New insight ontide-dominated estuary and deltain the Eocene-Miocene Mrayt Group, North-Western Rif, Morocco

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Abstract

The sedimentary deposits of Eocene-Miocene Mrayt Group, North-Western Rif, Morocco has been the subject of controversy by previous worksregarding their depositional environments. Detailed sedimentological study based on petrographic study, and sedimentary facies and paleocurrent measurements analysis, leads to several results and new insights.

Petrographic study provided the first evidence of mixed siliciclastic and carbonate sediments and their nomenclature:silty micrites, micritic siltstones, micritic sandstones, sandy micrite, and allochemic sandstones, as well as the nature of the sedimentsources and their geological context.

Twenty two sedimentary facies that have never been described before are identified, and based on their succession and associationa new interpretation of depositional processes and depositional systems are proposed. The paleoenvironments of the Mrayt Group are interpreted as littoral andshallow marine settings: tides-dominated estuary, tides-dominated delta systems and open coast tidal flat, under complex hydrodynamics strongly influenced by river discharge, tidal currents, waves and storms action.

Sedimentation occurred in “the Maghrebian basin” under the interplay of:i) tectonics relatedto the Cenozoic collision of the African and Eurasian continental plates, ii) Cenozoic alternation of warm climate and cooling due to the increasing influence of Antarctica glaciation, iii) sediments supplies induced by rejuvenation of sedimentary sourcesandiv)sea level fluctuation related to the advance and retreat of ice-sheet on Antarctica.

Key wordsTide dominated delta, mixed siciliciclastic/carbonate rocks, Mrayt Group, NW Rif, Morocco, Eocene –Miocene

Introduction

The alpine Rif belt has been studied since 1846 in the frame of several national and international programs. Most of these researches focused on tectonic, geochemistry, petrography, biostratigraphy and geophysics, while sedimentology was mostly neglected. Thus, the paleogeography and the geology of the region reported in geological maps of the NW Rif sections were interpreted without taking into account the sedimentary facies and their variations. This has given origin, to the many controversies on the relationships between the tectono-paleogeographic units, and their lithostratigraphy (Hamoumi 1995a). The paleogoegraphy in this area is complex and mostly unconstrained, therefore, sedimentological facies and depositional environemental analysis is important to reconstruct this.

Sedimentological studies conducted in the flysch domain of the NW Rif belt, in the framework of "The Linked Project Cross the Strait of Gibraltar between Africa and Europe" (Hamoumi 1995b; Hamoumi et al. 1995; Ouldchelha et al. 1995; Salhi et al. 1995), has highly contributed to the knowledge of the depositional environments that prevailed over the Cretaceous-Miocene period and their allogenic and autogenic control.

The Eocene-Miocene Mrayt Group, in the North Western Rif, Morocco was described for the first time by Suter and Fiechter (1966) and called "Flysch de Sidi Mrayt" by Suter (1986). It has been studied for its tectonics, lithostratigraphy, biostratigraphy and sedimentology (Suter and Fiechter 1966; Suter 1980; Suter 1986; Morley 1992; Tejera of Leon 1993;Abdelkhaliki 1997; Raissouni et al. 2008). Although these studies have agreed on the lithostratigraphic characteristics of these sedimentary series, there are, however, discrepancies concerning the environment in which they were deposited. Indeed, the deposits of this group have been interpreted as: 1) synorogenic turbidites organized in two sequences (Morley 1992): a lower sequence referred to a Type I deep sea fan system, and an upper sequence linked to a Type III deep sea fan system (sensu Mutti1985) ; 2) reworked and redeposited slope sediments by bottom currents on an abyssal plain, capped by slides and mass flow deposits that accumulate at the end of slope in un-channelized areas (Tejera de leon 1993); 3) a sedimentary prism adjacent to the outer edge of the platform subjected to storm waves action and passing to a Mutti type III deep sea fan system (Raissouni et al. 2008).

Detailed sedimentological study conducted for the first time in the Mrayt Group, allows bringing new results concerning: the nature of the sediments and their sources, thesedimentary facies, the depositional systems, the sedimentary processes and the allogeniccontrol. The aims of this work are: 1) to highlights the mixed composition (siciliciclastic/carbonate) of the Mrayt Group sediments and to introduce a more adequate nomenclature for these deposits;2) to bring new findings, including the characterization of new sedimentary facies never described before anda new interpretation of the depositional processes and sedimentary environments corresponding to tide-dominated estuary, tide-dominated delta systems and open-coast tidal flat; 3) to documentthe evolution from tide-dominated estuary to tide-dominated deltaand then to open-coast tidal flatand it's control during the Eocene–Miocene in the Rif alpine belt.

