JURASSIC CLAY MINERAL SEDIMENTATION CONTROL FACTORS IN THE ESSAOUIRA BASIN (WESTERN HIGH ATLAS, MOROCCO)

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(9 figures, 1 table)

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ABSTRACT. Variations in the Jurassic clay mineral assemblages of sediments cropping out in the Essaouira field (North of the Western High Atlas Basin) make it possible to identify three mineralogical zones. As the effects of burial diagenesis seem weak, the vertical evolution of clay minerals depends mainly on various combinations of palaeogeographic factors. The inputs of illite and sometimes of chlorite throughout the series result from tectonic movements of the continental margins connected to the basin's subsidence. This tectonic activity was interspersed with phases of deceleration of subsidence, which allowed the formation under a hot climate, of pedological covers responsible for the input of kaolinite and mixed layers into the basin. Smectites are assumed to be mainly neoformed in shallow environments under hot climates. Variations in sea-level are also expressed in the Callovian, where generalized transgression allowed the development of detrital clay sedimentation instead of chemical sedimentation in the basin.

KEY WORDS: Essaouira, Jurassic, clay minerals, diagenesis, tectonics, climate, eustatism

1. Introduction

The Essaouira Basin is the most important oil-producing basin in Morocco. Onshore oil fields are believed to be sourced from Oxfordian shales, Carboniferous coals, and Silurian shales (Broughton & Trepanier, 1993). The Oxfordian shales are type II sapropelic kerogen and are richer in the Neknafa Syncline, reaching up to 4.3% total organic carbon (TOC) over at least a 10 m thick interval. This shale is mature for oil generation in the centre of the Syncline (Davison, 2005); in the Essaouira Basin, little information exists regarding the clay assemblages and their evolution throughout the Jurassic series, despite the host of oil wells that have been drilled there. Clay minerals are often used as thermobarometers, or at least as a tool to complement conventional parameters as the reflectance of vitrinite (Ro). For the purpose of this study of the clay assemblages in this part of the basin, we took two complementary sections from the sedimentary series of the Amsittene Anticline (Figs 1 & 2), where all of the Jurassic formations of the region form outcroppings (Duffaud, 1960). This region is the Western tip of the Northern slope of the Western High Atlas Basin (Fig. 1), which extends into the Atlantic Ocean (Hafid et al., 2006). The Jurassic sediment series, which is approximately 2200 m thick, was subdivided into twelve formations (Duffaud et al., 1966), later reduced to seven formations (Bouaouda, 2004, 2007). The aims of our study were (1) to identify the clay mineral successions characteristic of the sedimentary formations; (2) to determine the respective contribution of diagenesis and heritage, especially from the thermo-tectonic regime, in the clay assemblages and sediment deposits; (3) to provide more information about the depositional environment and palaeogeographic evolution of the basin and, finally, (4) to compare the results with data on the contemporary series in the Agadir Basin, part of the Atlantic margin. This comparison (Daoudi et al., 1988, 2010) will give more information of the combined effects of the tectonic instability of the margins and the increasing burial of the basin (Daoudi et al., 2002). However, identifying the respective influences of heritage and diagenesis is difficult. This is a real problem if the series were subjected to these two factors in comparable ways, as was the case in the Agadir region.

2. Geodynamic context

The Essaouira Basin extends from the Atlantic margin eastward into the High Atlas. To the North, it is separated from the Doukkala Basin by the Safi strike-slip fault, and, to the South, from the Souss Basin by the Agadir canyon system and the South Atlasic fault (Hafid, 1999; Hafid et al., 2000; Le Roy & Piqué, 2001; Tari et al., 2003; Davison, 2005).

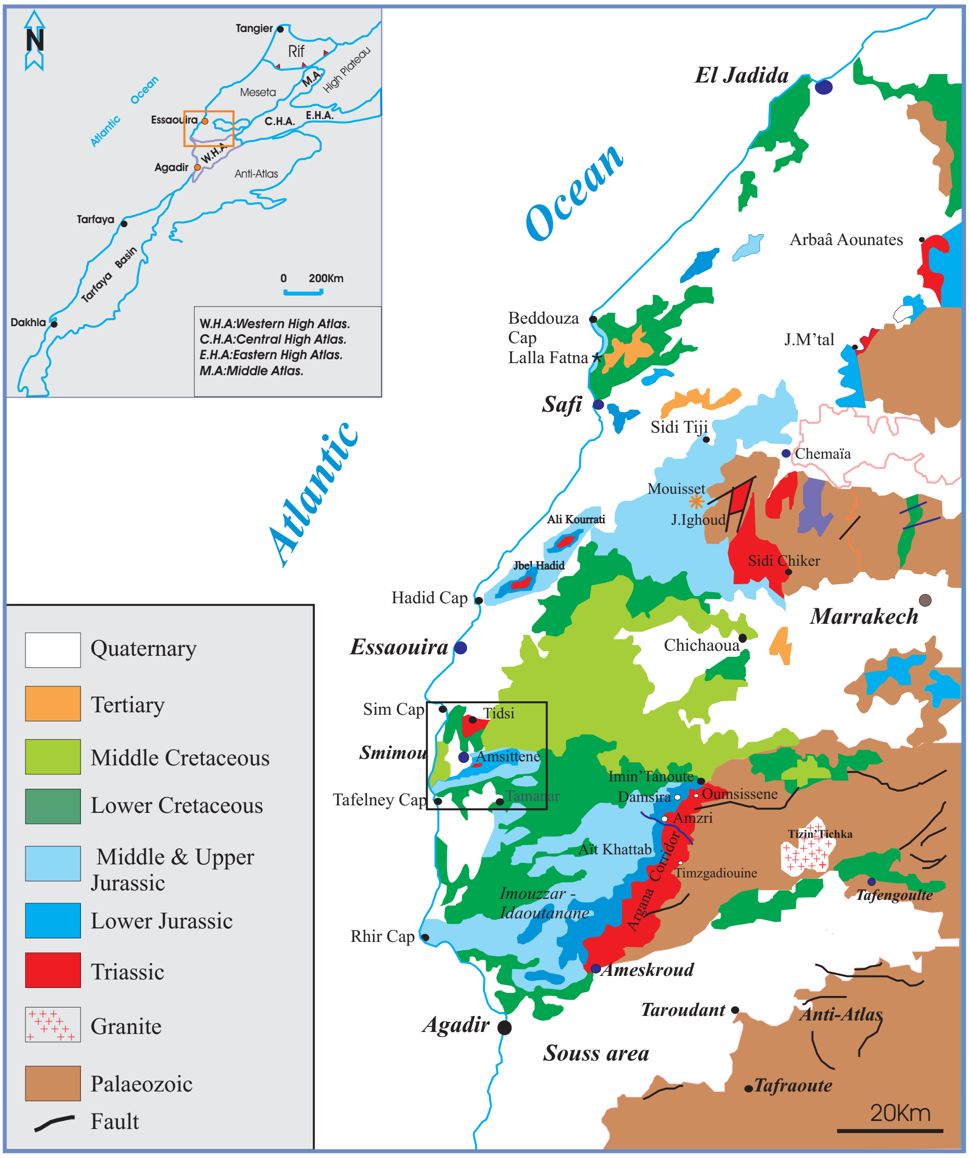

Figure 1 : Location map and geological context of the domain studied in the Essaouira basin

