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Paleoenvironment and sequence stratigraphy of the late Miocene from the Guercif basin (Northeastern of Morocco)

Paléoenvironement et stratigraphie séquentielle du Miocène supérieur du bassin de Guercif (Nord-est du Maroc)

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Abstract. Micropaleontology and sedimentological analyses of sediments in the Guercif basin (Northeastern, Morocco) allowed biostratigraphic, paleoenvironmental and sequential reconstructions. The samples were taken from a geological section located at the southwestern part of the basin. The section can be divided in three lithological units, dated from the Tortonian to the Messinian. The transition and lithostratigraphical continuity between the late Tortonian and the Messinian are defined by the characteristics of planktonic foraminifera in the sediments horizons of (eg., *Globorotalia menardii* group, right coiling) for the upper Tortonian, (eg., *Globorotalia miotumida* group, left coiling) for the Messinian. Benthic foraminifera associations evidence an evolution of the sedimentary environments over the studied section. The Tortonian calcarenitic units were deposited in the shallow neritic (infralittoral) environment, especially marked by the species *Ammonia beccarii* accompanied by *Nonion commune* and *Textularia sagittula*. The environment gradually evolves to a deep epibathyal environment, evidenced by the presence of an association of Uvigerinids at the base of the marls-sandstones levels. The intermediate upper Tortonian unit is marked by an association of Lenticulinids and by an alteration of gypsiferous marls and sandstones suggesting rather a circalittoral environment. Finally the Messinian gypsiferous marls were first deposited in circalittoral identified by an association of Lenticulinids. The co-occurrence of *Ammonia beccarii* and *Cibicides lobatulus* rather suggest an infralittoral environment. The sequential analysis attests for the presence of a complete sedimentary cycle consisting of different staking sedimentary environments which are related to local eustatic variations.

Keywords: Biostratigraphy, Foraminifera, Sequence stratigraphy, Paleoenvironment, Late Miocene, Guercif basin, Morocco.

Résumé. Les analyses micropaléontologiques et sédimentologiques des sédiments du bassin de Guercif (Maroc-Oriental) ont permis des reconstitutions biostratigraphiques, paléoenvironnementales et séquentielles. Les échantillons ont été prélevés le long du secteur SW du bassin de Guercif. La coupe synthétique comprend trois niveaux lithologiques dont les âges s'étendent du Tortonien au Messinien. L'analyse biostratigraphique des espèces de foraminifères planctoniques a permis de préciser la limite Tortonien-Messinien d'une part et la continuité lithostratigraphique d'autre part. Cette approche a permis de déterminer les événements biostratigraphiques caractéristiques du Tortonien supérieur (e.g., groupe de *Globorotalia menardii*, enroulement dextre) et du Messinien (e.g., groupe de *Globorotalia miotumida,* enroulement senestre). L'analyse des associations de foraminifères benthiques montrent une évolution de l'environnement sédimentaire sur la coupe étudiée. Les niveaux calcarénitiques d'âge Tortonien ont été déposés dans un environnement infralittoral surtout marqué par l'espèce (*Ammonia beccarii* associée avec *Nonion commune* et *Textularia sagittula*), évoluant progressivement vers un milieu épibathyial profond représenté par le cortège des Uvigerines dans la base des niveaux marno-gréseux. Les niveaux intermédiaires du circalittoral sont eux marqués par le cortège des Lenticulines et par une alternance de marnes gypsifères et de grés d'âge Tortonien supérieur. Quant aux marnes gypsifères messéniennes, elles se sont déposées dans un milieu circalittoral identifié par l'assemblage des Lenticulines puis infralittoral marqué par (*Ammonia beccarii* and *Cibicides lobatulus*). La stratigraphie séquentielle montre la présente d'un cycle sédimentaire complet formé de différents cortèges sédimentaires liés aux variations eustatiques locales.

Mots clés: Biostratigraphie, foraminifère, stratigraphie séquentielle, paléoenvironnement, Miocène supérieur, bassin de Guercif, Maroc.

INTRODUCTION

Several Neogene ″post-nappes″ sedimentary basins are developed in the Betico-Rifian-Tellian chains following the Oligo-Miocene tectonic paroxysm. At present, these basins are located at the edge of the Alboran Sea, or within the surrounding mountains (i,e., intermountain basins). Among them, the Guercif basin is located in the northeast of Morocco between the Rifian nappes and the Middle Atlas chain (Fig. 1). This Guercif basin is located in the eastern part of the South Rifian Corridor (Hodell *et al*. 1989, Morel 1989, Krijgsman *et al*. 1999, 2000, Dayja 2002) (Fig. 1A), bordered to the north by the Mazgout and Beni Bou yahi massifs, to the east by the eastern Meseta and limited to the west and south-west by the Middle Atlas chain (Fig. 1B).

Previous works (e.g., Benzaquen 1965, Coletta 1977, Wernli 1988, Rezqi 1988, Bernini *et al*. 1994, 1996, 1999, 2000, Barhoun *et al*. 1999, Barhoun 2000, Dayja *et al*. 2003) have focused on lithostratigraphic, tectonic and micropaleontological investigations in the Guercif basin. Palynological studies were carried out by Bachiri Taoufiq (2000) and Bachiri Taoufiq *et al*. (2001, 2008). In addition, correlations between the Neogene basins were realized through magnetostratigraphic, cyclo-stratigraphy and biosrtratigraphic investigations in the Mediterranean (Sierro *et al*. 1993, 2001, Hodell *et al*. 1994, Hilgen *et al*. 1995, 2000, Benson *et al*. 1996, Krijgsman *et al*. 1999, 2000, Dayja 2002, Dayja *et al*. 2005).

In contrast with the Neogene basins close to the Rifian belt (Azdimousa *et al*. 2006, Cornée *et al*. 2016), the Guercif basin is folded by a series of NE-SW anticlines (Colleta 1977, Gelati *et al*. 2000) parallel to the Middle Atlas structures, but other fault directions (e.g. NE-SW, NW-SE, N-S and E-W) were also identified (Zizi 1996). Stratigraphically, this basin developed during the late Miocene (Wernli 1988). It was filled with marine Neogene and continental Pliocene-Quaternary sediments (Fig. 1) that cover Paleozoic and Jurassic deposits (Benzaquen 1965, Colleta 1977, Gelatti *et al*. 2000).

This study aims to investigate the foraminifera biostratigraphy and make paleoenvironmental reconstructions, focusing on the benthic and planktonic microfauna. Indeed, stratigraphic distribution of benthic and planktonic foraminifera identified in the different sedimentary units allows reconstruct the sedimentary environments as well as the eustatic evolution of the basin during the Tortonian/Messinian transition. The paleontological data were combined with a sequential analysis of the sedimentary units, in order to trace the history of the Guercif basin during the Neogene period.

METHODOLOGY

A total of ten samples have been taken in the marl and marl-sandstone sedimentary units for the foraminiferal study. The sampling resolution is variable according to the facies changes. In each level, 1 to 2 kilograms of unaltered sediments were taken.

The superficial altered horizon was removed until about 30 cm deep. The collected sediments were washed and sieved at different fractions of 250, 200 and 125µm. The indurated sediments were soaked in a hydrogen peroxide solution of 10% during 24 h in order to disaggregate. After drying, the three fractions were examined under a binocular microscope. Scanning Electron Microscopy (SEM) of planktonic and benthic foraminifera was carried out at the University of Liège, Belgium. This study is based on associations of foraminiferal species corresponding to their respective living environments. The quantitative data (specific diversity and abundance) represent the total number of species recorded at the stratigraphic levels and their abundances. The paleoenvironmental reconstructions were carried out according to the following steps:

1. The application of the Actualism concept. All collected benthic species are present in the modern marine basins. We assume that their distributions were controlled by similar abiotic factors during the Neogene and the modern period (Rezqi 2000, Rezqi *et al*. 2000, Dayja *et al*. 2003).

2. The use of the P/B ratio defined by [P/ (P + B)] where P = number of planktonic foraminifera; P + B = total number of planktonic and benthic foraminifera (Gibson 1989, Van Der Zwaan *et al*. 1990).

3. The use of the detritus ratio defined by FD/FO where FD = mineral fraction, FO = organic fraction including foraminifera and any other associated microfaunal elements (foraminifera and other microfaunas) (Rezqi 1988).