In addition to these new results this study is important for increasingour knowledge about ancient tide-dominated delta that is less investigated in comparisonto the other deltaic systems (waves or river dominated) and its responses to sea level changes and tectonics. Tide- dominated deltas arethose where tide currents are the dominant process controlling sediment dispersal (Galloway 1975; Goodbread and Saito 2012, and references therein). Furthermore correct interpretation of Eocene–Miocene sedimentary sections of the North Western Rif is essential to understand the paleogeography and the geodynamic evolution of the Rif alpine belt which is a part of the peri Mediterranean alpine belt.It's also critical for regional economies as deltas may contain significant volumes of oil and gaz.

Geological setting

The Mrayt Group is a 1730 m-thick sedimentary unit crops out in the North Western Rif along the Atlantic littoral between the cities of Asilah and Larache in North Morocco (Fig.1). It belongs to the Prerif domain of the Rif belt (Suter and Fiechter 1966). The Rif beltrepresents the westernmost part of the Maghrebide belt that belongs to the western part of the alpine Mediterranean orogen and its connected to the Betic belt through the Gibraltar arc (Fig.1A). It corresponds to a syntectonic province characterized by the alpine folding related to the Tertiary collision between Alboran microplate, the Iberian plate and the African from the Oligocene to the Late Miocene (9-8 Ma) (Dewey et al. 1989;Srivastava et al. 1990; Leprêtre et al.2018 and references therein).

The Rif belt (Fig.1B) is composed of three main structural units, from West to East: i) the "external Zone" that consists of three stacked units (in ascending order): the Prerif, the Mesorif and the Intrarif, ii) the flysch thrust sheets composed of several tectonic units as the Numidian flyschs, the Mauritanian flyschs and the Merinideflyschs and iii) the "internal Zone" considered as a part of the "Thetysian Alboran Terrane" (Durand-Delga et al. 1962; Andrieux1971; Suter 1980).

The Mrayt Group (Fig.1B and Fig.1C) crops out in the North western "external Zone" of the Rif North of the Jebha-Chrafat accident and is overlapped to the East by the allochthonous Habt unit (Suter 1980 and 1986). It's deformed by a section of anticline and syncline folds trending S-N, and separated by overthrust faults (Tejera de Leon1993). Stratigraphically, the Mrayt Group rests on Cretaceous marlstones and consists of four Formations(Tabl.1)from base to top: Lower pelitic" formation, Sandstone-pelitic formation, Upper sandstone-pelitic formationand Si Moussa Formation which rests unconformably on the underlying formation. These formations are ranging in age from the Lower Eocene to the Middle Miocene based on microfossils (Suter and Fiechter1966; Suter 1980 and 1986; and Tejera de Leon 1993).

Tabl. 1 Lithostratigraphy of theMrayt Group formations (after Suter and Fiechter 1966; Suter 1980 and 1986; and Tejera de Leon 1993)

Formation		Thickness	Lithology	Age
Si Moussa Formation		500m	Interbedded sandstones and marly pelites	Middle Miocene (Langhian)
Upper pelitic Formation		100m	Interbedded sandstones andpelites	Upper Oligocene to LowerMiocene
Sandstone and pelitic Formation	Upper conglomeratic member	400m	Interbedded sandstones, pelites and conglomerates	Early to Upper Oligocene
	Lower sandstones and pelitic member	600m	Interbedded sandstones, pelites and microglomerates	
Lower peliticFormation	Upper member	100m	Interbedded sandstones and pelites	Lower Eocene
	Lower member	50m	Interbedded microglomerats, sandstones and marlstones	

Methods

Reconstruction of Mghait Group depositional environments is based onanalysis and interpretation of sedimentary facies and sedimentary facies associations as well as paleocurrent measurements. Sedimentary facies are identified on the basis of their petrofacies and lithofacies. The petrofacies is here defined in term of composition and texture introduced for rocks classification (Mansfield 1971; Dickinson and Rich 1972). The lithofacies refers to a body of rock with specific characteristics that form under certain conditions of sedimentation, reflecting a particular process or environment. It’s defined on the basis of lithology, colour, bedding (thickness, geometry, nature of the contacts separating the strata, internal architecture) and physical and biological sedimentary structures (see references in Reineck and Singh1980; Reading 1986; Walker 1992).

