Storm deposits: evidence of event sedimentation in the Bajocian of the Central High Atlas, Morocco

Abdellah AIT ADDI

Cadi Ayyad University, Faculty of Sciences and Techniques, Earth Sciences Department,
P.O. Box: 549, Guéliz-Marrakech, Morocco; e-mail: aitaddi@fstg-marrakech.ac.ma

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ABSTRACT: Storm beds interbedded with marls, claystones and beds of nodular to undulose bioclastic limestones have been recognized in the Central High Atlas of Morocco. These provide the first evidence of event sedimentation in the Bajocian of the area. The outcrops studied are included in the Agoudim and Tazigzaout formations in the center of the basin, and are parts of the Bin El Ouidane Group at the margins of the basin. The storm deposits comprise calcarenites and bioclastic packstones-grainstones. These beds have symmetrical wave-ripples at their tops and an internal structure of hummocky cross-stratification. They are considered to have been formed by tropical storms and hurricanes. Multiple reworking and winnowing of siliciclastic or bioclastic material by oscillatory currents related to storm and to currents resulting from storm/tide interactions is inferred. Bed features are the most important evidence in favour of a palaeobathymetric interpretation of related pelagic sediments, with calcareous tempestites representing episodic resedimentation, mainly coincident with relative sea-level falls during which major storm waves affected the sea bottom. This interpretation is in agreement with the regional palaeogeography and is further supported by evidence of Jurassic storm-controlled sedimentation in adjacent Mediterranean basins.

INTRODUCTION

In spite of numerous geological studies (Michard 1976; Du Dresnay 1979, 1987; Laville 1985; Warme *et al.* 1988; Sadki 1996; and others) on the Moroccan Central High Atlas (Figs 1, 2), the presence of event deposits in this trough was not recognized until Ait Addi's (2002) work on the Middle Jurassic of the Central High Atlas of Morocco.

The present paper gives details of all beds that reflect event sedimentation (most likely storm deposits) in the hemipelagic and shallow carbonate deposits, dated as Bajocian (Choubert and Faure-Muret 1962; Du Dresnay 1979; Warme *et al.* 1988; Sadki 1996; Ait Addi 2002) of the Central High Atlas of Morocco (Figs 1, 2). The sections studied are located along N-S and E-W transects on the southern flank of the High Atlas north of Errachidia (Fig. 1: B). Evidence of event sedimentation is provided by bioclastic packstones/grainstones forming beds of nodular to undulose, thin-bedded limestone, and by thin-bedded (a few cm) calcarenites, especially in the lower members of the Agoudim and Tazigzaout formations of the basin center, and in thin-bedded and undulose limestones of the southern platform. The main purposes of this study are to: (1) describe the prominent event beds; (2) provide evidence for their deposition by storm wave processes; and (3) discuss their significance in reconstructing the Central High Atlas basin during Middle Jurassic times.