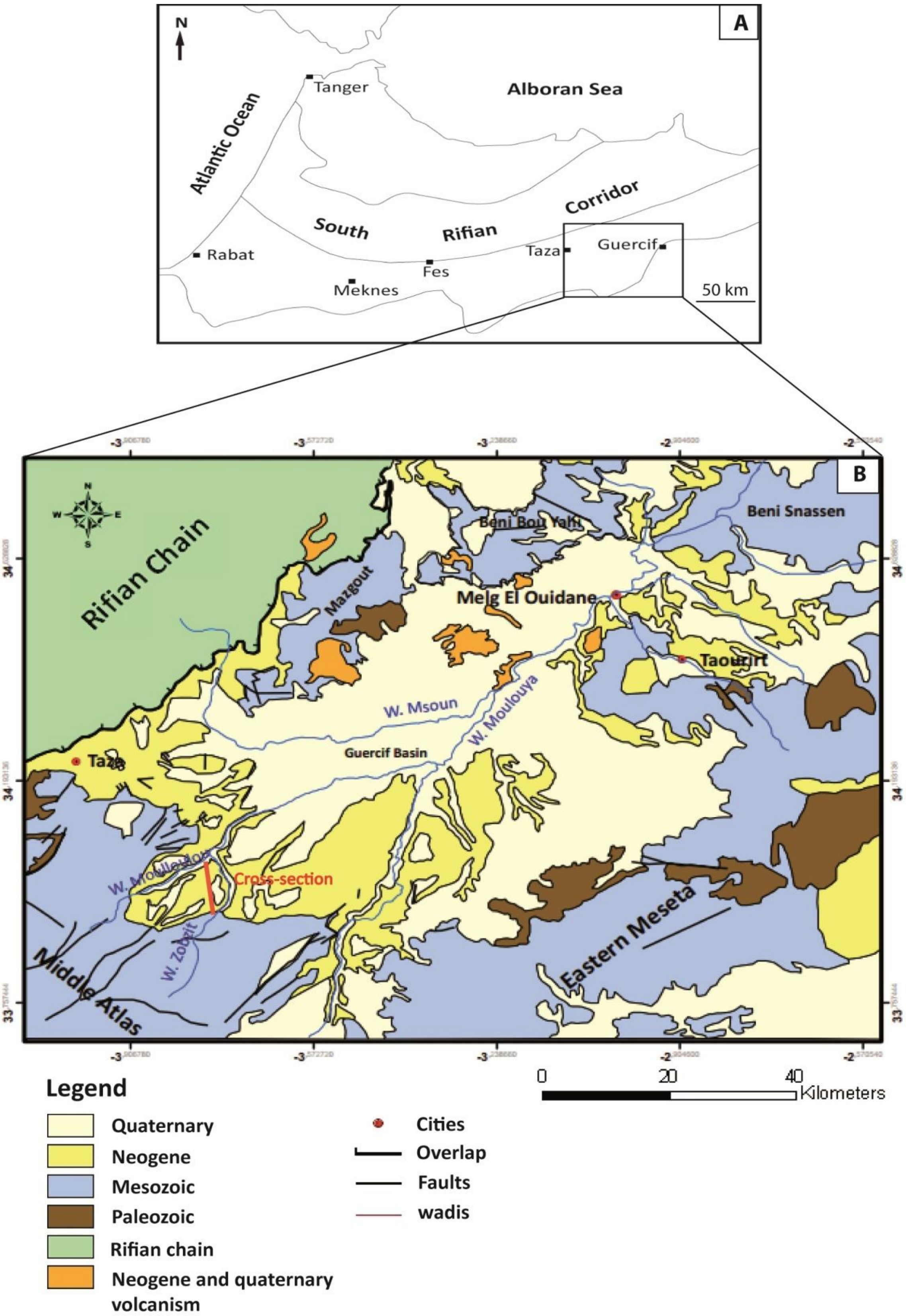

Figure 1. A. Simplified map indicates the South Rifian Corridor (northern Morocco) situation during the Late Miocene (Hodell *et al*. 1989) and location of the Guercif basin. B. Simplified geological map of the study area based on the geological maps of the Guercif-Taourirt basin (Bouazza *et al*. 2008) and 1/500000 Oujda map (Choubert 1954).

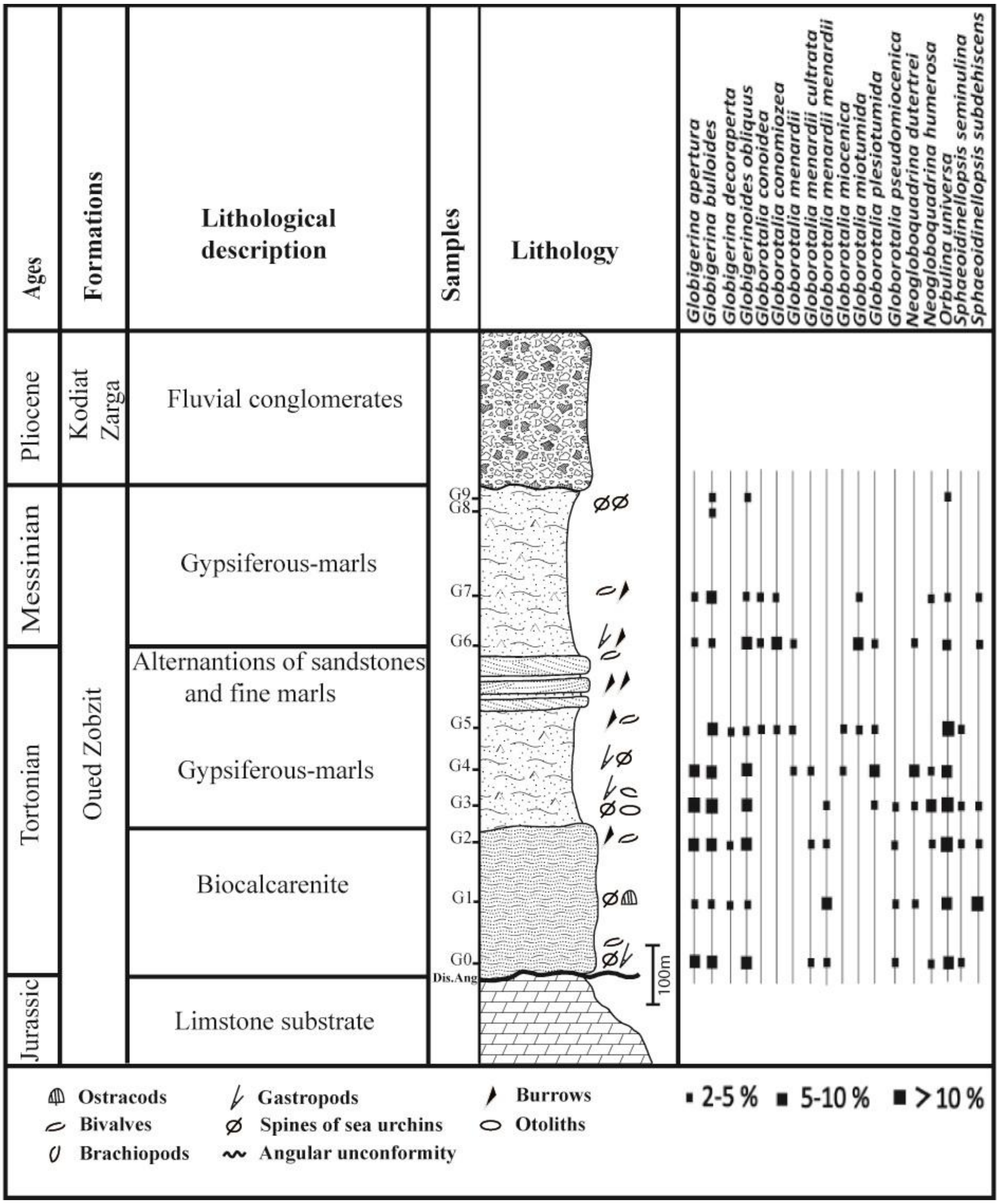

Figure 2. Synthetic stratigraphic log description and distribution of planktonic foraminiferas in the Guercif basin.

LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY STUDY OF THE LATE MIOCENE FROM THE GUERCIF BASIN

Upper Neogene sediments crop out at the Zobzit Wadi are located in the SW of the Guercif basin. Indeed, sediments are directly overlying the Jurassic substrate by an angular unconformity. The studied series of the Guercif cross-section is 900 m-thick. Three lithological units were identified, ranging from the upper Miocene to Pliocene (Fig. 2).

- Unit I, 250 m-thick, is formed of yellow (G0, G1) to light gray (G2) biocalcarenitic sediments, with marl-sandstone laminations. It contains various planktonic foraminifera species (Figures 2, 3): *Globorotalia menardii menardii* (Parker, Jones &

Brady), 1865, *Globorotalia menardii cultrata* (Orbigny), 1839, *Globorotalia pseudomiocenica* Bolli & Bermudez, 1965, *Orbulina universa* Orbigny, 1839, *Globigerina bulloides* Orbigny, 1826, *Sphaeroidinellopsis subdehiscens* Blow, 1959, *Sphaeroidinellopsis seminulina* Schwager, 1866, *Globigerina apertura* Cushman, 1918, *Globigerina decoraperta* Takayanagi & Saito, 1962 and *Globigerinoides obliquus* Bolli, 1957. *Neogloboquadrina humerosa* Takayanagi & Saito, 1962 and *Neogloboquadrina dutertrei* Orbigny, 1839 were also founded but with lesser frequency. The foraminifera assemblages are characterized by the omnipresence of the *Globorotalia menardii* group, left coiling, suggesting a middle to late Tortonian age, in agreement with the study of Barhoun *et al*. (2008).