Fivesections belonging to the Mrayt Group, totalizing 1730 min thickness has beensubjected to detailed sedimentological studyincluding sampling (Fig. 1C). They are named: MG1- Damina section, 80m thick (X= 6.06; Y= 35.42), MG2- Marabout section, 750m thick (X= 5.85; Y= 35.36), MG3- Sidi Mrayt beach section, 200m thick (X= 5.85; Y= 35.41), MG4- Merja section, 520m thick (X= 5.96; Y= 35.43), and MG5- Merja ravine section, 280m thick (X= 6.05; Y= 35.44).The stratigraphic sections were logged in a high detail using bed by bed centimeter-scale description of: lithology, colour, bedding (thickness, geometry, nature of the contacts separating the strata and internal architecture) and physical and biological sedimentary structures.

The petrographic study has been based on the examination of 50 thin sections under polarizing microscope.The determination of the composition takes into account the detrital, authigenic and organic constituents and the texture includes the proportion of clay matrixand the shape, roundness, surface features, grain sizeand fabric of the grains. The petrographic study, indicate that the investigated sedimentary rocks are composed of mixtures of siliciclastic and carbonate sediments. The existence of carbonates had already been demonstrated by the reaction to HCL during the fieldwork. Therefore it was necessary to apply the classification of Mount (1985) in order to establish the precise nomenclature for the petrofacies. This classification defined eight general classes of mixed sediments based on the percentage of the four components: i) siliciclastic sand (sand-sized quartz, feldspar, etc.), ii) mud (mixtures of silt and clay), iii) allochems (carbonate grains such as peloids, ooids, bioclasts and intraclasts > 20pm in size) and iv) carbonate mud or micrite (< 20 pm in size). The name of the class is based on both dominant grain type and the most abundant antithetic components. For example a sedimentary rock that contain more than 50% sand-sized siliciclastic components and accessory allochems,is named an allochemic sandstone.

In each section, the sedimentary facies identified were clustered into sedimentary facies association (Reading 1986)according to the following criteria: their environmental significance, their genetic relationship and their situation in relation to each otheraccording to Collinson (1969) and Reading (1986). The paleocurrent measurements were performed on 48 flute casts in the five studied stratigraphic sectionsand the dip of longest axis of the clasts in the three conglomerate levels (Facies F17).

Sedimentary facies analysis

The Petrofacies

The Petrographical analysis show that the Mrayt Group deposits consist of mixed siliciclastic / carbonate sediments, composed of: siliciclastic and carbonate grains, matrix and cement (Fig. 2). The siliciclastic minerals consists of: 1) moderately sorted, angular, sub-rounded or rounded detrital quartz grains, that may be monocrystalline with undulating extinction or polycrystalline (polygonised quartz, slightly sutured grains and chert) and sometimes with a secondary quartz overgrowths; 2) sub-rounded to sub-angular, < 0.125 mm in size feldspar grains (microcline, plagioclase and orthoses) which are affected by alteration to various degrees ; 3) sub-rounded to angular, > 2 µm in size lithic clasts of sedimentary, volcanic or metamorphic origin,; 4) altered micas (muscovite, biotite and chlorite); 5) glauconitic grains; 6) heavy minerals (rounded zircons, green tourmaline) and 7) opaque minerals including iron oxides. Carbonate components consist of: calcite lithoclasts which may include benthic and planktonic foraminifera including e.g., Orbitolina and sometimes micritized Calpionella, skeletal fragments of: gastropods, bivalves, echinoderms, bryozoans and algae and sometimes rhombohedral crystals of dolomite. The bonding phase is composed of carbonate cement (microsparite and sparite), ferruginous and siliceous cements, and sometimes by a clay matrix. Five petrofacies were identified based on the percentage of the dominant grain type and the most abundant antithetic components,according to Mount (1985) classification.These petrofacies are:siltymicrites, micritic siltstones, micritic sandstones, sandy micrites, and allochemic sandstones(Fig. 2, photos A, B, C and D).

The Sedimentary Facies

Sedimentological field studies combined with petrofacies analysis have resultedin the recognition for the first time of twenty two sedimentary facies,in the five studied outcrops of the Mrayt Group(Fig. 3, 4, 5, 6, 7and 12).