The most distinctive feature of the Essaouira-Agadir segment is its localization in an area where the High Atlas fold belt intercepts the Atlantic passive margin. Moreover, the area is one of the key basins of the North-Western African margin for understanding the events linked to the opening and expansion of the Central Atlantic. The geological evolution of this large area can be subdivided into three main stages (Hafid et al., 2008): (i) the Syn-Rift stage from Middle-Late Triassic to Early Liassic; (ii) the Pre-Atlasic Post-Rift stage from late Early Jurassic to Mid-Late Cretaceous; (iii) the Atlasic Post-Rift stage from Mid-Late Cretaceous to the present. The area has been the subject of numerous stratigraphic, sedimentological, diagenetic and tectonic studies in recent decades (Ager, 1974; Adams, 1979; Medina, 1994; Ouajhain & Laduron, 2001, 2003; Ouajhain et al., 2002; Bouaouda, 2007; Michard et al., 2008), as well as oil exploration (Duffaud, 1960; Duffaud et al., 1966; Broughton & Trepanier, 1993; Morabet et al., 1998; Davison, 2005; Ouajhain et al., 2005).

The geodynamic evolution of the basin is linked to three major geological events, as follows. (i) The rifting of the Central Atlantic as of the Middle Triassic in conjunction with dislocation of Pangea. In the course of this phase, the foundation was structured in horsts, grabens, and half-grabens bordered by accidents, some of them corresponding to reactivated Late Hercynian faults (Brown, 1980; Manspeizer, 1988; Medina, 1994, Hafid, 1999). (ii) The development of a passive margin during the Jurassic and Cretaceous (Sahabi et al., 2004). This was the post-rift phase, characterized by general subsidence and filling with, for the most part, evaporitic and carbonate sediments (Le Roy et al., 1997; Ellouz et al., 2003; Bouatmani et al., 2007). (iii) The convergence of Africa and Europe as of the Upper Cretaceous. The orogenesis of the Atlas, which reached its paroxysm in the Mio-Pliocene era, took place during this period (Medina, 1994; Sébrier et al., 2006).

3. Stratigraphy, sedimentology and depositional environments

Several Jurassic formations have been identified in the Essaouira Basin (Figs 2-4) (Duffaud, 1960; Duffaud et al.,

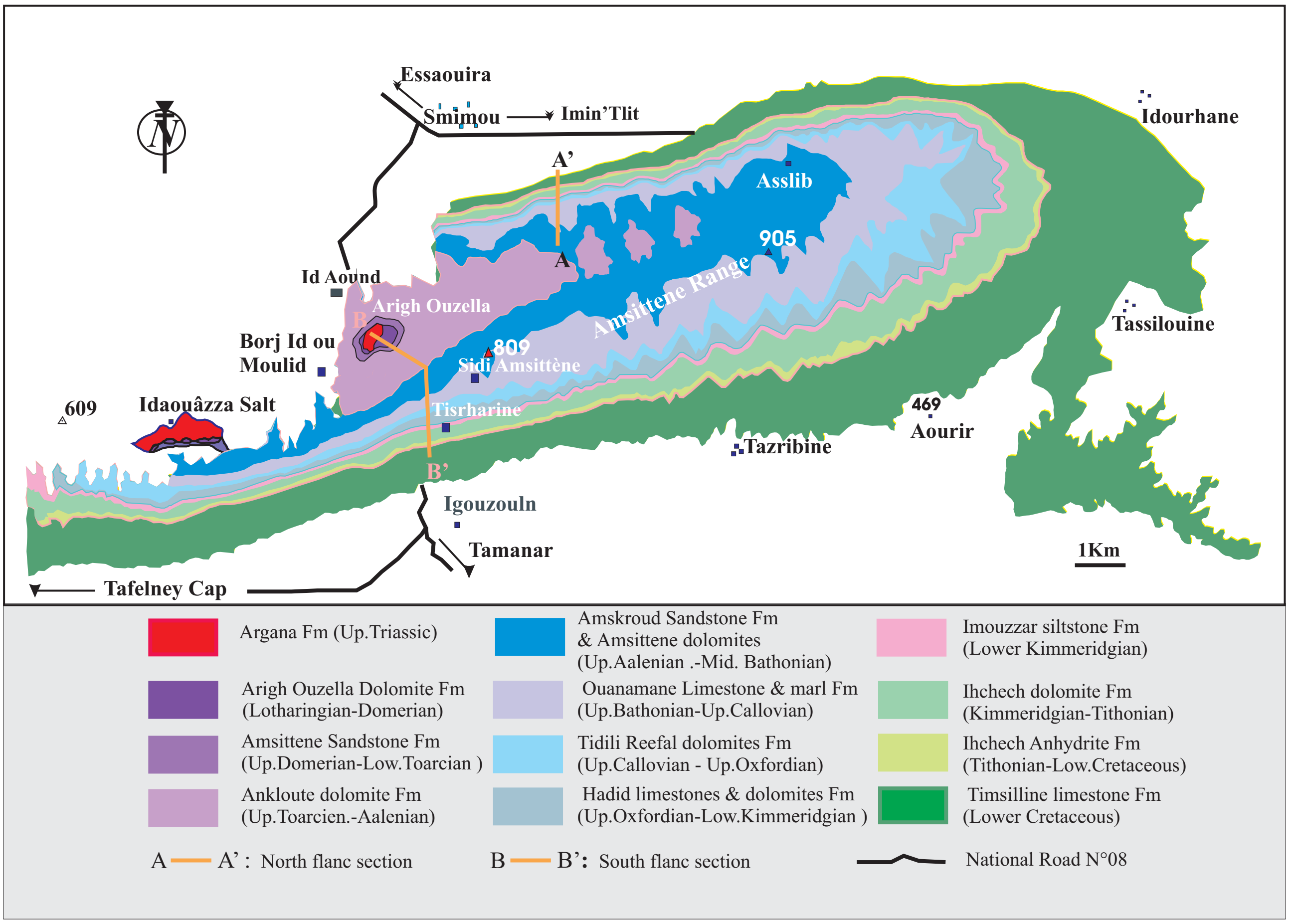

Figure 2: Geological map of the Jurassic formations using the nomenclature of Duffaud et al., (1966) in the Essaouira basin.