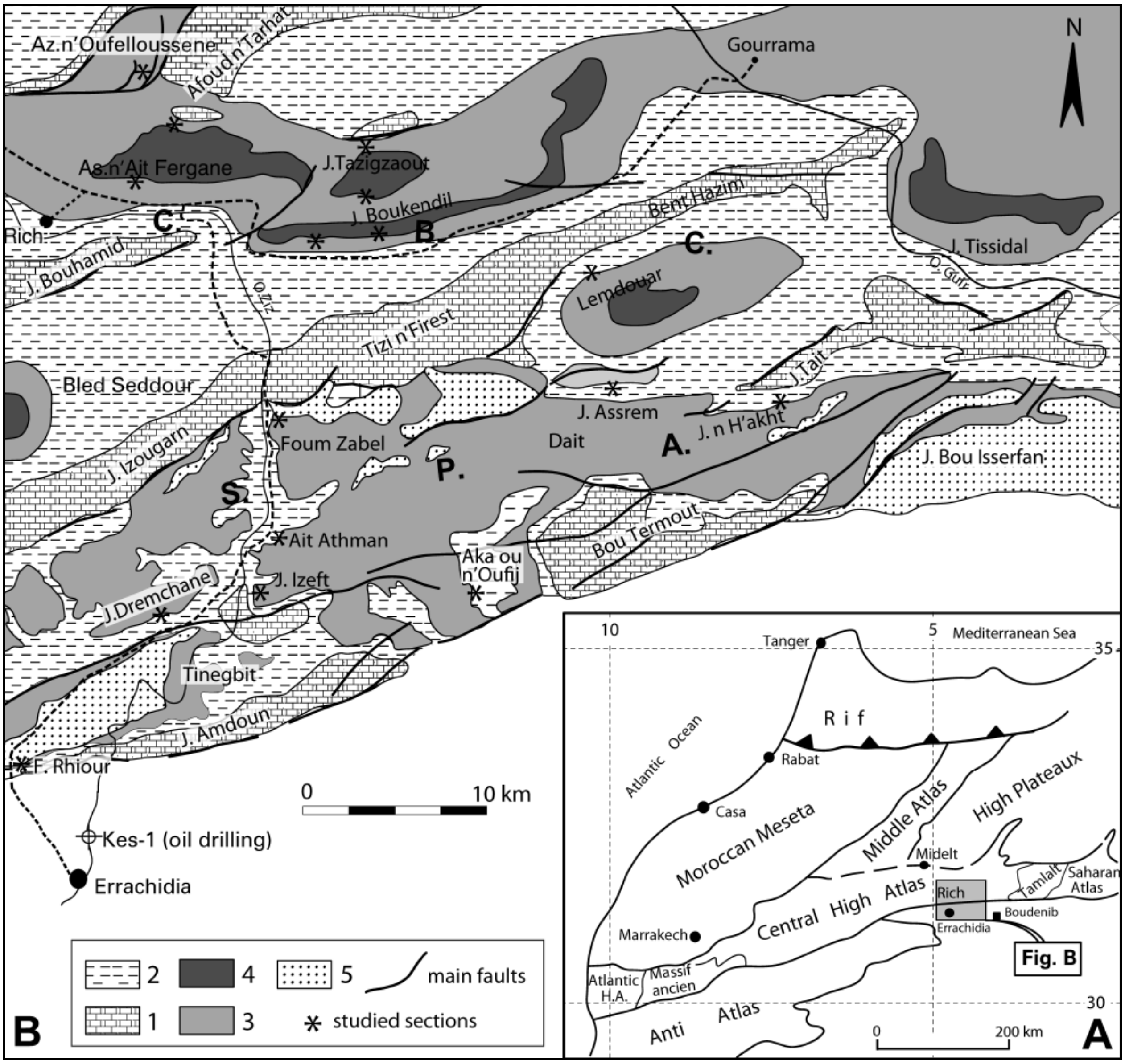

Fig. 1. A – Structural provinces of northern Morocco; B – simplified geological map of the area north of Errachidia, Central and Eastern High Atlas Trough (modified after Choubert *et al.* 1956); 1 – Lower and Middle Lias (limestone and marly limestone with ammonites; reefal limestone and dolostone); 2 – Toarcian-Aalenian (ammonite-bearing marl and marly limestone); 3-4 – Bajocian-Lower Bathonian (N basin: marls with *Posidonomyes*, thin-bedded limestones with *Zoophycos* and patch reefs; S platform: dolostone and bioclastic limestone and locally reefal carbonates); 5 – Bathonian (marl and limestone with brachiopods (rhynchonelles), red beds and conglomerates); C. B. C. – Central basin complex; S. P. A. – Southern platform area.

GEOLOGICAL SETTING

In the Moroccan Central High Atlas Mountains, along the geotraverse Midelt-Errachidia (Fig. 1), thick sequences of Jurassic rocks, several hundreds of meters thick, are exposed. These marine carbonates were deposited in the short-lived Atlasic Basin over continental Triassic and Liassic rocks. Continuous sedimentation terminated when subsidence ceased and erosion began. In some places Middle Jurassic rocks are capped by Lower Cretaceous continental red beds. Middle Jurassic carbonates belong to the Agoudim (Studer 1980) and Tazigzaout formations in the basin center (Ait Addi 1994) and to the adjacent, age-equivalent “formations 1 and 2” of the Bin El Ouidane Group (Monbaron 1981) in the southern platform area (Ait Addi 2002, 2005; Fig. 2). In the basin center the Agoudim (Toarcian-Bajocian) and Tazigzaout (Upper Bajocian-Bathonian) formations show the same type of facies evolution. Each is represented by hemipelagic marls and marly limestone overlain by lagoonal or peritidal limestones and patch reefs. Along the southern margin of the basin center, this succession passes into bedded carbonates with packstone, grainstone, boundstone and dolostone textures. During the Aalenian-Early Bajocian the southern rimmed shelf contained some coral buildups prograding basinwards towards the north (Crevello 1988; Ait Addi 1998, 2000, 2005, 2006).

EVENT DEPOSITS: FACIES DESCRIPTION AND INTERPRETATION

In this paper, only the event deposits of Bajocian age are described and interpreted. Not considered are the lenticular oobioclastic, allodapic limestones of the Aalenian-Early Bajocian (Agoudim's Member II), whose deposition was controlled by tsunamis, tectonic events and gravitational processes enhanced by eustatism (Ait Addi 1998). Four major facies associations are described and interpreted in terms of their sedimentology, palaeontology, and palaeoenvironmental significance.

Thin-bedded rippled sandstone

Description: This facies is developed only at one level within the third member (Lower Bajocian, Fig. 2; Ait Addi 2002) of the Agoudim Formation in the Assameur/Boukendil and Lemdouar synclines (Figs 1: B; 4). In these areas, it corresponds to an interval (~2 m thick) of thin-bedded calcareous sandstone (a few centimeters to 20 cm thick), sporadically interbedded with shaly marls and claystones or thin-bedded nodular to undulose bioclastic limestone (Fig. 3: A). Bed bases are sharp and planar. Most of the beds show