- Unit II, 200 m-thick, is formed by gypsiferous marls, yellow at the base (G3) and gray at the top (G4, G5). Marls are then followed by alternations of 100 m of sandstones and marls which were interpreted as turbidite deposits by Bernini *et al*. (1992). The sandstone beds are characterized by a progressive thickening and coarsening-upward. The foraminifera association is similar to that of unit I but characterized by significant decreases of the *Globorotalia menardii* group, left coiling (Figures 2, 3). These decreases is in agreement with three events (labeled event 1, 7 and 2) as defined by Sierro *et al*. (1993), Hilgen *et al*. (1995), Krijgsman *et al*. (1995, 1997) and Dayja *et al*. (2005). The appearance of *Globorotalia menardii* group, right coiling (Figures. 2, 3), in the upper part of this unit (samples 4 and 5) indicates a late Tortonian age.

- Unit III, 300 m-thick, is formed by marls with gypsum of Zobzit Wadi, which conformably overlies the previous units (I and II). The gypsiferous marls sub-unit of the Melloulou unit (Bernini *et al*. 1992) is widely exposed on the right bank of the Zobzit Wadi (Fig. 1) having a yellow color at its base (G6, G7) and becoming gray at the top (G8, G9). Identical species as in unit II are found at the base of unit III. In addition, specimens of the *Globorotalia miotumida* group, left-coiling, are present in sample G5 with a small amount (~2%), while specimens belonging to the *Globorotalia menardii* group, right-coiling, are not found in sample G7 (Figures 2, 3). The disappearance of the *Globorotalia menardii* group, right-coiling from the sample (G7) and the abundance of *Globorotalia miotumida* group, left-coiling allowed us to specify the Tortonian-Messinian boundary at the sample G6 located at the base of the Messinian gypsiferous marls. This substitution is considered as a good criterion for the recognition of the Tortonian-Messinian boundary in the Guercif basin (Bernini *et al*. 1992).

The gypsiferous marls were deposited during the Messinian. At the top of the gypsiferous marls, samples G8 and G9 revealed only *Globigerina bulloides*, *Orbulina universa* and *Globigerinoides obliquus*, due to the poorly preserved microfauna. In addition, no specimen of the Globorotalia group observed in the gypsiferous marls. The sediments of unit III are also eroded at the top and unconformably covered by the Pliocene continental deposits (i.e. Kodiat Zarga) (Gelati *et al*. 2000).

PALEO-BATHYMETRIC RECONSTRUCTION BASED ON BENTHIC FORAMINIFERA ASSOCIATIONS

The sediments from the Neogene series of the Guercif basin reveal a total of 41 species and 26 genera of benthic foraminifera organized in five associations (Figures 4, 10).

1- Association I is found at the base of the Tortonian biocalcarenitic levels (sample G0). It contains many gastropods, bioclasts, sea-urchin spines, and planktonic and benthic foraminifera. The benthic forms are more abundant (92%) compared to the planktonic foraminifera (8%). The benthic foraminifera faunas are characterized by a low diversity and mainly represented by the association of *Ammonia beccarii* Linne, 1758, accompanied by *Nonion commune* Orbigny, 1826, *Cibicides dutemplei* Orbigny, 1846 and *Textularia sagittula* Defrance, 1964. In addition, some species of *Sigmoilopsis schlumbergeri* Silvestri, 1904, *Dentalina acuta* Orbigny, 1846, *Siphotextularia concava* Karrer, 1868, *Uvigerina californica* Cushman, 1926 and *Uvigerina carapitana* Hedberg, 1937 were found at the base of the biocalcarenitic deposits (Fig. 5).

Ammonia beccarii (Blanc-Vernet *et al*. 1983, Mathieu 1986, Jorissen 1987, Rezqi *et al*. 2000) is very abundant on the actual Atlantic margin, living in coarse sandy and sandy mud sediments between 38 and 50 m depth (i.e., stenobathic species). *Nonion commune* is often described from both the internal and external platform (Wright 1978, Mathieu 1986, Murray 1991). The species lives on similar substrates as *Ammonia beccarii*, but deeper, between 38 and 150 m depth (i.e. eurybathic species). *Textularia sagittula* and *Cibicides dutemplei* characterize an intermediate depth of 60 to 150 m (Van Marle 1988, Rezqi 2000). The P/B ratio is very low (8%), while the detrital fraction is higher than the organic fraction (32%).

These paleoecological data rather suggest an infralittoral shallow environment (38 to 50 m depth).

2- Association II is located at the top of the Tortonian biocalcarenitic levels (sample G1 and G2), which contains benthic and planktonic foraminifera associated with burrows, sea-urchin spines, gastropods and bivalves.