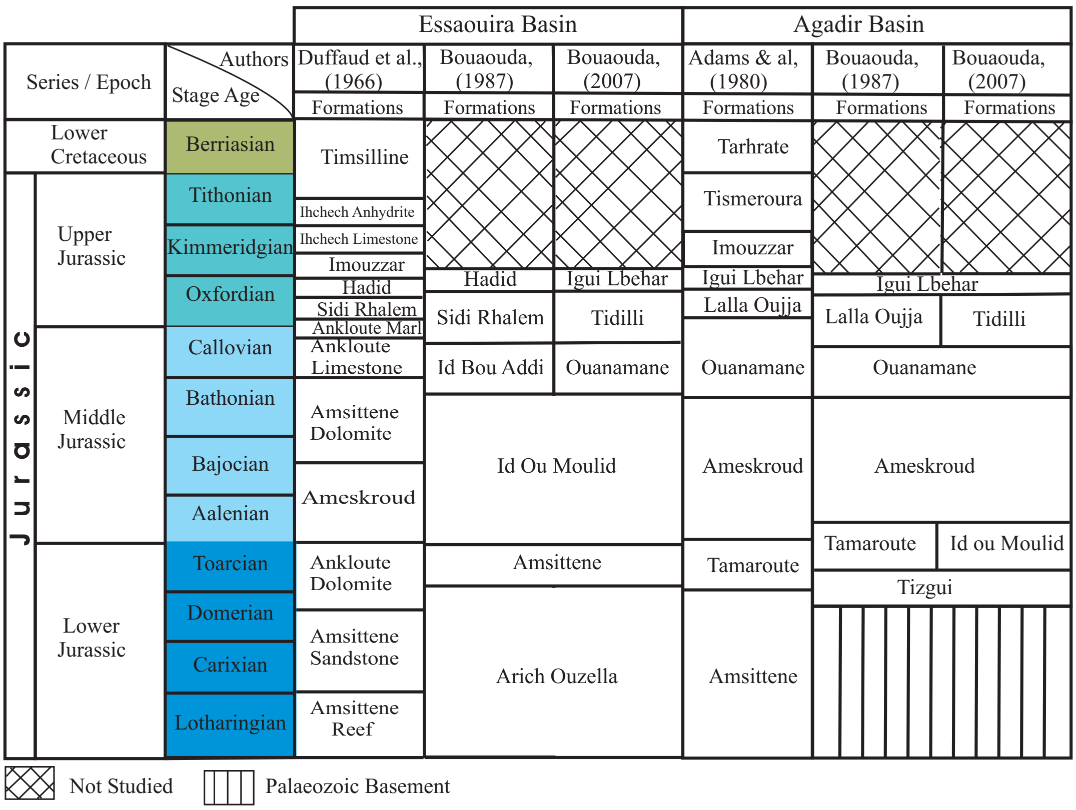

Figure 3 : Correlation charte synthesis of the Jurassic Formations nomenclature In the Western African margin by Duffaud et al., (1966)&Bouaouda, (2007). (Modified).

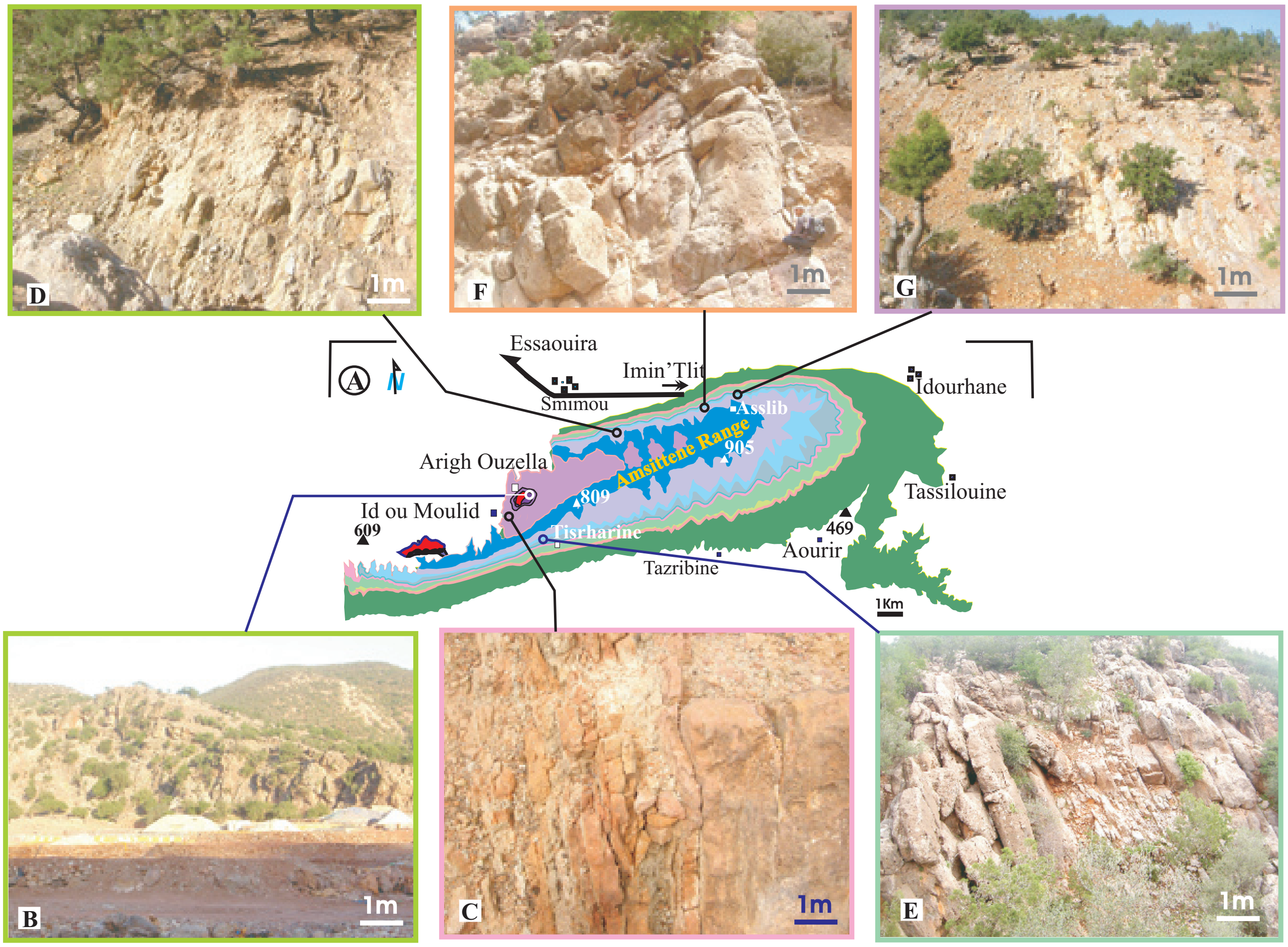

Figure 4: Photomicrographs of main Jurassic Formations in the Amsittene area. (A) location in the geologic map. (B) Arich Ouzella dolomites and Triassic evaporites. (C) Id ou Moulid dolomites. (D) Ouanamane Formation, North flanc of the Amsittene anticline.(E) Tidili reefal dolomites, South Flanc of the Amsittene anticline.(F) Tidili reefal dolomites Fm, North Flanc of the amsittene anticline. (G) Igui lbehar limestone and dolomite succession.