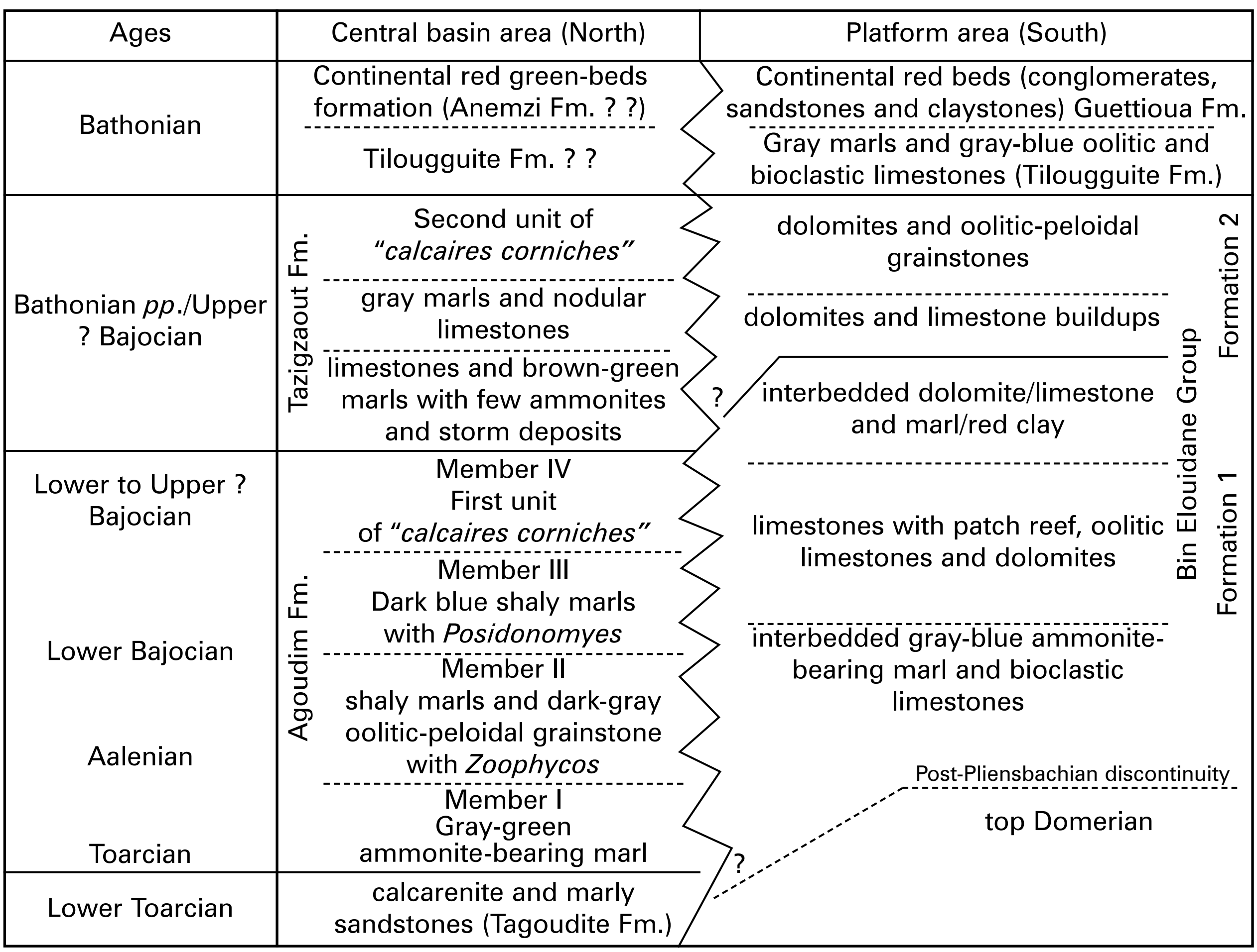

Fig. 2. Lithostratigraphic framework of Jurassic rocks (Upper Lias-Bathonian), N of Errachidia, High Atlas (Ait Addi 2002).