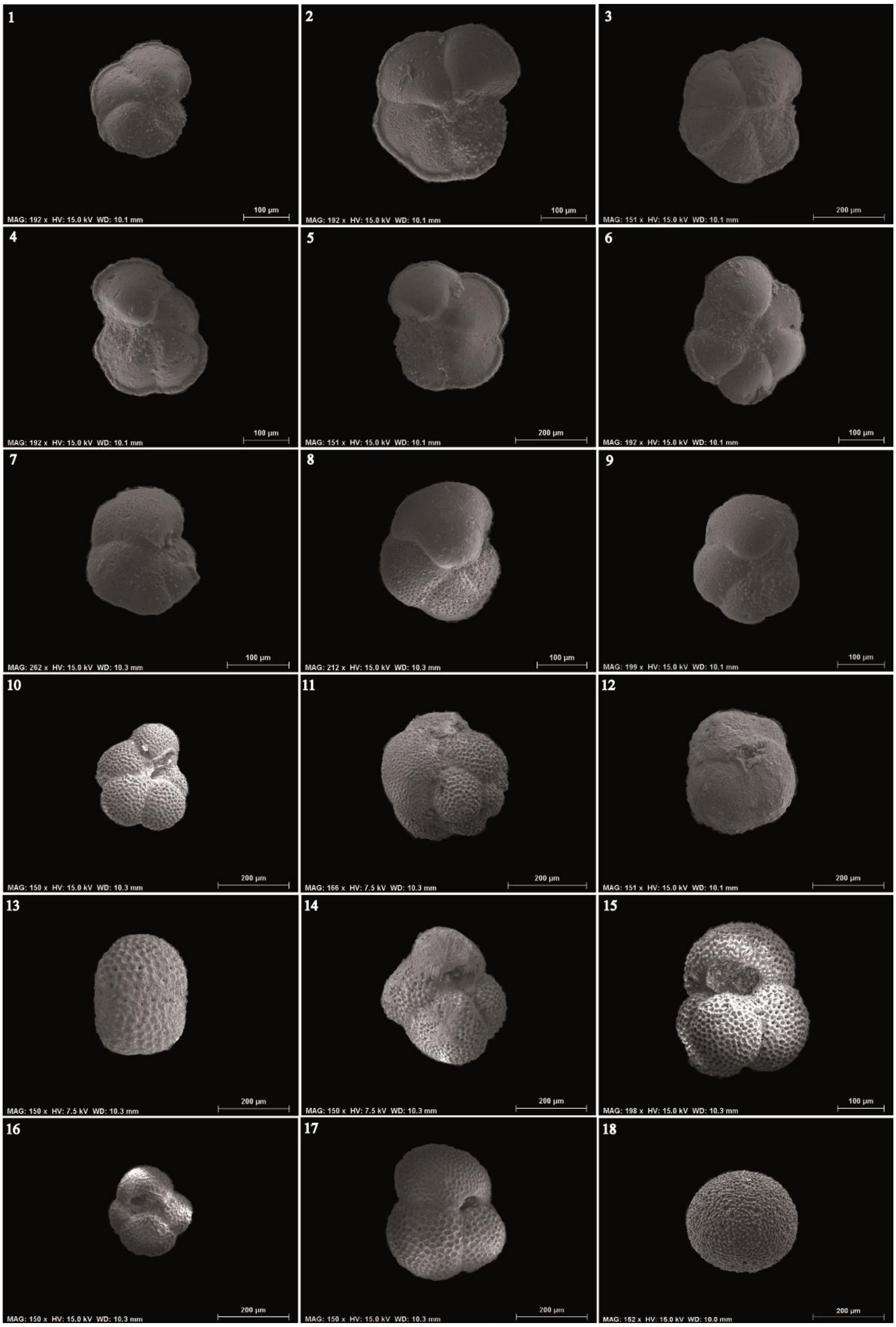

Figure 3. Scanning Electron Microscopy (SEM) images of planktonic foraminifera. 1-3. *Globorotalia menardii* group, left coiling: 1, *Globorotalia menardii menardii* (Parker, Jones & Brady), 1865; 2, *Globorotalia menardii cultrata* (Orbigny), 1839; 3, *Globorotalia pseudomiocenica* Bolli & Bermudez, 1965. 4-6. *Globorotalia menardii* group, right coiling: 4, *Globorotalia menardii* (Parker, Jones & Brady), 1865; 5, *Globorotalia plesiotumida* Blow & Banner, 1965; 6, *Globorotalia miocenica* Palmer, 1945. 7-9. *Globorotalia miotumida* group, left coiling: 7, *Globorotalia miotumida* Jenkins, 1960; 8, *Globorotalia conoidea* Walters, 1965; 9, *Globorotalia conomiozea* Kennett, 1966. 10-18. 10, *Neogloboquadrina humerosa* Takayanagi & Saito, 1962; 11, *Neogloboquadrina dutertrei* Orbigny, 1839; 12, *Sphaeroidinellopsis seminulina* Schwager, 1866; 13, *Sphaeroidinellopsis subdehiscens* Blow, 1959; 14, *Globigerina decoraperta* Takayanagi & Saito, 1962; 15, *Globigerina bulloides* Orbigny, 1826; 16, *Globigerina apertura* Cushman, 1918; 17, *Globigerinoides obliquus* Bolli, 1957; 18, *Orbulina universa* Orbigny, 1839.

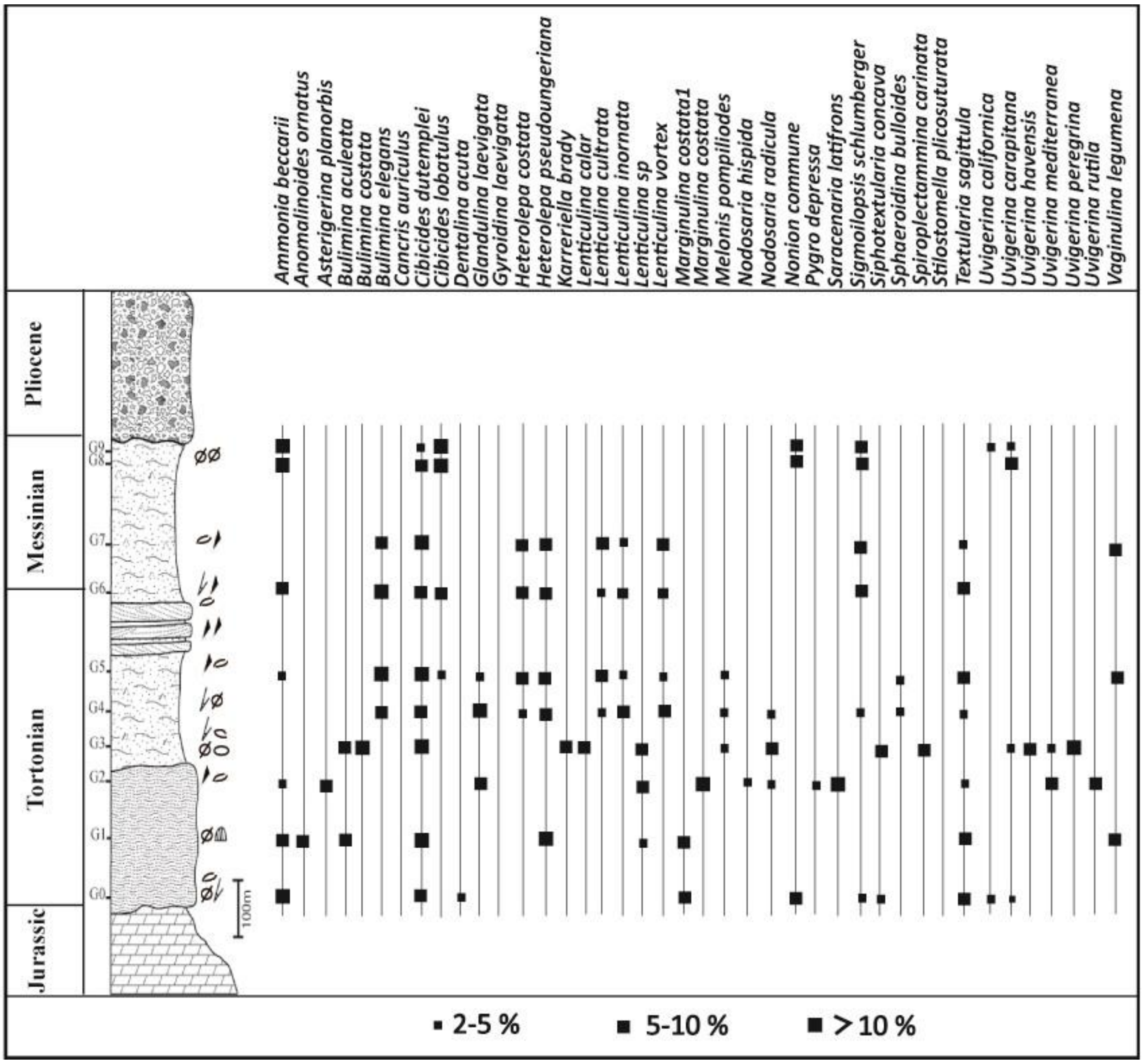

Figure 4. Distribution of benthic foraminifera in the Guercif basin cross-section.

The most widely represented benthic foraminifera species are *Cibicides dutemplei* Orbigny, 1846, *Heterolepa pseudoungeriana* Cushman, 1922, *Marginulina costata* Silvestri, 1896 and *Saracenaria latifrons* Brady, 1884. These species are associated with *Ammonia beccarii* Linne, 1758, *Marginulina costata 1* (*var. coarctata*) Silvestri, 1896, *Textularia sagittula* Defrance, 1964, *Vaginulina legumen* Linne, 1758, *Anomalinoides ornatus* Costa, 1856, *Bulimina elegans* Accordi & Selmi, 1952, *Uvigerina rutila* Cushman & Todd, 1941, *Glandulina laevigata* Orbigny, 1846, *Uvigerina mediterranea* Hofker, 1932, *Nodosaria hispida* Orbigny, 1846, *Pygro depressa* Orbigny, 1826, *Gyroidina laevigata* Orbigny, 1826, *Cancris auriculus* Fichtel & Moll, 1798 and *Uvigerina pergrina* Cushman, 1923 (Figures 5, 6, 7). This microfauna consists of species derived from a mixture of infralittoral (*Ammonia beccarii* and *Textularia sagittula*) (Fig. 5), circalittoral (*Vaginulina legumen*, *Anomalinoides ornatus*, *Glandulina laevigata*, *Marginulina costata 1* (*var. coarctata*), *Uvigerina rutila*, *Gyroidina laevigata*, *Cancris auriculus* and *Uvigerina mediterranea*) (Figures 5, 6) and deep epibathyal environments (*Asterigerina planorbis* and *Pygro depressa*) (Fig. 7).

This association would reflect ecological stress. It may be an equivalent of the “blue marls” deposit (Tortonian age) of the Jorf El Baroud, located in the NE of the Guercif basin (Jadid *et al*. 1999). The same association is found in the Miocene marls found in the NW of the Melilla-Nador basin (Rezqi 1988, Azdimousa 1991). The P/B ratio increases slightly (20% to 30%) and the detrital fraction (80%) is important in this facies. All the micro-fauna and sedimentological data are consistent with an internal circalittoral shallow environment (50 to 150m depth) that gradually evolves to an external circalittoral environment (< 400m depth). The increase of the P/B