1966; Bouaouda, 1987, 2007). In this study, we focussed on the formations dating from the Lotharingian to the Kimmeridgian periods, as the last three formations dating from the Kimmeridgian to the Tithonian age have already been studied by Marrakchi (1993), Daoudi & Dekoninck, 1994 and Daoudi (1991, 1996). Description, lithology, microfacies, texture and the environment of deposition of the Jurassic Formations in the Amsittene area are summarized in Table 1 & Fig. 5.

4. Clay mineralogy

4.1. Method

Fifty four samples were taken from two complementary sections (sections AA' & BB' in Fig. 2): the basal part was taken from the Southern flank of the Amsittene Anticline and the upper part from the Northern flank. We used X-ray diffraction on oriented mounts to identify the clay fraction (particle size less than 2 µm) of the sediments. Deflocculating was accomplished by successive washing with distilled water after decarbonation with 0.2N HCL. The detailed technique is described by Holtzapffel (1985). Three XRD runs were performed, following air-drying, ethylene glycol salvation for 12 h, and heating at 490 °C for 2 h. A fourth diffractogram (hydrazine treatment) was run on certain samples to distinguish between kaolinite and chlorite. The clay minerals were determined according to the positions of the (001) reflexions on the three diffractograms (Moore & Reynolds, 1989). Determination of the clay mineral proportions was based on the intensity and relative area of the main peak of each mineral. The margin of error was of the order of 5%. In addition, we performed transmission electron microscopy (TEM) in order to determine the structure of clay particles.

4.2. Results

The clay assemblages identified in the Jurassic sedimentary series of the Essaouira Basin were composed of seven clay mineral species (Fig. 6). We identified five simple minerals (chlorite, illite, smectite, kaolinite, and vermiculite), and two irregular mixed-layer edifices (illite-smectite and chlorite-smectite). Within the clay fraction, quartz was ubiquitous, whereas feldspars and oxides appeared sporadically. The variations in the relative

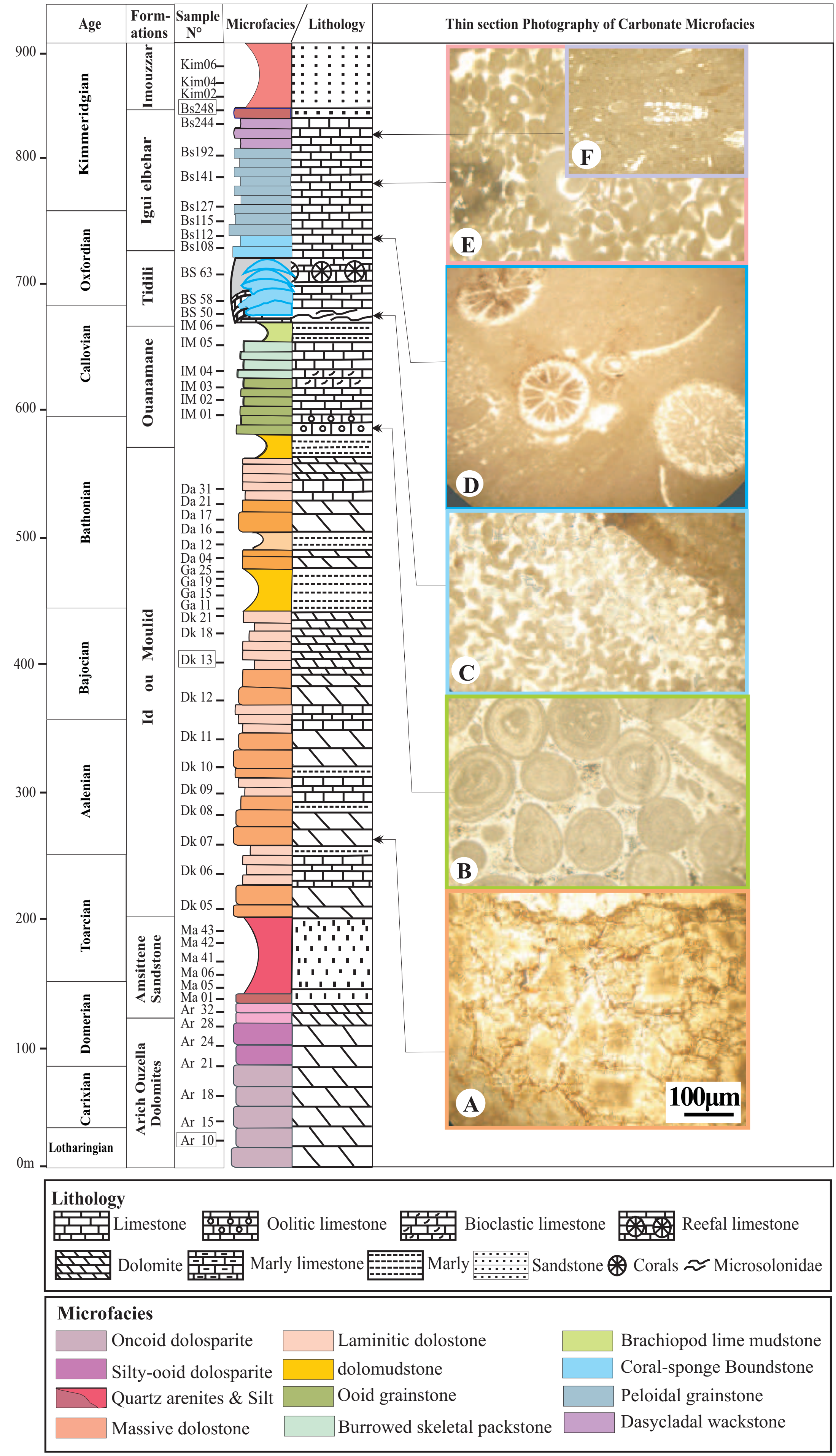

Figure 5: Thin-section photomicrographs of some representatives microfacies from Jurassic Formations in the Amsittene area. (**A**) Idiotopic zoned dolosparite (Id Ou Moulid Fm). (**B**) Oolitic grainstone (Ouanamane Fm). (**C**) Floatstone Corals (Tidilli Fm). (**D**) Bindstone Microsolinidae Corals (Tidilli Fm). (**E**) Bio-Pelsparite consisting of peloids and gastropods (Igui Lbehar Fm). (**F**) Mudstone with dasycladacean algae (Igui Lbehar Fm).