Facies F1 (Fig. 3Aand Fig. 6),is observed in the lower PeliticFormation of Early to Middle Eocene age (Fig.3). It consists of alternating centimetric to decimetric micritic siltstone bed and decimetric bioturbated marl interbed. The bed has an undulated; erosive lower base and generally contain five intervals(from base to top): 1) an interval (a) limited to its top by a reactivation surface and made up of successive couplets ofthick (1-5cm) and thin(0,5-1cm)planar parallel micritic siltstonelaminae limited each one to its upper surface by very thin mud layers (mm-scale)or mud drapes, 2) an interval (b) composed of ripple- cross- stratified micritic siltstoneand mud layerslightly following the concavity and convexity of the underlying rippled surface, 3) an interval (c) with alternating planar parallel laminae of silty micrite and mud drapes, 4) an interval (d)composed ofripple-cross-laminated micritic siltstone which display symmetrical and asymmetrical ripplesin which small lenses of mud are preserved in the trough of the ripple and 5)an interval(e) composed ofmicritic siltstone with ripples that vary in size and shape in the same layer. The top of bed shows centimetric to decimetric-scale desiccation cracks.

Facies F2 (Fig. 3B and Fig.6),occursin the lowerPeliticFormation of Early to Middle Eocene age (Fig.3). It consists of alternating centimetric to decimetric micritic siltstone bed and decimetric bioturbated marl interbed.

The bed is erosively basedand display three intervals (from base to top): 1) an interval (a) composed of ripple-cross- laminated micritic siltstone which display symmetrical and asymmetrical ripplesin which small lenses of mud are preserved in the trough of the ripples, 2)an interval (b) composed of ripple-cross -stratified micritic siltstone and mud layers, slightly following the concavity and convexity of the underlying rippled surface, and 3) an interval (c) composed of rippled micritic siltstone lenses on a muddy layer. The top of bed shows Zoophycos trace fossil, Psilonichus Y-shaped burrows and centimetric to decimetric-scale desiccation cracks.

Facies F3 (Fig. 3C and Fig.6),is identified in the lowerPeliticFormation of Early to Middle Eocene age andthe upper part of the Sandstone and pelitic Formation ofUpperOligocene age (Fig.3). It consists of lenticular, cm-thick sandy micrite layer, intercalated with metric pelitic level. The sandy micrite bed is erosively based and is composed of two intervals. The lower interval (a) is slightly deformed, without visible bedding and the upper interval (b) is characterized by asymmetrical ripples which may display two types of internal structures:1) offshooting and draping laminations expressed by forest laminae which ascend and overlap the flank of the adjoining ripple, 2) composite internal structure made up of an assemblage of differently structured, generally bidirectional lenses. The top of this interval contain straight-crested ripples and sometimes containsZoophycos trace fossil, Psilonichus Y-shaped burrows and centimetric to decimetric-scale desiccation cracks.

Facies F4 (Fig. 3D and Fig.6),occurs in the lower PeliticFormation of Early to Middle Eocene ageandthe upper part ofthe Sandstone and pelitic Formation ofUpperOligocene age (Fig.3). It consists of centimeter to decimetric lenticular sandy micrite bed intercalated with metric pelitic level. The bed has an erosively undulating base and an erosive top. It’s composed of two intervals: the basal interval (a) comprises sets of parallel plane laminae, separated by reactivation surfaces. The upper interval (b) consists of tangential cross laminated cm-bundles separated by erosional surface and mud drape. The top of this interval exhibits centimetric to decimetric desiccation cracks.

Facies F5 (Fig. 3E and Fig. 6), is identified in the lowerPeliticFormation of Early to Middle Eocene age (Fig.3). It consists of interbedded centimeter to decimetric silty micrite bed and decimetric bioturbated pelitic layer. The silty micrite bed has an erosive undulating base and its generally composed of 3 intervals: 1) a lower interval (a)exhibiting mud pebbles and asymmetric ripples characterized by a planar base and planar cross-lamination, 2) a structureless intermediate interval (b), and 3) an upper interval (c), characterized by parallel undulated laminations, pinching and swelling laterally and passing to incipient lenses. The top of the upper interval is characterized by linguoid ripples and may shows centimetric to decimetric desiccation cracks.

Facies F6(Fig. 3F and Fig. 6)occurs in the lowerPeliticFormation of Early to Middle Eocene age (Fig.3). It consists of alternating centimeter to decimetric silty micrite bed and decimetric bioturbed pelitic interbed. The bed is erosively based and comprises four intervals. The first interval (a) displays stacked sequences separated from each other by mud drapes, each sequence is composed of a set of thick laminae, which thin progressively from the bottom to the top. The second interval (b) is characterized by asymmetrical ripples displaying offshooting and draping laminations expressed by foreset laminae which ascend and overlap the flank of the adjoining ripple. The third interval is similar to the first one and the fourth intervalis similar to the second one. The top of the bedexhibits straight-crested ripples.

