents a transgressive succession onto an open shelf with sediments becoming more characteristic of deeper water environments (Oued Tlit and Jbel Talbourine sections) or progressively more marine (Imi N'Tanout section). This depositional sequence does not reach the Amizmiz area, to the east.

The Bedoulian-Gargasian boundary discontinuity (D4) is marked by a hard-ground that has a ferruginous crust. It heralds a new increase in water depth, accompanied by an on-lap of the overlying Gargasian sediments towards the back of the Atlasic Gulf.

The Gargasian sequence (SV) is exclusively found in the central and eastern parts of the area, from the Zem-Zem Mountains to Amizmiz. It is represented by outer platform marls and calcareous-dolomitic deposits that are organized in several klupfelian sequences. The general tendency is to deepening. The Gargasian was a period of sedimentary hiatus in the Essaouira region (Jbel Mradma and Oued Tlit sections).

The Gargasian-Clansayesian boundary discontinuity (D5) indicates a sudden termination of sedimentation, being characterised by a hard-ground (Jbel Talbourine, Amizmiz) or by a condensed horizon (Imi N'Tanout), both of which signal a new increase in water depth.

The Clansayesian-Albian sequence (SVI) is cyclic. It begins with a general inundation of the outer basin environments, up to the Amizmiz meridian (Lemgo Formation and base of the Oued Tidzi Formation). Then, the progressive in-filling of this basin by circa-littoral marls deposited, in euxinic conditions (Oued Tidzi Formation) induces a progressive stillstand or shallowing and the (probably) diachronous deposition of dolomites of Vraconian age.

4. Sedimentary dynamics

The megasequential organization and the geometry of the formations allows an understanding of the sedimentary dynamics of the northern border of the Atlasic Gulf during the Early Cretaceous (Figs 4 and 5). Four phases are identified.

4.1. The distensive phase of the final Berriasian

During the Tithonian and Berriasian, the topography inherited from the Jurassic appears to have been relatively uniform. The progressive increase in water depth caused a gradual expansion of the carbonate platform and a marine transgression onto the Hercynian basement of the High Atlas (disconformity of the Amizmiz Formation). A major change occurred at the boundary between the Berriasian and Valanginian Stages. This marks:

—the topographic differentiation of the margin, together with the creation of a deep marine basin to the west, open towards the Atlantic, and an exposed area to the east;

—the replacement of the essentially carbonate-rich and evaporitic sedimentation of the latest Jurassic-Berriasian by the dominantly terrigenous deposition of the Valanginian-Barremian interval.

—a global fall of sea level.

This distensive phase is reflected in the stratigraphic sections of the Lower Cretaceous by the major discontinuity D1.

4.2. The basin-infilling and increased sea levels of the Neocomian-Bedoulian

From the Valanginian to the Bedoulian, the northern border of the Atlasic Gulf shows a remarkable stability. The sedimentary evolution is essentially punctuated by successive changes of sea level which controlled, together with variations in the sediment supply, the depositional pattern forming a series of megasequences of variable orientation:

—progressive rise of sea level during the Valanginian, in a sedimentary basin to the west of Igourdane. The increase of terrigenous sediments during the late Valanginian marks a regressive tendency towards the end of the sequence. The local discontinuity observed in Jbel Mradma, at the limit of

Lower and Upper Valanginian can be interpreted as an indication of a sudden bathymetric change on the site of the future Oued Tidzi diapir;

—sudden fall of sea level (D2 discontinuity) and the deposition of argillaceous sediments of early Hauterivian age, enabling the development of small platform reefs between Ichemrarn and today's Atlantic coast;

—renewed increase in sea level during the late Hauterivian and Barremian, with a rapid extension of lagoonal and coastal environments in the eastern part of the studied area (the regions of Imi N'Tanout, then Amizmiz). This coastal on-lap, underlain by the D*c* discontinuity, is associated with terrigenous influx which affected the whole basin, and created a regressive mesosequence of late Hauterivian age. Following a renewed increase in sea level at the Hauterivian and Barremian boundary (D*d* sequential discontinuity) the Barremian succession is characterised by a period of cyclical sedimentation. This basin infilling tended to level the sedimentary topography. The border of the Atlasic Gulf then constituted a platform with a slight slope towards the west, thereby allowing a more pronounced oceanic influence;

—relative sea level rise, sudden (D3 discontinuity) but less extensive during the Bedoulian, onto a sediment-starved platform. Carbonate sedimentation became dominant once again in a sequence of general sea level rise.

4.3. The intra-Aptian tectonic phase

The tectonic activity marking the end of rifting and the opening of the north of the Atlantic Ocean would only have had a slight influence on this basin. We relate this to the sedimentary hiatus of Gargasian age in the Smimou and Essaouira areas, near the ocean, and link the D4 discontinuity to it.

4.4. The sea-level rise and topographic levelling phase of the Gargasian-Albian interval

During the Gargasian to Albian interval, the relative level of the sea rose intermittently (D5 discontinuity) before stabilizing during Albian. As a result, marine conditions are found on the eastern border of the Atlasic Gulf, having previously been under lagoonal conditions (regions of Imi N'Tanout and Amizmiz). By the end of Albian times, sedimentary filling had created a very uniform topography favouring the general extension of Vraconian dolomites.

5. Palaeostructures

The sedimentary evolution of the area is a record of the important roles played by two palaeostructures during the Early Cretaceous:

The paleostructure of the Oued Tidzi, on the site of today's Oued Tidzi diapir fold, has restricted sedimentation and the Lower Cretaceous succession is thinner. This is particularly evident during the late Tithonian Berriasian, Hauterivian, early Barremian and Bedoulian, which are all devoid of terrigenous deposits. These features can be explained by an outer bevel on the upper part of a tilted block.

The palaeostructure of the Ameznez faults (oriented N 130° to N 170° E) between Ichemrarn and Imi N'Tanout, has caused a major stratigraphic boundary during the late Tithonian, Berriasian, Valanginian and early

Hauterivian. Even after the Hauterivian transgression this structure still created lateral facies variations in deposits of late Hauterivian, Bedoulian and Clansayesian ages.

6. Conclusions

The sedimentary history of the northern border of the Atlasic Gulf during the Early Cretaceous displays some of the major characteristics of the evolution of the Atlantic passive margin. These have been previously described in Portugal (Rey, 1986a), on the Moroccan margin (Lancelot & Winterer, 1980) and on the Canadian margin (Jansa & Wade, 1975). As Wurster and Stets (1982) have already noted, the same features can be identified over a wide geographical area.

We would draw attention to the distensive phase of the end of Berriasian and, to a lesser extent, the intra-Aptian tectonic phase separating three periods of stability of the sedimentary basin that are punctuated by progressive or sudden changes of water depth, from latest Jurassic to Berriasian, from Valanginian to Bedoulian and from Gargasian to Albian. These relative variations of sea level can be compared to those described by Vail *et al.* (1977). Notably the sudden fall of sea level in the earliest Valanginian, the progressive rise during the Valanginian, the slight fall at the Valanginian-Hauterivian boundary, the continual rise during the Hauterivian and Barremian, and a more rapid rise during Gargasian, Clansayesian and Albian times. This parallelism of the bathymetric changes here recognized and dated by a rich ammonite fauna causes us to suggest a eustatic control of the sedimentary history of the area.

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