Formation : (Description, lithology & texture)	Environment of deposition	Formation : (Description, lithology & texture)	Environment of deposition
Arirh Ouzella: (*upper Lotharingian - lower Domerian, 60 -70m,)* The facies (***Fig.7a)*** are represented from the base to the top by dolomites with porous oncoids (dolosparites with vugy porosity and moldic dissolution) surmounted by bioclastic limestones with wackstone to packstone texture. The serie ends with quartz-rich detrital dolosparites that preceds the red detrital overlying formation of the Amsittene Sandstones.	Distal platform environment that turns into the high energy sandstone and oo- dolomitic facies series upwards.	**Ouanamane:** *(upper Bathonian –upper Callovian, 135m,)* This formation Fig.7c corresponds to a generalized transgression, consists of Limestone & marl intercalations composed of the following succession of facies : thick oolithic limestones with a grainstone texture (Fig. 8b) , bioclastic limestone banks rich in brachiopods (with a packstone texture), marls rich in brachiopods, foraminifera and some rare fragments of ammonites.	This facies and microfacies distribution indicates a distal carbonate ramp environment, even a basin
Amsittene Sandstones: (*upper Domerian to middle Toarcian, **75m**)* This formation is composed of conglomerates at the base that are gradually followed by microconglomerates, sandstone, silts, and then clays. The detrital facies show cross-bedded channel structures that are organised in sequences of gradually decreasing particle size that end with the fine deposits of the flood plain.	Fluviatile depositional environment evolving upwards to a deltaic plain subject to marine influences.	**Tidili Reefal Dolomite:** *(upper Callovian to upper Oxfordian, 1**30m,*** Fig.7d***)*** The first reef complex (Fig.7d) is characterised by an abundance of lamellar microsolenid corals with a bindstone texture (Fig.8d), bivalves, and Echinidae. This facies is thought to correspond to the reef "colonization" stage, upon which the higher reef complex or reef "diversification" stage – rich in corals, red algae and crinoids. (Ouajhain *et al.*, 2005). The represented textures are essentially boundstone and floatstone textures (Fig.8c); rudstone textures are rare.	This formation attests to the development of a vast barrier reef-type carbonate platform during the Oxfordian in the Essaouira basin.
Id Ou Moulid *(upper Toarcian – middle Bathonian)* ***300m)*** This formation (Fig.7c is composed of an alternation of limestones and pink to yellowish cargneulized dolomites; brecciated dolomites and stromatolithic limestones with a constant rhythmicity and marls with gypsum are also presents. The upper part of this unit is occupied by pinkish massive dolomites (30 banks) rich in bioclasts and dissolution pores. Upwards the massive dolomites become strongly bioclastic (bivalves, radioles, etc.) and bioturbated, indicating a relative deepening. Microfacies are basically crystalline dolomites (Fig.8a) with a dolosparitic texture.	The complete set of facies attests to the installation of an evaporitic proximal platform environment in a hot climate with some rare frankly marine incursions.	**Iggui El Behar:** *(upper Oxfordian to lower Kimmeridgian,* 140m) This formation corresponds in the area to a thick greyish calcaro-dolomitic series (Fig.7f). Several facies and microfacies (Fig.8E,f) can be identified in the series, with a sequential pattern that is sometimes repetitive, indicating a deposition environment with highly variable energy. The identified facies are pelletic limestone sometimes associated with algal laminites, bioturbated limestones, bioclast-rich limestones with a packstone texture, grainstone oolithic limestones, and micritic limestones with bioclasts and dasyclad algae.	The set of facies indicates a sheltered platform environment such as a lagoon. Some reference point levels of pinkish dolomites mark the end of the Hadid formation's sequences and seem to be linked to periods of emersion.

Table 1: Description, lithology, textures and environments of deposition of the Jurassic formations in the Essaouira basin.

proportions of the clay minerals allow us to define, from the base to the top, three zones as follows (Fig. 6):

Mineralogical Zone I (Lotharingian to Upper Domerian): This zone corresponds to the Arich Ouzla Formation. The clay assemblages are mostly represented by illite (65% on average), associated with chlorite (15-25%) and quartz (5-10%).

Mineralogical Zone II (Upper Domerian to Upper Bathonian): This zone comprises Amisittene and Id Ou Moulid Formations. This zone is characterized by the development of smectites. The proportion of smectite ranges from 20 to 80% at the expense of illite (20 to 60%) and chlorite (5 to 25%). Kaolinite is absent at the base of the zone, then it gradually increases upwards and reaches a content of between 10 and 20%. Vermiculite (10-15%) appears sporadically in two levels of the Aalenian and the Bajocian.

Mineralogical Zone III (Callovian to Kimmeridgian): This zone comprises the Ouanamane, Tidili, Iggui El Behar, and Imouzzar Formations. The clay is characterized by the disappearance of smectite and chlorite and the development of illite, which reaches up to 85% of the clay fraction in certain levels.

Irregular illite-smectite and chlorite-smectite mixed layers are observed in the first half of this zone. They account for 15% of the clay fraction on average. Towards the upper part, smectite increases upwards at the expense of the irregular mixed layers. Kaolinite is present throughout the zone, reaching up to 30%, but slightly decreasing upwards.

The value of illite crystallinity, expressed by the half height width of the 10 Å peak, (Kübler, 1968; Kisch, 1991) is highly variable through the series (ranging from 0.2 to 0.8°2 θ), but it does not show any significant changes with depth (Fig. 6).