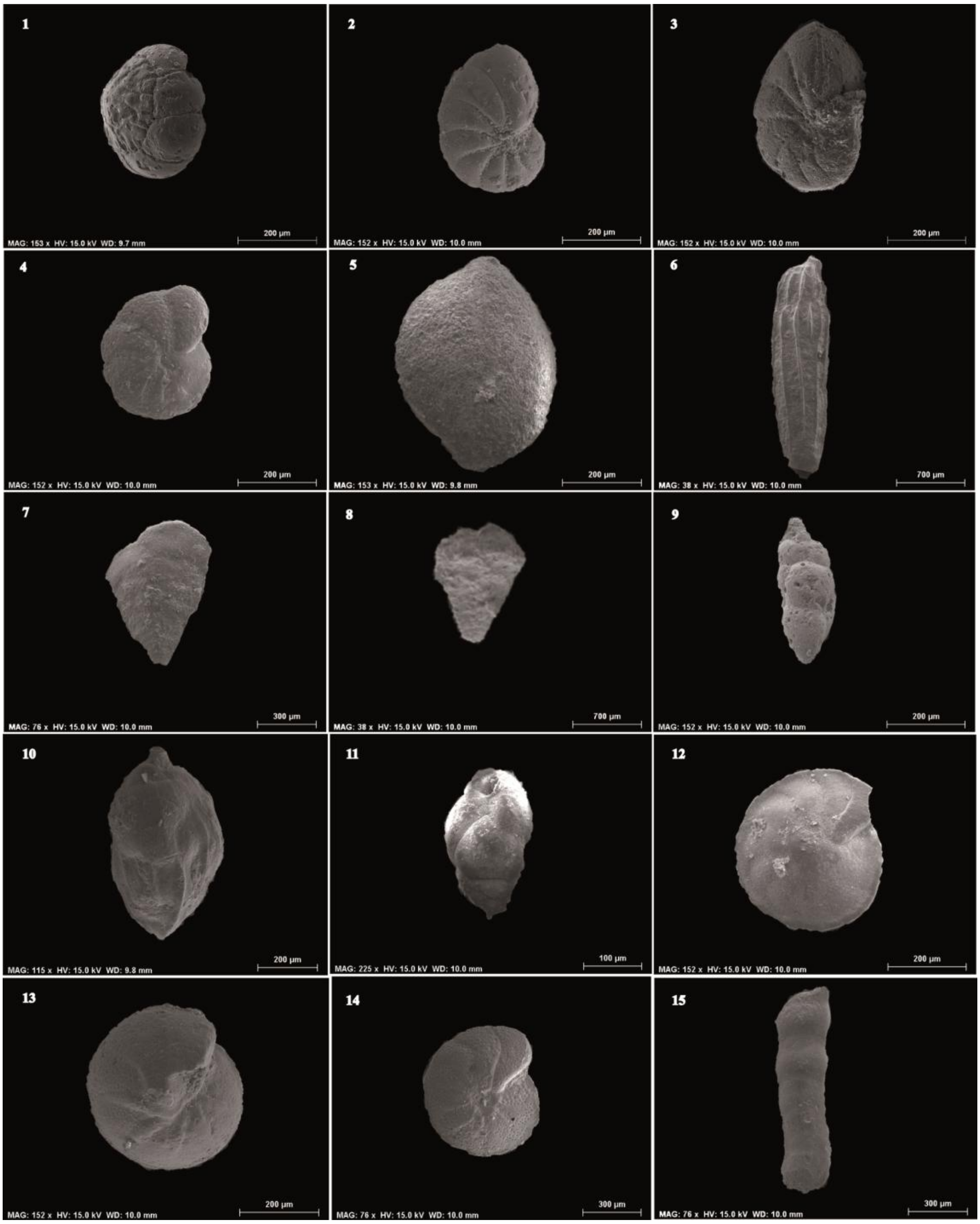

Figure 5. Scanning Electron Microscopy (SEM) images of benthic foraminifera. 1-10. Infralittoral foraminifera group: 1, *Ammonia beccarii* Linne, 1758; 2-3, *Nonion commune* Orbigny, 1846; 4, *Cibicides lobatulus* Walker & Jacob, 1798; 5, *Sigmoilopsis schlumbergeri* Silvestri, 1904; 6, *Dentalina acuta* Orbigny, 1846; 7, *Textularia sagittula* Defrance, 1964; 8, *Siphotextularia concava* Karrer, 1868; 9, *Uvigerina californica* Cushman, 1926; 10, *Uvigerina carapitana* Hedberg, 1937. 11-15. Internal circalittoral foraminifera group: 11, *Bulimina elegans* Orbigny, 1826; 12, *Heterlepa pseudoungeriana* Cushman, 1922; 13, *Heterolepa costata* Ruscelli, 1953; 14, *Cibicides dutemplei* Orbigny, 1846; 15, *Vaginulina legumen* Linne, 1758.

ratio confirms the slight deepening of the environment. The high percentage of the detrital fraction could be explained by detrital input from the continent.

3- Association III is usually found in the lower part of the gypsiferous marls (sample G3), dominated by *Uvigerina peregrine* Cushman, 1923, *Bulimina costata* Orbigny, 1852 and *Cibicides dutemplei* Orbigny, 1846, also associated with *Nodosaria* *radicula* Linne, 1758, *Uvigerina havensis* Cushman & Bermudez, 1936, *Stilostomella plicosuturata* Dervieux, 1894, *Karreriella brady* Cushman, 1911, *Lenticulina calar* Linne, 1767, *Spiroplectammina carinata* Orbigny, 1846 and *Bulimina aculeata* Orbigny, 1826. The species *Uvigerina meditterranea* Hofker, 1932, *Uvigerina carapitana* Hedberg, 1937 and *Melonis pompilioides* Fichtel & Moll, 1798 were also founded but with a lower frequency (Figures 5, 6, 7).

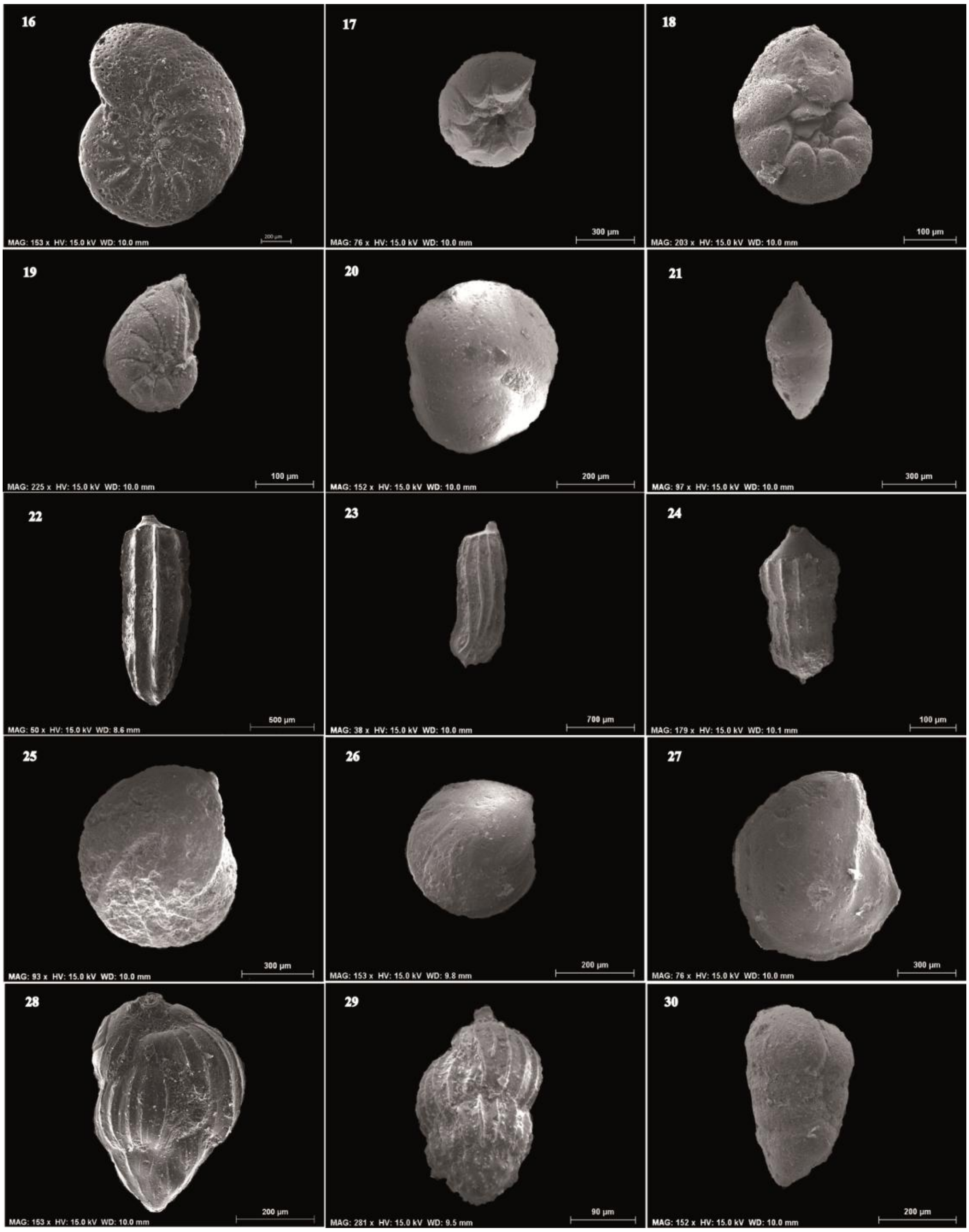

Figure 6. Scanning Electron Microscopy (SEM) photographs of benthic foraminifera. 16, *Anomalinoides ornatus* (Costa), 1856 which is internal circalittoral foraminifera. 17-29. External circalittoral foraminifera group: 17, *Gyroidina laevigata* Orbigny, 1826; 18, *Cancris auriculus* Fichtel & Moll, 1798; 19, *Saraceneria latifrons* Brady, 1884; 20, *Sphaeroidina bulloides* Orbigny, 1826; 21, *Glandulina laevigata* Orbigny, 1846; 22, Marginulina costata 1(var. coarctata) Silvestri, 1896; 23-24, *Marginulina costata* Batsch, 1791;25, *Lenticulina vortex* Fichtel & Moll, 1798; 26, *Lenticulina inornata* Orbigny, 1846; 27, *Lenticulina cultrata* Montfort, 1808; 28, *Uvigerina rutila* Cushman & Todd, 1941; 29, *Uvigerina mediterranea* Hofker, 1932. Fig. 30. *Karreriella brady* Cushman, 1911 epibathyal foraminifera.