Facies F7 (Fig. 3G and Fig. 6), is documented in the lowerPeliticFormation of Early to Middle Eocene age (Fig.3).It consists of alternating centimeter to decimeter-thick micritic siltstone bed containing thin mud layers or mud drapes and decimetric bioturbated pelitic interbed. The bed has undulating erosive base and it's composed of 2 intervals. The lower interval (a) consists of stacked microsequences separated from each other by a reactivation surface.Each microsequence display successive couplets composed ofthick (1-5cm) and thin (0, 5-1cm) planar parallel micritic siltstonelaminaelimited each one to its upper surface by very thin mud layers (mm-scale). The individual couplet thickness thin and thicken progressively from the bottom to the top of the microsequence. The upper interval (b) displaysigmoid-shaped sets separated by reactivation surface or mud drape and made up ofsuccessive couplets composed of thick (1-5cm) and thin(0,5-1cm)sigmoidal oblique micritic siltstonelaminaelimited each one to its upper surface by very thin mud layers (mm-scale). The upper surface of this interval contains centimetric to decimetric-scale desiccation cracks.

Facies F8 (Fig. 4A and Fig. 6), is identified the lower Sandstone and pelitic Formation of Lowerto Upper Oligocene age (Fig.3). It corresponds to an alternation of centimetric silty micrite bed and metric pelitic interbed. The bed display planar parallel laminations or tabular cross-laminations that may be disturbed by convolute bedding. Its basal bounding surfaceis erosive and highly bioturbated, itsometimes show Paleodyctionand Cruzianatrace fossils.

Facies F9 (Fig. 4B and Fig. 6), is documented in the lower Sandstone and pelitic Formation of Lowerto Upper Oligocene age (Fig.3).It consists of alternating cm- to dm-thick sandy micrite bed and bioturbated pelitic dm-thick interbed. The bed is lenticular with tangential cross laminations and an erosive base exhibiting Paleodyctionand Cruzianatrace fossils,grooves casts, prod casts and bounce casts. The upper surface of the bed contains centimeter to decimetric desiccation cracks.

Facies F10 (Fig. 4C and Fig. 6), occurs in the lower Sandstone and pelitic Formation of Lowerto Upper Oligocene age (Fig.3).It consists of alternating decimetric pelitic interbed and centimetric to decimetric sandy micrite bed composed of4 intervals (a,b,c and d from base to top), separated by erosional surface and mud drape. The first interval(a)exhibits an erosive base with grooves casts, prod casts, flute casts and Ophiomorpha burrows, and stacked microsequences separated from each other by a mud drapes. Each microsequence display successive coupletsofthick (1-5cm) and thin (0, 5-1cm) planar parallel micritic siltstone laminae limited each one to its upper surface by very thin mud layers (mm-scale). The individual couplet thickness thin progressively from the bottom to the top of the microsequence. The second interval (b) is cross laminatedcharacterized byasymmetrical ripples displaying various internal structures: 1) offshooting and draping laminations expressed by inclined foreset laminationspassingthe trough and ascendingonto the flank of the adjacent ripple,2) composite internal structure, made up of an assemblage of differently structured, generally multidirectional lenses, 3) swollen lens-like sets, and 4) undulating parallel laminations passing into cross laminations, The third interval (c) shows an undulating highly erosive lower bounding surface and it is fully disturbed by flame and convolute structures. The fourth interval is similar to the first one, and display in its upper surface symmetrical ripples and mud pebbles.

Facies F11 (Fig. 4D and Fig. 6),is observed in the lower Sandstone and pelitic Formation of Lowerto Upper Oligocene age (Fig.3). It is composed of alternating decimetric lenticular allochemic sandstone bed, and decimetric pelitic interbed. The bed is erosively based withgrooves casts, prod casts, bounce casts and flute casts may display convolute bedding, and it contains 3 intervals separated by reactivation surfaces. The lower interval (a) shows interbeddedrippled sandy layersand continuousmud drapes overlapping the rippletroughs and crests.The intermediate interval (b) is a laminated sandy bed displaying sigmoidal cross laminations, successive foreset laminations directed inopposite directions in superimposed layers andreactivation surfaces.The upper interval (c) exhibits stacked microsequences separated from each other bymud drape. Each microsequence display successive couplets composed ofthick (1-5cm) and thin (0, 5-1cm) planar parallel micritic siltstone laminae limited each one to its upper surface by very thin mud layers (mm-scale). The individual couplet thicknesses thicken progressively from the bottom to the top of the microsequence). The upper surface of this interval is erosive and may shows decimetric-scale desiccation cracks and mud pebbles.