Under the transmission electron microscope (TEM), the illite crystals from the Essaouira series show xenomorphic forms with irregular or rounded contours of

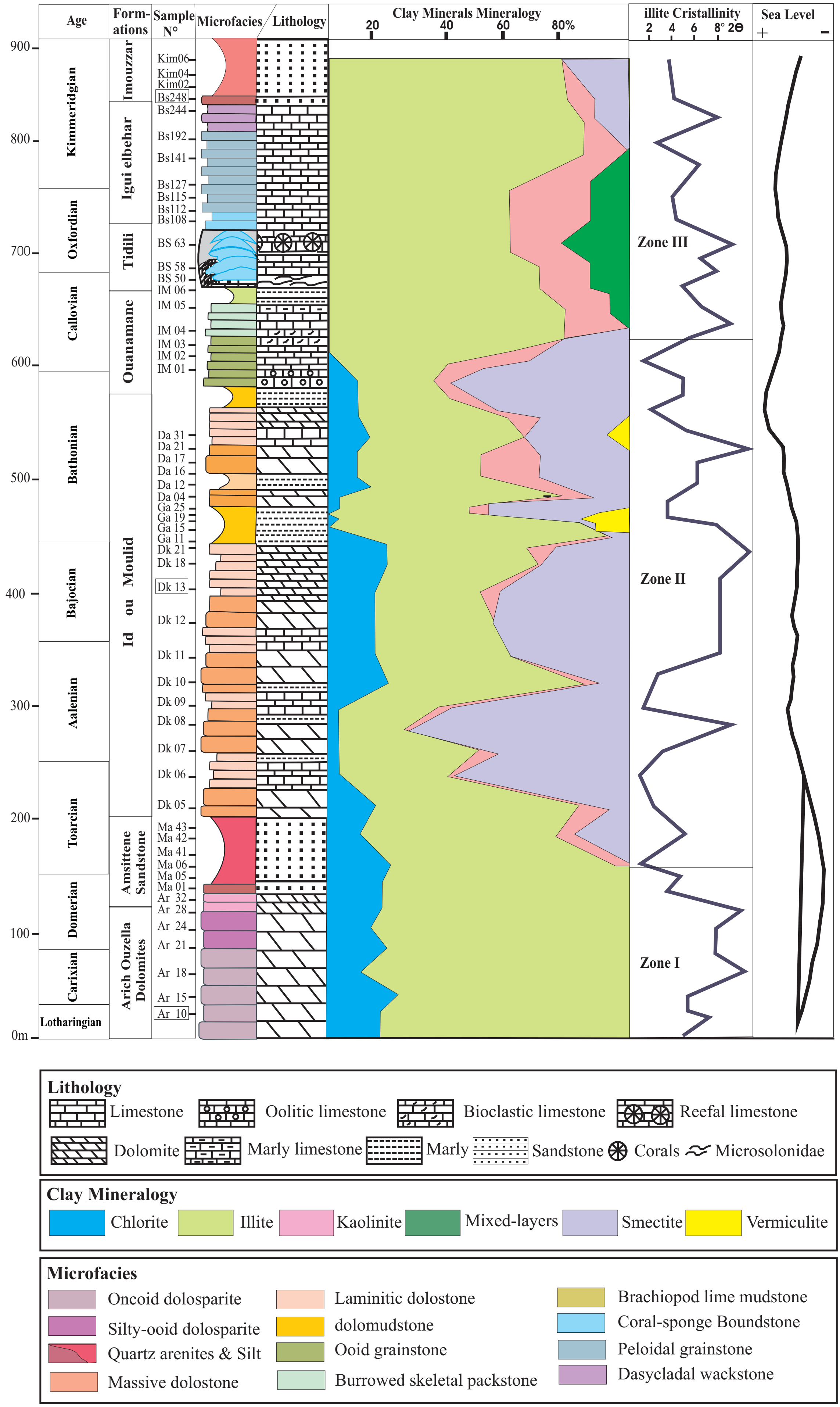

Figure 6: Lithology and evolution of clay minerals assemblage during the Jurassic in the Essaouira basin.

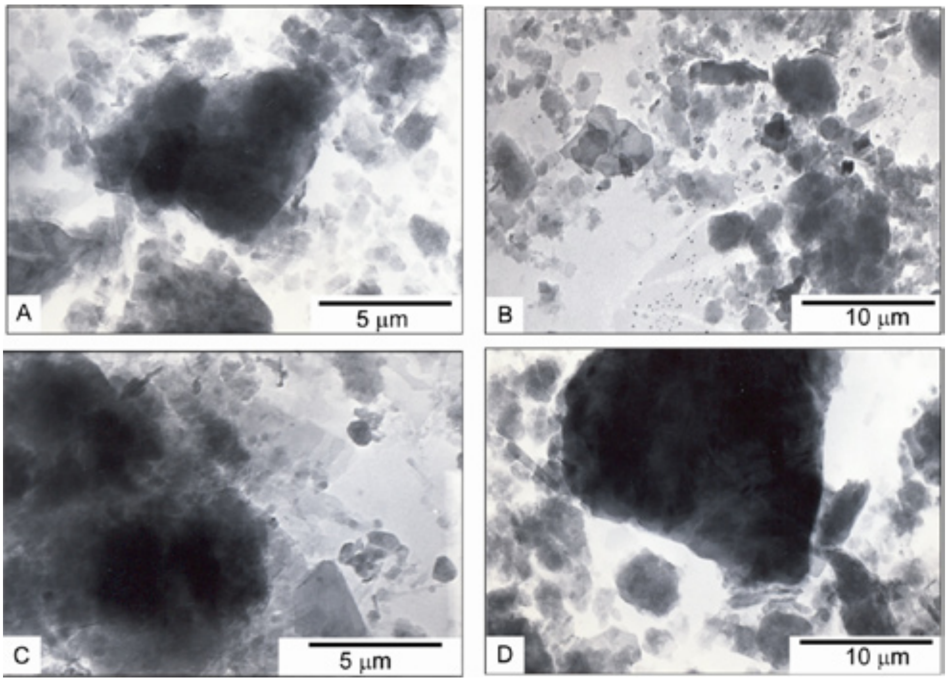

Figure 7: Transmission electron microscope images showing illite crystals of various sizes and irregular or rounded contours from Zone I (A and B); smectite particles with flakey structures and indistinct contours (C). In the lower left hand corner of the photograph one can distinguish some small pseudo-hexagonal and hexagonal kaolinite crystals, and, in the middle, a large particle of illite, from Zone III (D).

various sizes (Figs 7a, b). Smectite particles are seen as flakelike structures with fuzzy edges (Fig. 7c).

5. Interpretation and discussion

5.1. Effects of diagenesis on the clay assemblages

The distribution of the clay assemblage does not correlate with the lithology. For instance, in Mineralogical Zone II, the sharp changes in smectite, illite, and chlorite in the lithology (limestones, marly limestone, and marls) failed to reveal any systematic variations in the clay assemblage. This lack of correlation between clay mineralogy and lithology is particularly well expressed by the comparison of calcium carbonate levels and clay assemblages (Fig. 8). The vertical evolution of the clay assemblages in the Essaouira field shows that burial diagenesis is unlikely to have an effect on the Essaouira clay composition for several reasons: (1) the measured crystallinity values of the illite from Essaouira are relatively high (up to 0.8°2θ) and do not show any improvement with increasing depth; (2) smectite, which is unstable under burial diagenesis conditions (Dunoyer de Segonzac, 1969; Chamley, 1989), is abundant (up to 80% of the clay assemblages); (3) the total thickness of the Jurassic series in the Amsittene area is approximately 2200 m, whereas in the Agadir region it reaches at least 3000 m; (4) TEM observations show that illite crystals from the Essaouira series have xenomorphic forms with irregular or rounded contours (Figs 7a,b), whereas the illites resulting from burial diagenesis have automorphous structures (Chamley, 1989; Daoudi et al., 2002).