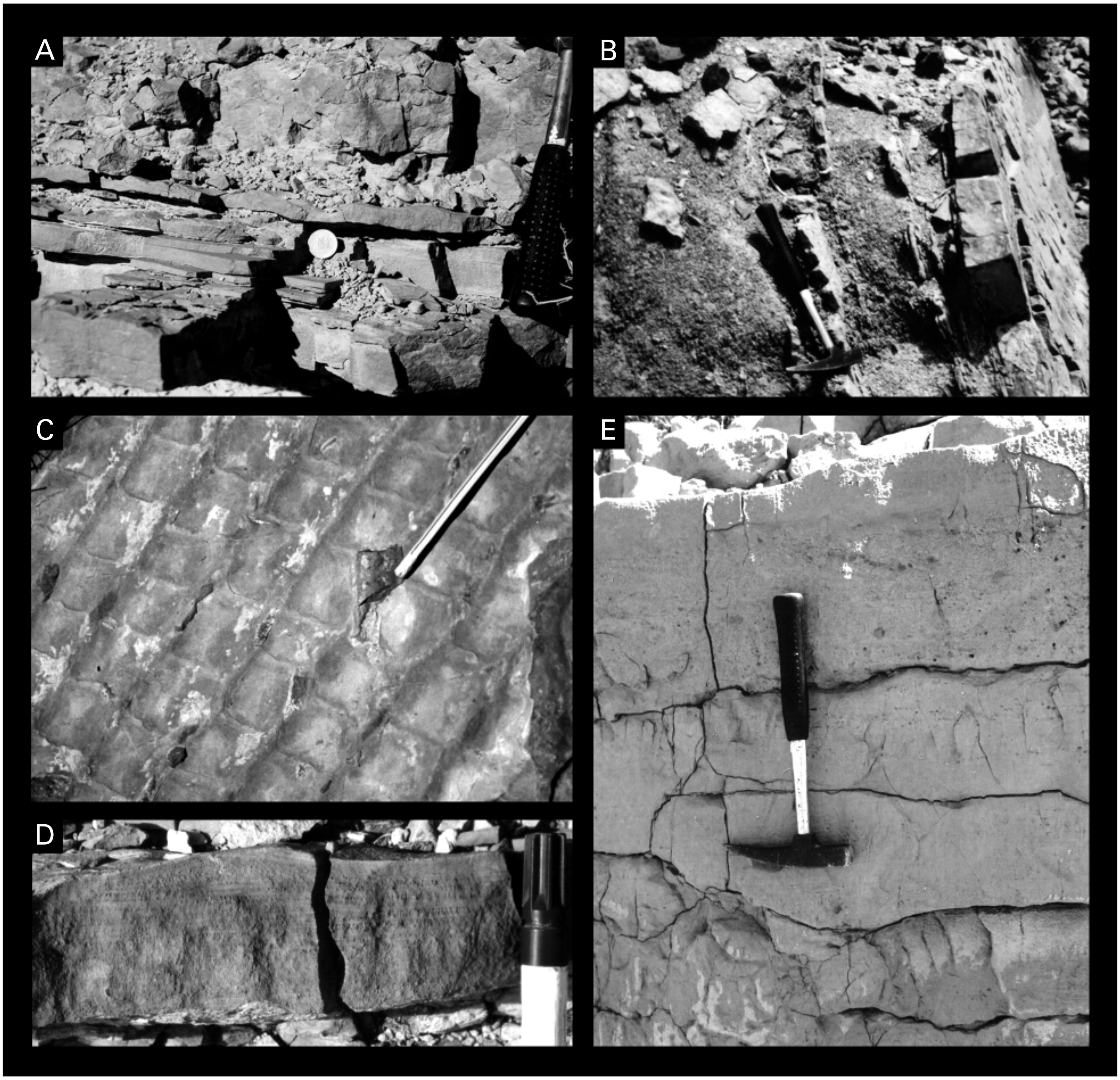

Fig. 3. A – Sandstone interbedded with marl and bioclastic limestone (Agoudim Member III, Lower Bajocian, Assameur syncline). Note wave ripples at the top of beds; B – Yellow-green marls with thin-bedded biocalcarenites (Lower member of Tazigzaout Fm., Upper Bajocian-Bathonian *pp.*, Tazigzaout syncline); C – Wave ripples at top of beds of sandstone facies (Member III of Agoudim Fm., Lower Bajocian, Boukendil syncline); D – Thin-bedded biocalcarenite from the lower member of the Tazigzaout Fm. Tazigzaout syncline. Note the fining-upwards trend and the horizontal lamination of the lower part which grades upwards into HCS and symmetrical wave ripples; E – Lithoclasts in graded bed with undulating stratification (? proximal storm deposit); J. Dremchane, southern platform.

graded bedding. Within the lower parts, lamination is horizontal or sometimes low-angled and similar to very flat hummocky cross-stratification (HCS; Harms *et al.* 1975; Dott 1983; Duke 1985). This interval may be overlain by a cross-stratified interval with symmetrical ripples, commonly linguoid ripples or HCS (Fig. 3: C). Microscope analysis shows that this facies is formed essentially by quartz (>50 %), peloids, some very small bioclasts, glauconite, and some wood debris. The matrix is carbonate mud and is less than 5 %.

Interpretation: Based on their stratigraphic position in a hemipelagic succession and on their lithology (sandstone) and internal structure, the thin-bedded and rippled sandstone levels are interpreted as the first manifestation of storm waves and oscillatory currents. These beds resulted from the transport and deposition of sand