Facies F12 (Fig.4E and Fig. 6),occur in the lower Sandstone and pelitic Formation of Lowerto Upper Oligocene age (Fig.3).It consists of alternating centimeter to decimetric silty micrite bed containing thin mud layers or mud drapes and decimetric bioturbed pelitic interbed.The bed is erosively based with groove and flute casts, and comprises four intervals (a, b, c and d from base to top), separated by erosional surface and/or mud drape. The first interval (a) is composed of asymmetrical ripples characterized by lateral variation in size and shape in the same layerand irregular, undulating lowerbounding surface, which may be disturbed by convolute bedding. The second interval (b) is made up of stacked microsequences separated from each other by a reactivation surface.Each microsequence display successive couplets composed ofthick (1-5cm) and thin (0, 5-1cm) planar parallel micritic siltstone laminae, limited each one to its upper surface by very thin mud layers (mm-scale). The individual couplet thickness thinprogressively from the bottom to the top of the microsequence. The third interval (c) is characterized by:1) asymmetrical ripples displaying offshooting and draping laminations expressed by foreset laminae which ascend and overlap the flank of the adjoining ripple and 2) ripples displaying unidirectionalcross lamina concordant with the lee side and laying on the same planarbase. The fourth (d) interval exhibits tangential cross laminated cm-bundles, separated by erosional surfaces and mud drapes.

Facies F13 (Fig. 4F and4G, and Fig. 6), occurs in the lower Sandstone and pelitic Formation of Lowerto Upper Oligocene age (Fig.3). It consists of alternating decimetric muddy layer and amalgamated decimetric, lenticular coarse-micritic sandstone bed. The bed has an erosively undulating base and an erosive top exhibiting metric scale wavelength hummocks, centimetric to decimetric desiccation cracks and soft pebbles. Its internal structure shows hummocky cross stratification expressed by successive lamina sets separated by low angle truncations surface and composed ofparallel low-angle curved lamina whichdome upward (hummocks) passing laterally into laminae that are concaveupward(swaley).

Facies F14 (Fig. 4H and Fig. 6),is observed in the lower Sandstone and pelitic Formation of Lowerto Upper Oligocene age (Fig.3). It consists of interbedded, centimeter -to -decimeter -scale microconglomeratic bed with rich in organic matter and strongly bioturbated plurimetric pelitic layer. The bed has a lenticular shape and an erosive base with flute casts. It’s made up ofa fining upward microconglomerate containingrock clasts andshell fragments.

Facies F15 (Fig. 4I and Fig. 6), occur in the lower Sandstone and pelitic Formation ofLower toUpper Oligocene age (Fig.3).It consists of alternation of decimetric pelitic layer and decimetric sequence of coarse-grained sediments. The sequence has an erosive base exhibiting flute casts and it is composed of 6 intervals (from base to top): 1) a lenticular metric fining upward microconglomeratecontaining rock clasts and shell fragments (a); 2) a massive allochemic sandstones with dish pillar structures and convolutes bedding (b); 3)ripple- cross-laminatedmicritic siltstone displaying unidirectionalcross lamina concordant with the stoss side(c);4) couplets ofthick (1-5cm) and thin (0,5-1cm)planar parallel micritic siltstonelaminaelimited each one to its upper surface by very thin mud layers (mm-scale) separated sometime by reactivation surface (d); 5) micritic siltstone interval boundedby reactivation surfaces and exhibitingsigmoidal cross laminated bundle (e)and 6) micritic siltstone bed with asymmetrical ripples in which small lenses of mud are preserved in the trough of the ripple (f). The top of the sequence shows mud pebbles and Ophiomorpha and Skolithos burrows.

Facies F16 (Fig. 4J and Fig. 6), is documented in the lower Sandstone and pelitic Formation of Lowerto Upper Oligocene age (Fig.3). It consists of an alternation of decimetric pelitic layer and decimetric sequence of coarse-grained sediments. The sequence has an erosive base exhibiting flute casts and it's made up of 3 intervals. The lower interval (a) is a lenticularfining upward microconglomerate with rock clasts and shell fragments, displaying tangential cross-stratification, which pass upward into sandy micrite disturbed by convolutes bedding. The intermediate interval (b) is an allochemic sandstones composed of stacked microsequences separated from each other by a mud drape. Each microsequence display successive couplets composed ofthick (1-5cm) and thin (0, 5-1cm) planar parallel micritic siltstone laminae limited each one to its upper surface by very thin mud layers (mm-scale). The individual couplet thickness thin and thicken progressively from the bottom to the top of the microsequence. The upper interval (c)is an erosively based and cross-stratified silty micrite displaying:bundle of sigmoidal laminae separated by mud drapes and reactivation surfaces. The top of this sequence shows Zoophycos, and Ophiomorphatrace fossils.