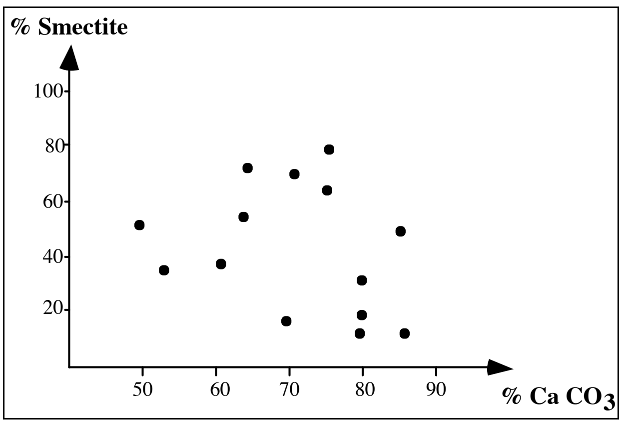

Figure 8: Ratio of calcium carbonate to smectite content in mineralogical zone II of the Essaouira basin.

In the Essaouira Basin, the clay mineralogical changes due to burial are weak to non-existent. This is in agreement with the geodynamic context of this area. The basin is situated in a stable area and the geothermal gradient is moderate, as one finds in slowly extending passive margins (Rimi, 1993; Bouatmani, 2002). The mineralogical assemblages of the Jurassic sediment series of the Essaouira Basin reflect more clearly changes in palaeogeography than intrinsic changes in the basin. In other words, they were able to preserve to a great extent a record of the contemporary geological history of sedimentation in the area.

5.2. Palaeogeographic significance

The co-existence of secondary mineral species (kaolinite, smectite, and mixed layers) and primary minerals (illite and chlorite) throughout the series suggests that the primary minerals come from the reorganization of the emerged old bedrock, which was initially rich in primary minerals. The Palaeozoic and Triassic bedrocks are rich in illite and chlorite (Huon et al., 1993; Daoudi et al., 1995; Daoudi, 1996; Rais, 2002). Periods of tectonic instability favour the reorganization of the clay minerals of the rocky substrata (illite and chlorite) over those of the soils (kaolinite, smectite, and mixed layers). Consequently, the relatively high abundance of illite in the series reflects the proximity of ranges (Western Meseta, for example) subjected to physical alteration, as well as the existence of sloping reliefs conducive to active erosion. An exhumation of deeply buried terranes containing abundant illite and chlorite is also possible because of the abundance of the salt tectonic in the area (Souid, 1984; Taj Eddine, 1991).

In Mineralogical Zone I, the mineral fractions are dominated by primary minerals such as illite and chlorite. The structures (Figs 7a, b) and the abundance of illite, and associated minerals such as quartz and feldspars, reflect a heritage of Palaeozoic materials delivered by active erosion. This period corresponded to the first stage of the opening of the Atlantic. The Moroccan Atlantic margin was marked by rapid subsidence (Medina, 1994; LeRoy, 1997; Labbassi, 1998; Bouatmani, 2002), combined with tectonic instability in the hinterland (Manspeizer, 1988; Medina, 1994). Such instability does not allow pedogenesis but enhances the erosion of minerals from the Palaeozoic substrata of the Anti-Atlas and essentially the Western Meseta, which are largely composed of micas-illites.

In Mineralogical Zone II, the abundance of illite and chlorite would indicate active erosion of the adjacent highlands following the subsidence of the basin. The abundance of well-crystallized smectites (Fig. 9, Sample DK13) in this area seems to result more from *in situ* neoformation rather than from a simple heritage. During this period, the instability of the margins following the opening and enlargement of the young Atlantic Ocean must have opposed the completion of the pedogenetic processes responsible for smectite crystallization. Moreover, as specified earlier, the outcrops are characterized by an illite and chlorite rich clay fraction and by the absence of smectite. What is more, an examination of parameter *b* of the smectites shows that the 060 ray is located around 1.53 Å, which is characteristic of magnesium trioctahedric structures. Under the transmission electron microscope, these smectites are seen as flakelike structures with fuzzy edges (Fig. 7c). In confined evaporitic environments, this type of smectite, which is similar to silicate evaporites, is generated *in situ* by the precipitation of highly concentrated chemical elements in the sedimentation (Weaver and Beck, 1977; Trauth, 1977; Chamley, 1989). The smectites of Mineralogical Zone II thus seem to result from this type of process, all the more so as they are associated with the facies of the shallow environments of deltaic plains and evaporitic proximal platform environments in a hot climate.

The sharp variations in the smectite content at the expense of illite may be explained by marine incursions already revealed in the description of the facies and microfacies (Table 1 & Fig.5). These marine incursions deepened the depositional environment. This would have prevented chemical sedimentation (a process that can give rise to evaporite) and would have been more favourable for the sedimentation of detrital materials rich in illite, chlorite and associated minerals such as quartz and feldspaths.

Towards the upper part of the zone, kaolinite, which occurs in small amounts, is associated with various lithologies. This supports the idea that kaolinite has a detrital origin; it would appear that this mineral comes from the soils of sloping reliefs. The appearance of kaolinite is thus a precursor of the start of the stabilization of the margin and of the formation of pedological covers.

In Mineralogical Zone III, illite continues to be the dominant mineral species and kaolinite is starting to take on importance. However, the main characteristic of this zone is the simultaneous disappearance of smectite and chlorite and the development of mixed layers. This mineralogical discontinuity may be explained by a generalized transgression that took place over the entire El Jadida-Agadir Basin in the Callovian (Haq et al., 1987; Bouaouda, 2004). As in the case of the marine incursions documented in Zone II, this generalized transgression deepened the depositional environment, thereby making it less suitable for the formation of smectites through the process of neoformation, hence their sudden disappearance. The mineralogical assemblage consequently originated mainly from detritus. This mineralogical disruption coincides totally with a major diversification of the fauna, which is dominated above all by benthic foraminifera, brachiopods, and a few ammonites, reflecting the importance of this event.