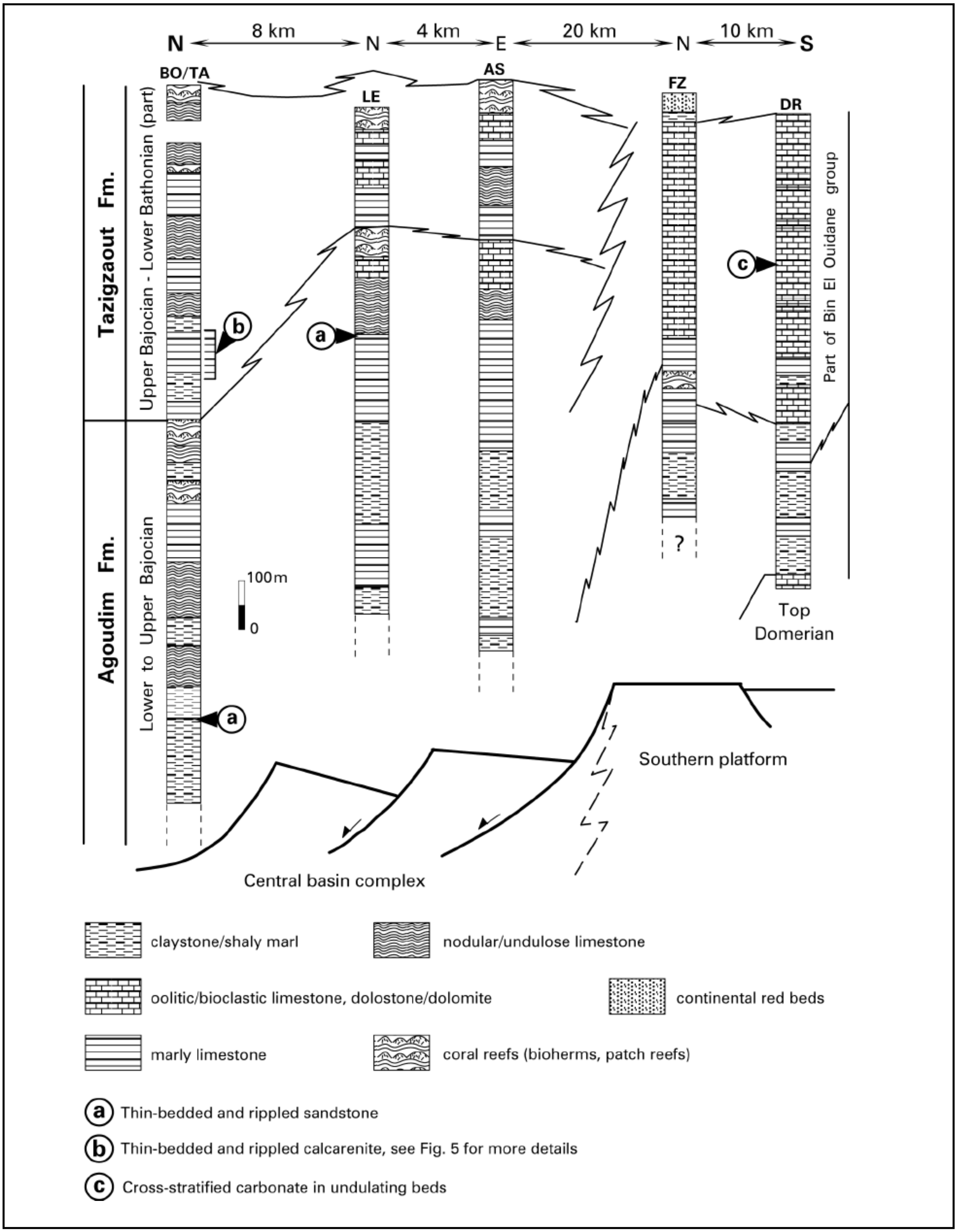

Fig. 4. N-S correlation of Middle Jurassic sections showing positions of main levels of event sedimentation (a, b, c), area north of Errachidia; Moroccan High Atlas. See Fig. 1: B for localities; DR – Dremchane; FZ – Foum Zabel; AS – J. Assrem; LE – J. Lemdouar; BO/TA – Boukendil/-/Tazigzaout.

by wave-induced currents and reflect relatively high-energy sedimentation. Individual sandstone beds were probably deposited rapidly (Dott 1983). One type of storm/fair weather sequence displays: (1) a flat basal erosion surface, (2) a hummocky cross-stratified interval (main storm deposition), and (3) wave-rippled sand layers corresponding to the progressive decrease in flow during the storm event and indicating a return to oscillatory currents of the lower flow regime (waning storm deposition).

Thin-bedded and rippled calcarenite

Description: In the lower member (Upper Bajocian, Fig. 2; Ait Addi 2002) of the Tazigzaout Formation (Tazigzaout syncline) (Figs 1: B; 4), thin beds (a few centimeters to 20 cm thick) of calcarenite are present in marls and shaly marls (4 to 20 m thick) and are intercalated between bioclastic limestones forming lenticular beds (0-25 m thick) (Fig. 5; Fig. 3: B). The clasts consist of quartz and sparser bioclasts and micritic peloids in an abundant micritic matrix. One bed contains locally nodules and concretions of chert. The bases of beds are highly irregular and scoured with palaeoflow features such as furrows, striations, grooves and flute casts. The calcarenites have horizontally laminated to low-angle cross-stratified lower parts and symmetrical to slightly asymmetrical wave-rippled and undulose upper parts with HCS or linguoid ripples (Fig. 3: D). These layers display the following: (1) an erosive base, (2) lags and mud clasts, (3) parallel to low-angle lamination with minor internal discordances (HCS), (4) wave ripples and HCS, and (5) mud layers (Fig. 3: D). The ripples have a wavelength of up to 8 cm and an amplitude of up to 3 cm. Occasionally, the calcarenite beds are associated with thin-bedded, bioturbated, bioclastic limestone (6.5 cm thick) intercalated between the marls and claystones. The basal part is thick (5.5 cm), mainly bioclastic and displays packstone and grainstone textures, reflecting shelly pebbly basal lags that probably indicate peak storm flow. The tops of the beds are overlain by highly bioturbated mud layers or mud blankets, generally less than 10 mm thick. Bioturbation consists especially of horizontal feeding traces and can be ascribed to the branching *Chondrites* (Seilacher 1967) that characterizes moderate to low energy conditions on offshore shelves.

Interpretation: The sedimentary structures of the thin-bedded and rippled calcarenites indicate that they were deposited from storm-enhanced currents in the hemipelagic basin. They reflect episodic, short-lived, high energy conditions which alternate with longer periods of lower energy conditions (marl intervals). All beds display general features of wave-ripple cross-lamination interpreted below as HCS structures (Fig. 3: D). These structures are formed primarily in response to high-energy currents with a strong oscillatory component and orbital velocities greater than 0.5 m/s (Harms *et al.* 1982; Johnson and Baldwin 1986). The HCS structures characterize storm wave base level. Consequently, the calcarenite beds correspond to proximal to distal storm sand deposited especially above storm-wave base-level. In contrast, the thin-bedded bioturbated bioclastic limestones provide evidence of storm deposition through the concentration of reworked skeletal and non-skeletal material and by the highly bioturbated, muddy storm layers ("mud tempestites" of Aigner and Reineck 1982). The depositional environment of these facies is above maximum storm-wave base, based on feeding traces of deposit-feeders (*Chondrites* isp.) and abundant HCS. The storm layers reflect two phases: storm peak is represented by a basal layer of shell debris during a period of increased wave turbulence, whereas the sediment of the overlying waning phase exhibits features characteristic of muddy tempestites deposited during a post-storm, fair-weather phase.