Facies F17 occurs in the upper part of the lower Sandstone and pelitic Formation of Upper Oligocene age (Fig.3); it can be divided into three subfacies: F17a, F17b andF17cSubfacies. F17a(Fig. 4Kand Fig. 6) is a reddish brown lenticular coarsebed with sharp baseranging in thickness from 4 to 5m. It consists of amatrix-supported conglomerate, structureless, ungraded and without any preferred clast imbrication/organization. The clasts consist of pelite, marlstone, sandstone, carbonate, granite and basalt.They are well rounded, angular or elongatedand poorly sorted, they range from 2 cm to 90 cm in length. The matrixis poorly sorted it's composed of fine grained gravels,fine to very coarse grained sand, mud and carbonate cement. Subfacies F17b (Fig. 4K and Fig. 6) is a decimetric brownish yellow medium to fine -grained sandstone bed with erosional base and flat top, displaying planar cross stratification with some horizontal laminations and ripples. Subfacies F17c (Fig. 4L and Fig. 6),consists ofa lenticular reddish brown, coarse-grained unit composed of two intervals. The lowerinterval (b) is a high erosively based clast-supported conglomerate bed ranging in thickness from 2 to 3 m. The clasts consist of pelite, marlstone, sandstone, carbonate, graniteand basalt. Theyare well rounded to angular and poorly sorted, they range from 2 cm to 25 cm in length and they display ENE - WSW AB-plane type. The matrix is composed of fine to very coarse grained sand, fine grained gravels, bivalve shells debris, and occasionally carbonates cement. The upper interval is an erosively based decimetric allochemic sandstone unit which fines upward to very fine-grainedsandstones and exhibits planar and through cross-stratified beds separated by erosionalsurfaces.

Facies F18 (Fig. 5A,5B, and Fig. 6),is observed in the upper part of the upper Sandstone and pelitic Formation of Upper Oligocene to the Lower Miocene age (Fig.3). It consists of alternating metric coarse-sandy micrite bed and decimetric to metric highly bioturbated muddy layer. The bed has an erosively undulating base with load cast, and an erosive top. It's composed oflow-angle cross laminated sets separated by erosional surfaces and displaysOphiomorphaburrows, convolutes bedding, slumps and ball and pillow.

Facies F19 (Fig. 5C and Fig. 6), is identified in the upper part of the upper Sandstone and pelitic Formation of Upper Oligocene to the Lower Miocene age (Fig.3).It consists of alternating metric coarse-sandy micrite bed and decimetric to metric highly bioturbated muddy layer. The bed has an erosively undulating base with load casts, and an erosive top and it's composed of stacked planar, quasi planar laminated tabular sets separated by reactivation surface or mud drap. The bedding may be disturbed by convolutes bedding and water escape structures.

Facies F20 (Fig. 5D and Fig. 6), occurs in the upper part of the upper Sandstone and pelitic Formation of Upper Oligocene to the Lower Miocene age (Fig.3).It consists of alternating metric coarse-sandy micrite bed and decimetric to metric highly bioturbated muddy layer. The bed is erosively based with load casts and its upper surface is sharp and may display decimeter scale wavelength hummocks or ripples. Its internal structure shows sets of planar parallel lamina passing to micro-hummocky cross stratification expressed by successive lamina sets separated by low angle truncations surface and composed ofparallel low-angle curved lamina whichdome upward (hummocks) passing laterally into laminae that are concaveupward(swaley).

Facies F21 (Fig. 5E and Fig. 6), is documented in the upper part of the upper Sandstone and pelitic Formation of Upper Oligocene to the Lower Miocene age (Fig.3).It consists of alternating metric coarse-sandy micrite bed and decimetric to metric highly bioturbated muddy layer. The bed has an undulated erosive lower base with load casts, and generally contain 3 intervals (a, b and c from base to top).The lower interval (a) islimited to its top by an erosional surface and made up of successive couplets ofthick (1-5cm) and thin(0,5-1cm)planar parallel micritic siltstone laminae limited each one to its upper surface by very thin mud layers (mm-scale)or mud drapes. The intermediate interval (b) iscomposed of symmetrical wave ripples passing tomegaripple cross bedding. The upper interval (c) ischaracterized by micro-hummocky cross stratification expressed by successive lamina sets separated by low angle truncations surface and composed ofparallel low-angle curved lamina whichdome upward (hummocks) passing laterally into laminae that are concaveupward(swaley).