The proportion of kaolinite in zone III increases significantly compared to Zones I and II (Fig. 6). This indicates for the region the establishment of a hot and strongly hydrolysing climate as well as the presence of sloping reliefs conducive to active ionic leaching (Millot, 1980; Chamley, 1989; Thiry, 2000). The co-existence of kaolinite with metal oxides and hydroxides such as hematite and goethite is in agreement with the development of this type of climate. The quasi absence of chlorite from the mineralogical assemblage of this zone also supports the idea that this zone was exposed to a strongly hydrolysing climate, given chlorite's vulnerability to hydrolysis (Dejou et al., 1972; Chamley, 1989). The development of this type of climate is, moreover, supported by the study of the distribution of marine microfauna (Bouaouda, 1987, 2007). The mixed-layer edifices (principally of the illite-smectite type) remain irregular everywhere and increase gradually towards the top of the zone. These mixed layers are probably of pedogenetic origin and represent the first, incomplete, stages of the meteoric alteration of crystalline rock. Indeed, in the sediment series, these interbedded minerals generally represent intermediate stages of development between illite and smectite (Paquet, 1970; Millot, 1980; Chamley, 1989).

Unlike the smectites in Zone II, which have a well-defined diffraction peak (Fig. 9, Sample DK13), the Zone III smectites have a poorly defined diffraction peak (Fig. 9, Sample BS 248), suggesting a poorly crystallized phase

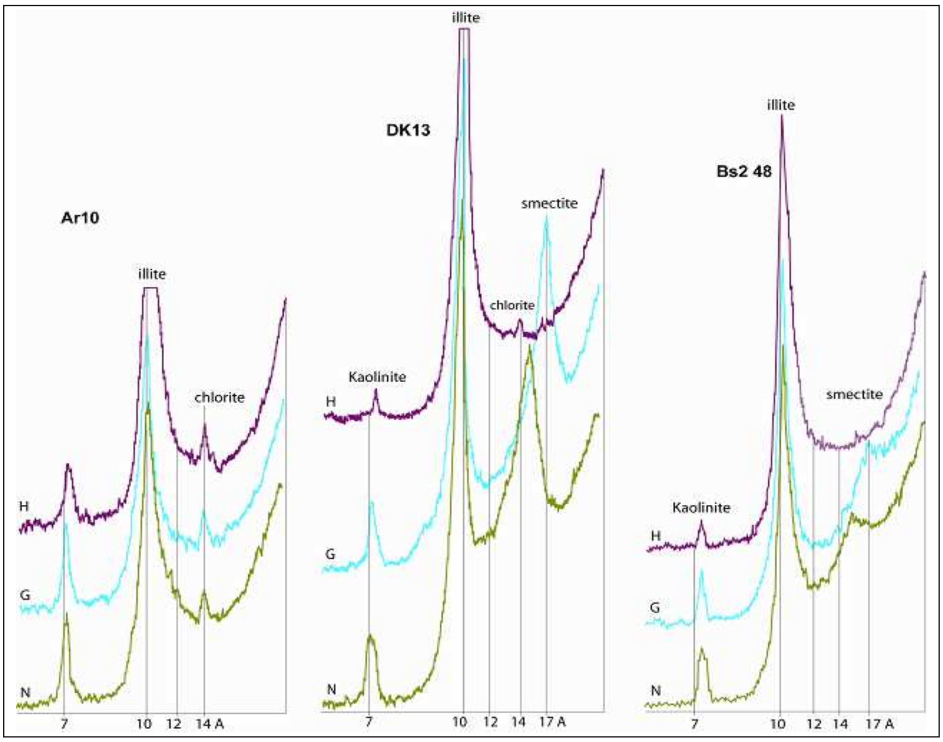

Figure 9: Typical diffractograms from the different mineralogical zones: Ar10 (Zone I), DK13 (Zone II) and BS248 (Zone III) (N ; Natural, G ; Glycolated and H ; Heated).

characteristic of pedological profiles (Paquet, 1970). The presence of smectites in small amounts in this level of the sediment series suggests the start of the flattening of the reliefs, which is necessary for the crystalline growth of smectites (Paquet, 1970; Millot, 1980). This interpretation of the origin and significance of smectite minerals in this zone is supported by the absence of volcanic substrates in the drainage basin of the studied area. The clay assemblages of the Essaouira Basin during the Upper Jurassic and Lower Cretaceous exhibit larger proportions of smectite (Daoudi, 1996; Ouajhain & Daoudi, 2004). This may be explained by the fact that the adjacent elevated areas were in a more advanced state of flattening (Wurster & Stets, 1982; Wiedmann et al., 1982).

5.3. Thermotectonic control

The tectonic instability of the margins prevents the completion of the surface pedological actions responsible for smectite formation, because the rocks that are subjected to chemical alteration are constantly rearranged by mechanical erosion. Pedological actions take on importance near the summit of the zone II. This explains the appearance of smectites. The development of smectites would appear to depend upon reduced tectonic activity in the basin. This is in agreement with the results of qualitative analysis indicating that the distensive periods of the Middle and Upper Jurassic were interspersed with phases of deceleration of the basin's subsidence (Labbassi et al., 2000; Zühlke et al., 2004). Another important factor that seems to have controlled the nature and degree of evolution of the clay minerals is the structural position of the Amsittene region during the Jurassic. The different published seismic sections show clearly that the Amsittene region was separated from the Essaouira Basin by the normal – reversed in the Tertiary – fault of Taghzout, running E-W and with a North dip (Hafid, 1999; Bouatmani et al., 2004). The Amsittene region is located on the ridge of the Southern compartment, whereas the Northern compartment harbours a fan that thickens towards the fault, which attests to the synsedimentary nature of the fault. This high position appears to explain the relatively small degree of burial and the lower temperatures recorded, whereas the temperatures achieved in the part of greatest subsidence in the Essaouira Basin were high enough to reach the gas window (Ro = 1.3-2.6) for the Oxfordian parent rock (Bouatmani et al., 2007).

6. Conclusions

The influence of diagenesis on the clay assemblages in the Jurassic sediment series of the Essaouira Basin is weak to negligible; heritage thus appears to be the main source of the clay successions in this series. The minerals result principally from erosion, alteration processes and chemical phenomena occurring before their sedimentation. They reflect the palaeogeographic, tectonic, climatic, and eustatic conditions under which the sediments containing these clay assemblages were deposited. The detrital influences on the composition of these assemblages depend upon a combination of three main factors, as follows:

1- Tectonic activity was seen throughout the series through the increased inputs of illite and sometimes chlorite, as well as associated minerals such as quartz and feldspaths. This mineralogical tract seems to be marked by the preponderant heritage of the actively eroded materials of the Palaeozoic and Triassic substratum.

2- The influence of climate was expressed during the periods when the tectonic effect slowed down through the input of mixed layers, smectites, or kaolinites, as well as associated minerals such as metal oxides and hydroxides, and by the rarity or disappearance of chlorite.

3- Eustatic variations are expressed particularly well in Zones II and III, where marine incursions prevented chemical sedimentation of trioctahedral smectite following the deepening of the basin. This situation would appear to have been more favourable for detrital sedimentation composed for the most part of illite and chlorite.

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