Dark-grey limestone in nodular to undulose beds

Description: This facies characterizes Agoudim Member III in the Assameur/Boukendil synclines and the middle to upper members of the Tazigzaout Formation (Figs 1: B; 2). Beds are cm-thick and show nodular to undulose bedding, and are organized in packages with varying thickness (2-8 and rarely 25 m). Usually, these facies show mudstone and wacke-packstone textures, locally with abundant reworked skeletal debris mainly of corals, mollusks, brachiopods, serpulids and bryozoans. The upper surfaces of beds are highly bioturbated and show traces preserved in iron oxide. Beds of calcarenite a few cm in thickness with quartz grains and peloids are sporadically intercalated in this facies as well as in the adjacent marl and claystone intervals.

Interpretation: The dark colour of the facies results from deposition in a low energy environment with poorly oxygenated water. Bedding is defined by thin marl or claystone seams with

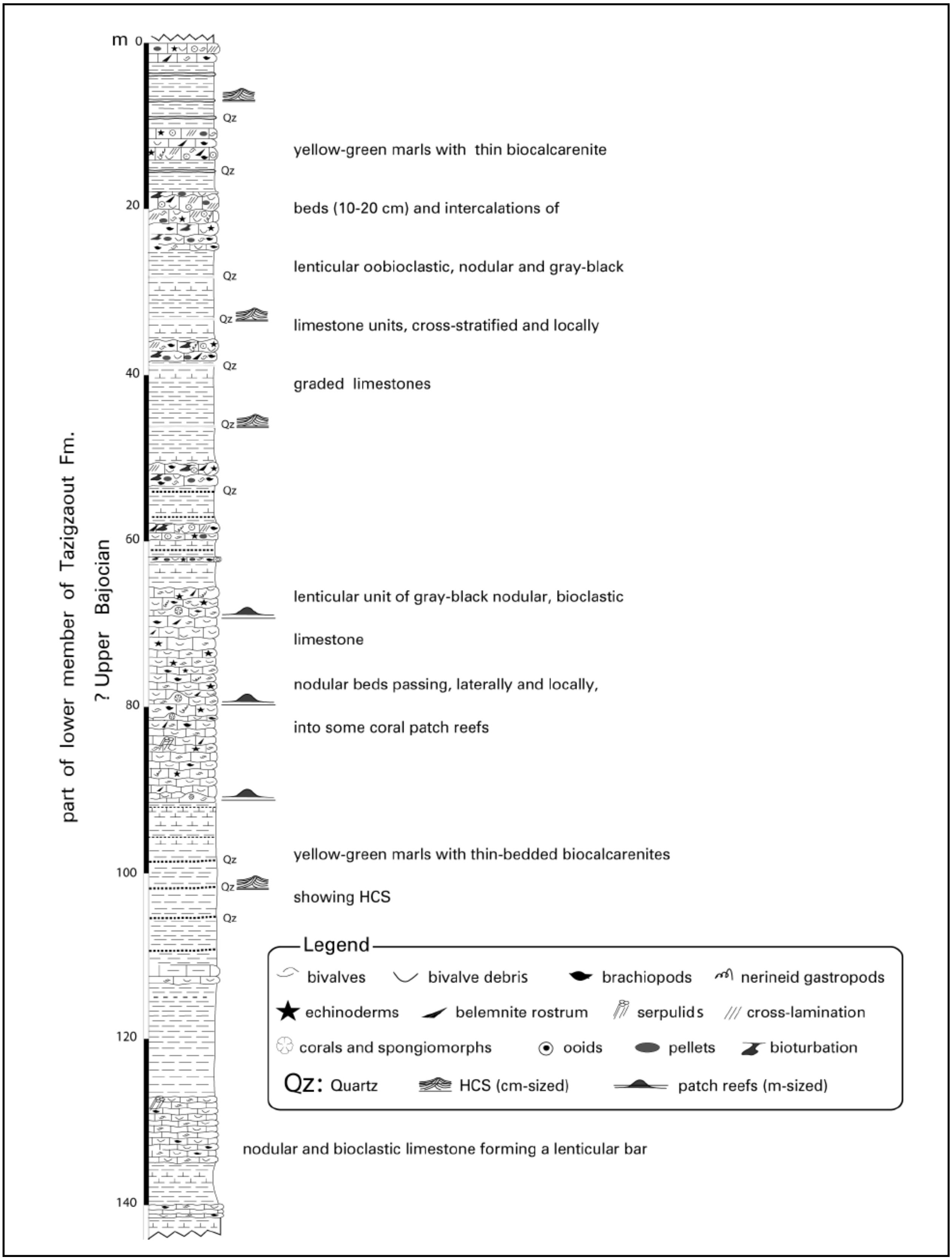

Fig. 5. Lithos-log of the lower member of the Tazigzaout Fm. (Upper Bajocian). Northern flank of Tazigzaout syncline.

distinct undulations that were originally interpreted as having formed by compaction and pressure solution (Ait Addi 1994). More recently, a major part of the undulations was reinterpreted as the result of oscillatory currents produced by major storms (Ait Addi 2002). Reworked skeletal debris was probably deposited under moderate energy conditions and may have been derived from the adjacent shallow water platform. The undulose bed geometry suggests an oscillatory flow for the origin of these deposits, while the calcarenite layers reflect relatively high energy currents. Bioturbated bed tops indicate periods of quiet water background conditions.