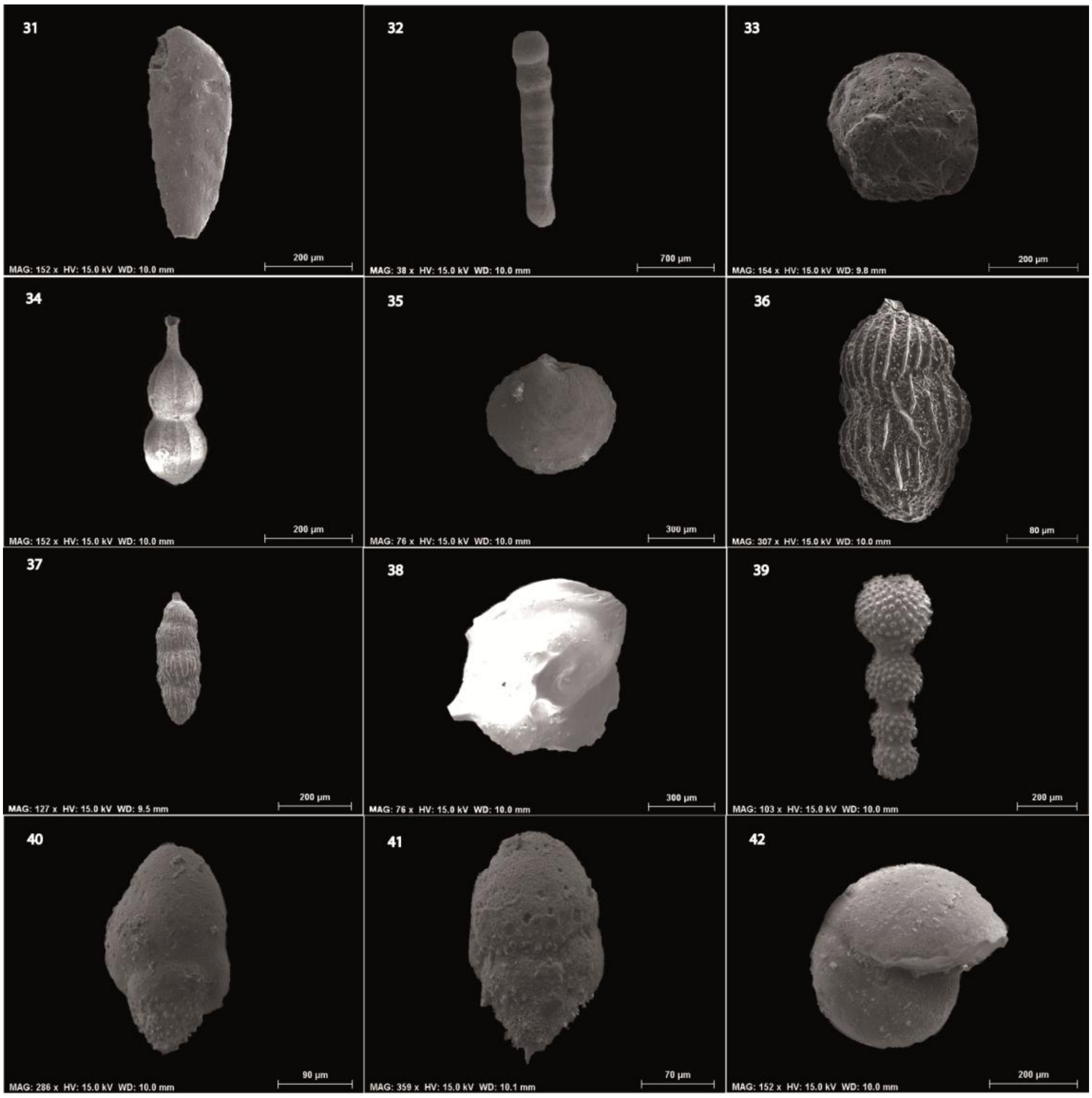

Figure 7. Scanning Electron Microscopy (SEM) of benthic foraminifera. 31-37. Epibathyal foraminifera group: 31, *Spiroplectammina carinata* Orbigny, 1846; 32, *Stilostomella plicosuturata* Dervieux, 1894; 33, *Asterigerina planorbis* Orbigny, 1846; 34, *Nodosaria radicula* Linne, 1758; 35; *Pygro depressa* Orbigny, 1826; 36, *Uvigerina havanensis* Cushman & Bermudez, 1936; 37, *Uvigerina peregrina* Cushman, 1923. 38-42. Mesobathyal foraminifera group: 38, *Lenticulina calar* Linne, 1767; 39, *Nodosaria hispida* Orbigny, 1846; 40, *Bulimina aculeata* Orbigny, 1826; 41, *Bulimina costata* Orbigny, 1826; 42, Melonis pompilioides Fichtel & Moll, 1798**.**

Bulimina costata is identified on the muddy substrate, indicating open marine environments which vary from 100 to 300 m in depth (Blanc Vernet 1969, Wright 1978). This species expands both in external circalitoral as well as in internal epibathyal (i.e. eurybathic species) environments. Its abundance is also known from Miocene deposits in the Mediterranean Sea (Van Der Zwaan 1982, 1983). The Uvigerinids are mostly represented by *Uvigerina peregrina* which is encountered at the high depth. This species develops under extreme conditions of oxygen deficiency and high organic carbon content (Bizon & Bizon 1985, Bizon & Burollet 1985, Borsetti *et al*. 1986). In parallel with the deepening of the environment basin, the ecosequence successively consists of *Uvigerina californica* Cushman, *Uvigerina carapitana* Hedberg, *Uvigerina rutila* Cuschman and Todd, *Uvigerina meditterranea* Hofker, *Uvigerina havensis* Cushman and Bermudez, *Uvigerina peregrina* Cushman (Fig. 8). The marl level is characterized by gastropods, otoliths, brachiopods and sea-urchin spines. The P/B ratio reaches up to 64% and the detrital fraction is low (40%). The association of benthic foraminifera and the P/B ratio are in agreement with a deep epibathyal paleoenvironment (200 to 600 m depth).

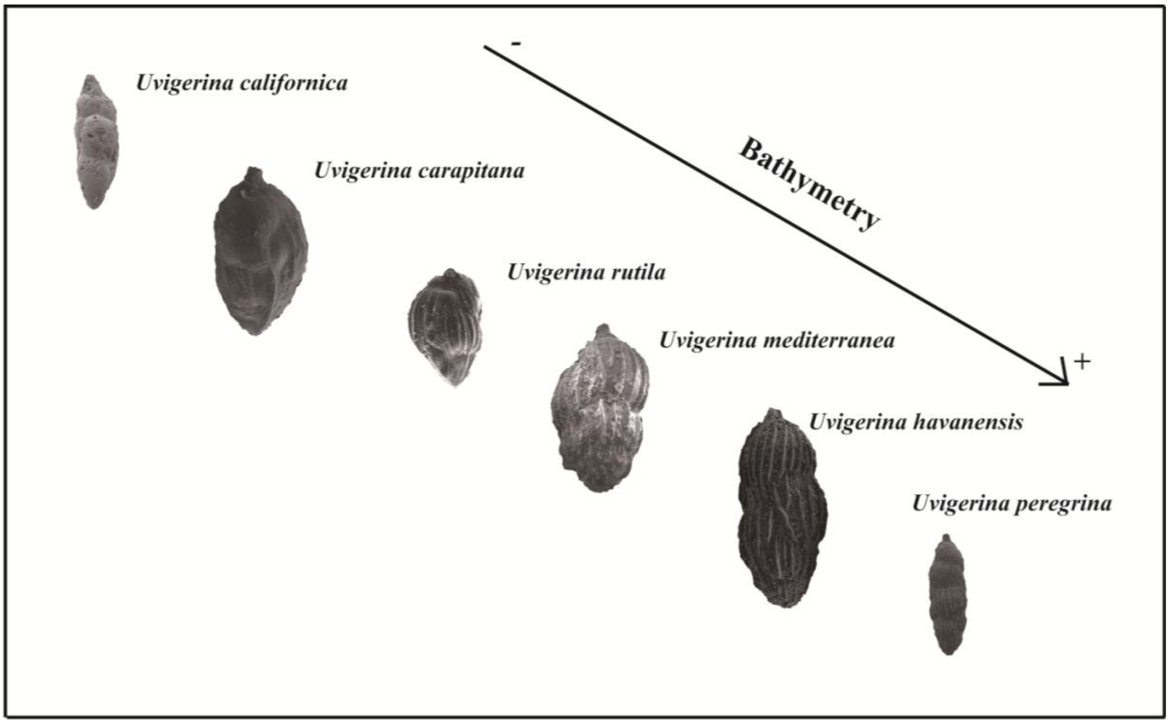

Figure 8. Ecosequence of Uvigerinidae according to the bathymetry evolution in the Guercif basin cross-section.