Thin-bedded and cross-stratified carbonate with lithoclats in undulated beds

Description: This facies is observed in the southern platform area (*e.g.* J. Dremchane, J. Izeft; Fig. 1: B) where it forms important cliffs (higher than 10 m; Fig. 4). The cliffs are separated by bioclastic, oncolitic and shaly limestone intervals (~1 m thick) or by tidal flat sequences with gray-green/brown marls. Typically these facies display medium- to large-scale cross-bedding, high textural and mineralogical maturity and considerable lateral extent. Texturally, these cross-stratified carbonates are limestone/dolostone and correspond to pack/grainstone, rarely wackestone, containing ooids, pellets, lithoclasts and common bioclasts. At Ait Athman/Izeft and Dremchane localities, amalgamation of beds by erosional processes is common. The deposits show clearly the presence of wave-formed sedimentary structures or shallow marine faunas intercalated in shale layers. The cross-beds formed at low-angles, and their upper surfaces are undulose (Fig. 3: E). Locally the upper surfaces of such beds are gently corrugated or wave rippled (symmetrical and asymmetrical). The asymmetrical ripples show a SE to NE current direction. Medium-sized clasts are more abundant in the basal parts of such beds, causing normal grading (Fig. 3: E). Some beds are highly bioturbated by *Thalassinoides*.

Interpretation: It remains uncertain whether the undulatory lamination in shallow marine environments is purely wave-formed or the result of combined unidirectional/oscillatory flow (Harms *et al.* 1975). However, the recognition of tidal flat sequences overlying the cross-stratified carbonate units indicates a tide/storm interactive system. In Bajocian times, the southern carbonate platform have produced large carbonate sand bodies that were influenced by tides and storms. Laterally, the carbonate bodies locally had erosional bases. During intense storms rates of sediment transport attained a maximum as currents appeared enhanced by storm surge and/or wind-driven currents (Johnson and Baldwin 1986 *in*: Reading 1986, p. 273). In proximal zones erosion produced shallow channels, planar erosion surfaces and winnowed pebble lags.

CONTROLLING FACTORS

The formation of storm deposits such as those discussed in this paper requires corresponding climatic and palaeogeographic conditions. Valdes and Sellwood (1992) proposed an intense winter storm belt on the southern side of the Tethys during the Late Jurassic. Similarly, the position of the area investigated (Central High Atlas of Morocco) in the SW part of the large Tethys Ocean seems to have made it subject to both strong tropical hurricanes and winter storms. Thin-bedded and cross-stratified carbonates with lithoclasts in undulose bedding formed in shoreface domains are characterized by interactions between tides and average storms. Storm-induced offshore flows may have transported very fine sand towards the basin center (localities of Lemdour, Assameur/Boukendil, Tazigzaout), where it contributed to the deposition of more distal, fine-grained HCS storm beds (sandstone and calcarenite deposits). A comparable model was proposed by Aigner and Reineck (1982) for modern shelf storm deposits of the German Bight (SE North Sea). Whether sediment is introduced by river floods or wave erosion, sand can be dispersed by a variety of mechanisms. Seaward return of storm surges, storm rip-currents, tsunamis, wind drift currents, and density currents have all been suggested (Coleman 1968; Dott and Bourgeois 1982; and others). The greatest preservation potential of storm deposits seems to be in the few to several tens of meters between fair-weather wave base and storm wave base. In the Central High Atlas, it seems that the storm and hurricane generation threshold was reached, at least episodically, during relatively short periods of the Middle Jurassic. The results of this study may used to improve and supplement palaeogeographic reconstructions of storm depositional systems and palaeoclimate models of the western Tethyan margin.

CONCLUSIONS

Storm deposits have been documented and interpreted for the first time from the Middle Jurassic of the Central High Atlas of Morocco. Sedimentary features of these event deposits were analyzed and yielded the following results: Thin-bedded, rippled sandstone intercalations are interpreted as event beds deposited by flows related to storms. They are interpreted as the first manifestation of storm waves and oscillatory currents in the area during Bajocian time. Calcarenite beds correspond to proximal to distal storm sands deposited in the interval of the wave-base level. Based on the preservation of branching *Chondrites* and abundant HCS, the bioclastic and burrowed limestone layers were deposited above maximum storm-wave base (offshore-transition interval). Undulations of dark-gray and nodular limestone beds were the result of oscillatory currents produced by major storms. In summary, storm units represent individual sandstone beds or calcarenitic layers that were deposited rapidly from single waning flow events, which generally possess a strong oscillatory flow component (Dott 1983). In Bajocian time the southern carbonate platform developed large carbonate bodies that were influenced by an interactive tide/storm system. This evidence of Middle Jurassic storm sedimentation on the western Tethyan margin is consistent with the records of event deposits from several other coastal Jurassic troughs bordering the Mediterranean basin.

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REFERENCES

Aigner T. and Reineck H. E. 1982. Proximality trends in modern storm sands from the Heligoland Bight (North Sea) and their implications for basin analysis. *Senckenbergiana Maritima*, **14**: 183-215.

Ait Addi A. 1994. Sédimentologie, biostratigraphie et diagenèse carbonatée des faciès du Lias supérieur-Dogger du Haut Atlas d'Errachidia (Maroc), 1-211. Thèse Doctorat de Spécialité (inédit), Université de Tunis II (Tunisie).

Ait Addi A. 1998. Nouvelles données sédimentologiques et géodynamiques sur les faciés de l'Aalénien-Bajocien inférieur du Haut Atlas marocain (Nord d'Errachidia). *Comptes Rendus de l'Académie des Sciences, Paris*, **326**: 193-200.

Ait Addi A. 2000. Les séries du Dogger moyen du Haut Atlas au Nord d'Errachidia (Maroc): Lithostratigraphie et sédimentologie d'une nouvelle formation, la formation Tazigzaout. *Géologie Méditerranéenne*, **27**, 1-2: 57-69.