The decrease of the FD/FO ratio with depth can probably be explained by the distance from the continent.

4- Association IV is found at the marl-sandstone levels and at the base of the Messinian marls (samples G4 to G7). The microfauna is represented by burrows, large bivalves, gastropods, some sea-urchin spines and foraminifera. The association of benthic forms is dominated by *Bulimina elegans* Orbigny, 1826, *Glandulina laevigata* Orbigny, 1846, *Cibicides dutemplei* Orbigny, 1846, associated with *Textularia sagittula* Defrance, 1964, *Cibicides lobatulus* Walker & Jakob, 1798, *Heterolepa pseudongeriana* Cushman, 1922, *Heterolepa costata* Rescelli, 1953, *Sigmoilopsis schlumbergeri* Silvestri, 1904, *Ammonia beccarii* Linne, 1758 and *Vaginulina legumen* Linne, 1758. The lower frequency of *Melonis pompiloides* Fichtel & Moll, 1798, *Sphaeroidina bulloides* Orbigny, 1826 and *Nodosaria radicula* Linne, 1758 is also characteristic of this association (Figures 5, 6, 7). The sedimentological analysis in these deposits reveals an important increase in the mineral fraction (73% to 87%). The P/B ratio ranges from 33 to 39%. Association IV is marked by the appearance of the circalittoral forms such as *Lenticulina vortex* Fichtel & Moll, 1798, *Lenticulina inornata* Orbigny, 1846 and *Lenticulina cultrata* Montfort, 1808 (Fig. 6). This regressive trend is also supported by a decrease in the P/B ratio. Similar results were obtained by Dyaja *et al*. (2003) in MSD1 borehole project (National Office of Research and the exploitation of oil in Morocco, 1985). The parallelism between the association of foraminifera, P/B ratio and mineral fraction points to a marine internal circalittoral environment (50 to 150 m depth). The high abundance of detrital fraction, represented mainly by gypsum grains is in agreement with the circalittoral environment. The alternation of sandstone and very fine marl associated with association IV is attributed to turbidite deposits (Bernini *et al*. 1992). However, the presence of sedimentary features such as oblique and cross stratifications, and clean sand with wave ripples rather suggest a shallow environment than a deep sedimentation as assumed by Krijgsman *et al*. (1999) and Bernini *et al*. (1992).

5- Association V is observed on the northern flank of the Zobzit Wadi (G8 and G9). It is composed of gypsiferous marls and contains foraminifera species, abundant sea-urchin spines and pyrite crystals. The abundance of benthic species gradually decreases and, thus, the fauna becomes less diversified. The association shows a dominance of *Ammonia beccarii* taxa Linne, 1758, *Cibicides lobatulus* Walker & Jakob, 1798 and *Nonion* *commune* Orbigny, 1846, accompanied by *Cibicides dutemplei* Orbigny, 1846 and S*igmoilopsis schlumbergeri* Silvestri, 1904 (Fig. 5). The detritus ratio is very high (~32) and is accompanied by a significant decrease in the P/B ratio (4%). The abundance of *Ammonia beccarii* indicates a shallow environment (Blanc-Vernet *et al*. 1983, Mathieu 1986, Jorissen 1987). The association of benthic foraminifera, the decrease of the P/B ratio and the high percentage of the detritus ratio indicate an infralittoral environment (38 to 50 m depth).

The microfauna (benthic and planktonic foraminifera) and sedimentological results allowed us to reconstruct the paleo-environment and its evolution during the Tortonian and the Messinian before the outbreak of the Messinian Salinity Crisis (MSC) in the Mediterranean.

Indeed, the oldest marine deposits are the Jurassic substrate dated to about 8 Ma (Krijgsman *et al*. 1999, 2000). Middle-Upper Tortonian sedimentary deposits are dominated by a shallow neritic (infralittoral) fauna identified by the presence of an infralittoral species association, including the species *Ammonia beccarrii*, *Nonion commune* and *Textularia sagittula* found at the basal part of the biocalcarenitic levels. Overlying Middle-Upper Tortonian sediments are characterized by a deepening neritic (circalittoral) environment, evolving from shallow environment (internal circalittoral) to moderately deep (external circalittoral). The deepening of the environment to the top of the biocalcarenitic levels is in agreement with the results of the benthic foraminifera (Krijgsman 1999) and the biostratigraphic study (Barhoun *et al*. 2008) which shows a relatively deep environment. The Upper Tortonian corresponds to a deep environment (epibathyal) as identified by the Uvigerinids species in the lowermost of the gypsiferous marl levels; this is confirmed by benthic foraminifera (Dayja 2002, Dayja *et al*. 2003, Krijgsman *et al*. 1999). Tortonian-Messinian sediments are characterized by a shallow environment (internal circalittoral), marked by the Lenticulinids at the marl-sandstone levels. This decrease in the bathymetry confirmed by tectonic activity, linked to the progressive of the Rifian chain which favors the reduction of the water column in the basin (Bernini *et al*. 1996). This bathymetry contrasts with the interpretation of Krijgsman *et al*. (1999), who rather suggested a Highstand System Tract (H.S.T) containing turbidites. In addition the observations of the lithology during the field work suggest the absence of turbidites during the Tortonian/Messinian. We founded only the alternation of sandstone and fine marl beds with some features such as: burrows galleries and clear sand with oblique and cross stratifications. In addition, the benthic foraminera indicating shallow environment are well conserved in marly matrix as showed in the SEM images. The Messinian is marked by the infralittoral species (*Ammonia Beccarri*, *Cibicides lobatulus*) in a shallow environment at the upper gypsiferous marls levels. This regressive trend is the result of a detrital filling important in the basin resulting its brief emergence at 6 Ma (Krijgsman *et al*. 1999, Dayja *et al*. 2003) and its isolation before evaporation and then outbreak of the Messinian Salinity Crisis (MSC).

SEQUENCE STRATIGRAPHY

Early stages of the sedimentary evolution of the Guercif basin as observed in the south-western outcrop of the basin are characterized by a relatively complete and continuous Neogene sedimentary succession (Figures 9, 10). The Tortonian marine transgression led to the biocalcarenitic deposits of the Zobzit Wadi formation, overlying the Jurassic substrate with an angular unconformity, type SB 1 (Vail *et al*. 1987). In addition, the transgression is responsible for a shift of the facies/microfacies towards the continent and covering largely the calcareous substrate (Gelati *et al*. 2000).

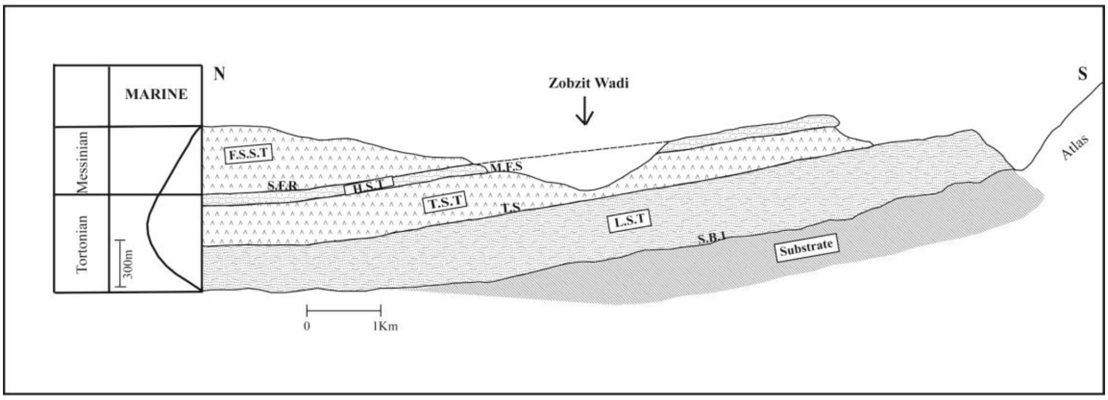

Figure 9. Paleogeographic reconstruction of the Guercif basin based on the variation of sedimentary cortege and the eustatic variations during the Tortonian and the Messinian. S.B.1: Angular Unconformity; L.S.T: Lowstand System Tract; T.S: Transgressive Surface; T.S.T: Transgressive System Tract; M.F.S: Maximum Flooding Surface; H.S.T: Highstand System Tract; S.F.R: Surface of Forced Regression; F.S.S.T: Falling-Stage System Tract.

During the Tortonian, the horizontal and vertical distribution of the facies is represented by lowstand and transgressive systems tract (LST & TST) deposits. The LST deposits of the middle – upper Tortonian are found between 0 to 200 m in the section and correspond to a thick biocalcarenitic unit that formed just after the Tortonian tectonic event, which resulted in the opening of the Guercif basin in agreement with the results of Gelati *et al*. (2000) and Sani *et al*. (2000).

In the Melloulou-Zobzit region, the sedimentary evolution is quite continuous, but it is periodically interrupted by erosive surfaces (SB) during sea-level falls in its upper part.

By contrast, the second unit corresponds to TST deposits (between 200 to 300 m), characterized by gypsiferous marl levels deposited during relative sea-level rise. The basal parts of these levels are characterized by a widespread transgressive surface (TS), while the maximum flooding surface (MFS) marks the end of the Tortonian transgression. In addition to the lithological character of these deep marine deposits, the MFS (end of the middle to late Tortonian) is also characterized by the *Globorotalia menardii* group of planktonic foraminifera (geometrical shifting from left coiling to right coiling).

The Highstand System Tract (HST), found between 300 to 500 m, consists of upper Tortonian marl-sandstone deposits. These deposits mark the shift from deep marine sedimentation to shallow marine deposits. This sea-level drop is significantly pronounced during the early Messinian. It is responsible for the installation of the falling-stage systems tract (FSST) deposits characterized by a high detrital input. The sediments of this FSST mainly consist of thick (≥400 m) gypsiferous marls, which are deposited on the paleo-coastal plain of the Guercif basin.

The basal limit of the gypsiferous marly sediments is delimited by the Surface of Forced Regression (SFR), related to a sharp decrease of the sea-level. The angular unconformity that marks the transition from the upper Tortonian to early Messinian in the eastern Rifian basins (Guillemin *et al*. 1982, Ait Brahim 1991, Azdimousa 1991, Azdimousa *et al*. 1993) is not marked in the Guercif basin.

The persistence of a continental regime during the Pliocene results in the deposition of conglomeratic fluvial deposits. These Pliocene continental deposits, unconformably overlying the marine sediments of the Messinian are related to the closure of Guercif basin. Their presence furthermore highlights an important synsedimentary tectonic event. This compression also controls the folding and the structural regime of the Guercif basin (Gelati *et al*. 2000).

Finally, comparing the reconstructed bathymetry with the global eustatic sea-level curve revealed a perfect agreement of the two curves during the Tortonian (LST, TST and HST) and the lower Messinian (FSST). The Highstand Systems Tract (HST) is the only regressive anomaly, not evidenced in the global sea level curve of Haq *et al*. (1987) (Fig. 10). This temporary decrease in sea-level is due to the uplift of the basin by a tectonic event.

CONCLUSION

The stratigraphic study of the Guercif basin is consistent with a transgressive Tortonian series corresponding to the sedimentary successions (biocalcarenitic, gypsiferous marl and marl-sandstone) of the Zobzit Wadi Formation. The Messinian regression is characterized by the deposition of gypsiferours marl sediments. These gypsiferous marls are covered by Pliocene continental deposits after the emersion of the basin.

The sequence stratigraphy interpretation reveals the presence of a complete sedimentary cycle made by the stacking of different sedimentary environments encountered in the Zobzit Wadi Formation. The basal sediments are characterized by the Lowstand Systems Tract (L.S.T), deposited over Jurassic limestone deposits. The subsequent deposition of deep-water gypsiferous marl levels in the same formation bears the characteristics of a Transgressive System Tract (T.S.T). This unit is covered by marl-sandstone levels that reveal a shallowing trend and are related to a Highstand System Tract (H.S.T). Next, the gypsiferous marl facies of the Zobzit Wadi Formation corresponds to a Shelf Margin System Track (S.M.S.T) and ends the sedimentary cycle. The end of the sedimentation in the basin is marked by Pliocene continental formations.

The planktonic associations allow to determinate the age of the basin sediments. Furthermore, to recognizing the Tortonian-Messinian boundary, based on the distribution and direction of coiling of the Globorotalia (eg., Globorotalia menardi group and Globorotalia miotumida group).

The benthic associations allow reconstructing the evolution of the marine environment before the Messinian salinity crisis. The micro-paleontological content of the Middle-Upper Tortonian unit of the Zobzit Wadi Formation is consistent with a shallow neritic to a deep neritic environment. The evolution into an epibathyal environment is marked by gypsiferous marl deposits of the upper Tortonian, marking a deep environment during maximum transgression. Alternation of uppermost Tortonian /Messinian sandstone and marls corresponds to a

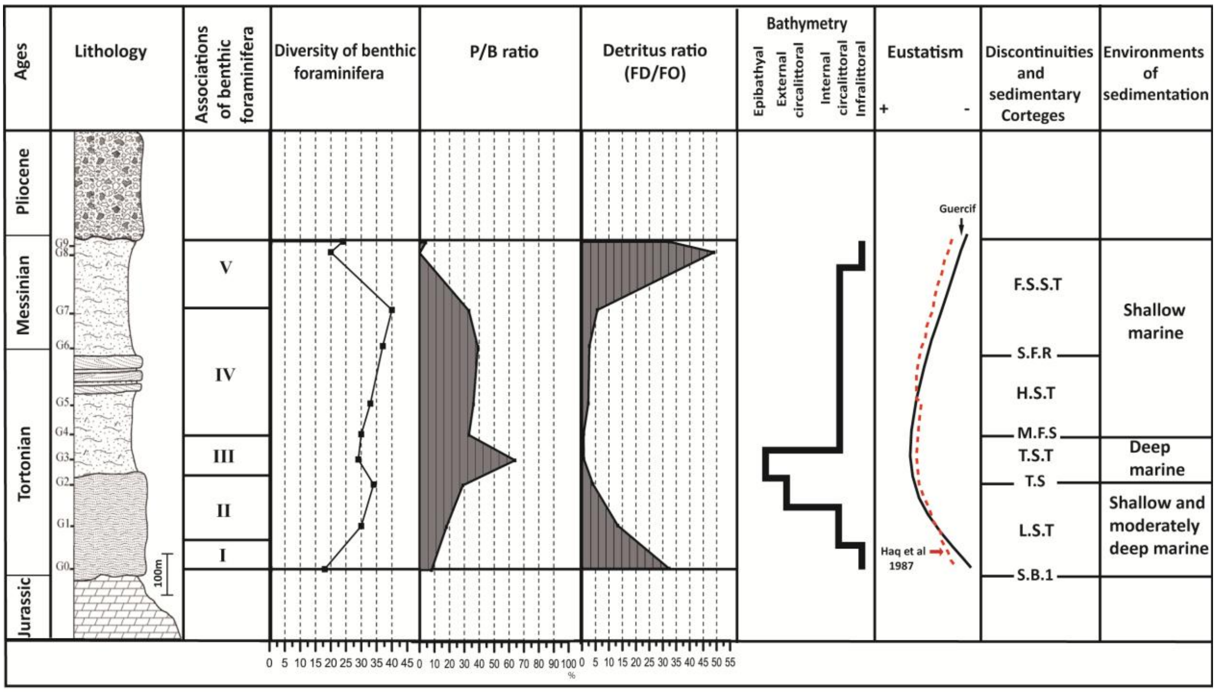

Figure 10. Relationship between the biostratigraphy, sedimentology and eustatism of the Guercif basin.

- - - Curve of the global variations of the marine level according to Haq *et al* (1987).

—— Curve of marine level variations of the Guercif basin.

Microfaunic characters	Sedimentary corteges	Discontinuities
P/B ratio,	L.S.T: Lowstand System Tract,	S.B.1: Angular Unconformity,
FD/FO: Detritus ratio.	T.S.T: Transgressive System Tract,	T.S: Transgressive Surface,
	H.S.T: Highstand System Tract,	M.F.S: Maximum Flooding Surface,
	F.S.S.T: Falling-Stage System Tract.	S.F.R: Surface of Forced Regression.

circalittoral environment. This bathymetry contrasts with the interpretation of Krijgsman *et al*. (1999) and Bernini *et al*. (1992), who rather suggested a Highstand System Tract (H.S.T) containing turbidites. The gypsiferous marls evolve from circa-littoral at the base to infra-littoral at the top, until emergence in the late Messinian (Krijgsman *et al*. 1999, Dayja *et al*. 2003). This drop in bathymetry reflects the rapid emergence of the basin. In addition, the sedimentation in the Guercif basin is consistent with a pre-MSC closure of the Rifan corridor (Flecker *et al*. 2015). This is demonstrate by mammal fossils between Spain and Morocco before 6.1 Ma (Agustí *et al*. 2006, Gibert *et al*. 2013), which favors continental connection before the installation of evaporitic conditions.

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