Ait Addi A. 2002. Les séries du Dogger du Haut Atlas marocain (Nord d'Errachidia/Boudenib): Lithostratigraphie, sédimentologie, stratigraphie séquentielle, cyclostratigraphie et évolution géodynamique, 1-242. Thèse ès-Sciences (inédit), Université Ibn Tofail, Kénitra (Maroc).

Ait Addi A. 2005. Les affleurements du Dogger du Haut Atlas au nord d'Errachidia (Maroc): unités lithostratigraphiques et nouvelles corrélations. *18ème Colloque des Bassins Sédimentaires Marocains, Fès, 10-12 novembre 2005,* 108-109.

Ait Addi A. 2006. The Dogger reef horizons of the Moroccan Central High Atlas: new data on their development. *Journal of African Earth Sciences*, **45**: 162-172.

Choubert G., Dubar G. and Hindermeyer J. 1956. Carte gèologique du Haut Atlas au Nord d'Errachidia (Ksar es souk) feuille Boudenib et Rich au 1/200 000. *Notes et Mémoires du Service Géologique du Maroc*, **81**.

Choubert G. and Faure-Muret A. 1962. Evolution du domaine atlasique marocain depuis les temps paléozoïques. *Livre à la mémoire du Professeur P. Fallot, Mémoire de la Société Géologique de France*, **1**: 447-527.

Coleman P. J. 1968. Tsunamis as geological agents. *Geological Society of Australia Journal*, **15**: 267-273.

Crevello P. D. 1988. Aalenian-Bajocian-Bathonian(?) shelf-platform prograding reef margin (segment 6). *In*: J. E. Warme, P. D. Crevello, B. A. Hazlet, F. Atmane and M. Benbouziane (*Eds*), Evolution of the Jurassic High Atlas Rift, Morocco: Transtention, structural and eustatic controls on carbonate facies, tectonic inversion, 15/1-15/5. *American Association of Petroleum Geologists (AAPG) Mediterranean Basins Conference, Field trip 9, Nice 1988.*

Dott R. H. J. 1983. Episodic sedimentation-how normal is average? How rare is rare? Does it matter? *Journal of Sedimentary Petrology*, **53**: 5-23.

Dott R. H. J. and Bourgeois J. 1982. Hummocky stratification: significance of its variable bedding sequences. *Geological Society of America Bulletin*, **93**: 663-680.

Du Dresnay R. 1979. Sédiments jurassiques du domaine des chaînes atlasiques du Maroc. *Symposium sur la "Sédimentation jurassique W-européen" Paris 1977. Publication Spéciale de l'Association des Sédimentologistes Français*, **1**: 345-355.

Du Dresnay R. 1987. Jurassic development of the region of the Atlas Mountains of Morocco: Chronology, sedimentation and structural signification. *Geological Society of Libya, Tripoli, Eighteenth Field conference, 1977*, **4**: 77-99.

Duke W. L. 1985. Hummocky cross-stratification, tropical hurricanes, and intense winter storms. *Sedimentology*, **32**: 167-194.

Harms J. C., Southard J. B., Spearing D. R. and Walker R. G. 1975. Depositional environments as interpreted from primary sedimentary structures and stratification sequences. *Society for Sedimentary Geology (SEPM) Short Course No. 2*, 1-161.

Harms J. C., Southard J. B. and Walker R. G. 1982. Shallow marine environments a comparison of some ancient and modern examples. *Society for Sedimentary Geology (SEPM) Short Course No. 9, Chapter 8*, 1-51.

Johnson H. D. and Baldwin C. T. 1986. Shallow siliciclastic seas. *In*: H. G. Reading (*Ed.*), Sedimentary environments and facies, 229-282. Blackwell Scientific Publication, Second Edition.

Laville E. 1985. Evolution sédimentaire, tectonique et magmatique du bassin jurassique du Haut Atlas (Maroc): modèle en relais de décrochements, 1-166. Thèse ès-Sciences, Montpellier, France.

Michard A. 1976. Eléments de géologie marocaine. *Notes et Mémoires du Service Géologique, Maroc*, **252**: 1-422.

Monbaron M. 1981. Sédimentation, tectonique synsédimentaire et magmatisme basique: l'évolution paléogéographique et structurale de l'Atlas de Beni-Mellal (Maroc) au cours du Mésozoïque; ses indices sur la tectonique tertiaire. *Eclogae Geologicae Helvetiae*, **74**, 3: 625-638.

Reading H. G. 1986. Sedimentary environments and facies. 1-615. Blackwell Scientific Publication, Second Edition.

Sadki D. 1996. Le Haut Atlas central (Maroc). Stratigraphie et paléontologie du Lias supérieur et du Dogger inférieur. Dynamique du bassin et des peuplements. *Documents du Laboratoire de Géologie, Lyon*, **149**: 1-245.

Seilacher A. 1967. Bathymetry of trace fossils. *Marine Geology*, **5**: 189-200.

Studer M. 1980. Tectonique et petrographie des roches sédimentaires éruptives et métamorphiques de la région de Tounfit-Tirrhist (Haut Atlas central, Maroc), 1-102. These 3eme Cycle, Université Neuchâtel.

Valdes P. and Sellwood B. W. 1992. A palaeoclimate model for the Kimmeridgian. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **95**: 47-72.

Warme J. E., Crevello P. D., Hazlet B. A., Atmane F. and Benbouziane M. 1988. Evolution of the Jurassic High Atlas Rift, Morocco: Transtention, structural and eustatic controls on carbonate facies, tectonic inversion. 1-310. *American Association of Petroleum Geologists (AAPG) Mediterranean Basins Conference, Field trip 9, Nice 1988.*