Facies F22 (Fig. 5F and Fig. 6), is identified in the Si Moussa Formation of Middle Miocene age (Fig.3). It consists of alternating metric sandy bar and decimetric to metric highly bioturbated muddy layer. The bar is composed of amalgamated lenticular metric cross stratifiedand cross laminatedcoarse-sandy micrite beds displaying sharp basal surfaces, low angle cross-stratified (less than 10°) laminations and sets of sigmoidal cross laminations delimited by reactivation surfaces. The beds are disturbed by convolute bedding, slumps, and ball and pillow and may shows decimetric desiccation cracks at their top.

Provenances anddepositional environments reconstruction

Petrofacies interpretation

The five petrofacies identified (Fig. 2, photos A, B, C and D) according to Mount (1985) classification: siltymicrites, micritic siltstones, micritic sandstones, sandy micrites, and allochemic sandstones, are very similar to those observed within the Eocene to Miocene sedimentary series outcropping in the North Western Rif (Hamoumi 1995b; Hamoumi et al. 1995; Ouldchalha et al. 1995; Salhi et al. 1995). Their compositional mixing indicate contemporaneous accumulation and sediment supply from both intra-basinal and extra-basinal sources under the control of allocyclic (e.g. sea level, tectonics, climate) and/or autocyclic (depositional processes) factors. The presence in the siliciclastic fraction of undulatory monocrystalline quartz with sometimes secondary quartz overgrowths, polycrystalline quartz grains, volcanic and metamorphic rock fragments and micas (muscovite, biotite and chlorite) and the roundness of heavy minerals suggest a provenance from sedimentary, volcanic and high rank metamorphic sources. The existence of calcite lithoclasts which may include benthic and planktonic foraminifera including e.g., Orbitolina and sometimes micritized Calpionella, indicate extrabasinal carbonate sources including a source of Cretaceous age. The poor sediment sorting, as well as the presence of rock fragments, feldspar and biotite is in favor of rapid erosion from a young and high relief continental source and a short transport and rapid deposition. Alteration affecting feldspar and micas as well as small size and lower frequency of feldspar suggest a hydrolyzing (humid to semi-humid) climate. The intra-basinal source provides the shell fragments which results from reworking of in situ exoskeletons and glauconitic peloids. Algae and rhombohedral crystals of dolomite, suggest nearshore to shallow marine depositional setting. Glauconite is authigenic and forms in shallow marine environment under reducing to slightly oxidizing conditions (Pettijhon et al. 1973, Odin 1985). The micritization which affects Calpionella is probably is inherited from the source. It can neither be generated by organisms such bacteria or algae, nor be linked to burial compaction, because it does not affect all microfossils.

Sedimentary structures interpretation

The sedimentary structures which characterize the sedimentary facies identified in the Mrayt Group series revealed significant informations on the depositional and the post-depositional processes that control the sedimentation. The primary sedimentary structures observed indicate erosion and deposition under the interplay of waves, storms, tidal and fluvial currents.

The waves action is expressed by: symmetrical ripples (F1, F2, F10 and F21) and asymmetrical ripples (F1, F2, F3, F6, F10, F12, andF15) whichpresent characteristics of wave-ripple bedding (De Raaf et al. 1977), such as: lateral variation in size and shape of the ripples in the same layer, offshooting and draping laminations expressed by foreset laminae which ascend and overlap the flank of the adjoining ripple, composite internal structure made up of an assemblage of differently structured, generally bidirectional lenses or multidirectional lenses, parallel undulated lamination, pinching and swelling laterally and passing to incipient lenses, small lenses of mud preserved in the trough of the ripple, swollen lens-like sets, undulating parallel laminations passing into cross laminations, ripple cross laminated layers which display unidirectionalcross lamina concordant with the stoss side and irregular undulating lowerbounding surface. Waves action is also expressed by low angle cross stratification (less than 10°) in coarse sandy micrite (F18 and F22), which results from parallel seaward-dipping lamination in foreshore-backshore (Shahin et al. 2009).

Storm action is indicated by: hummocky cross stratification(F13), micro-hummocky cross stratification (F20, and F21) and quasi planar laminated tabular sets (F19).The Hummocky cross stratification (HCS) was introduced and described by Harms et al. (1975), it’s produced by unidirectional and oscillatory flow generated by storm events beneath the fair-weather wave base and abovethe storm weather wave base. It’s widely recognized both in modern environments in the shoreface (Howard & Reineck1981) and in the upper offshore (Swift et al.1983). Micro-hummocky cross stratification occurs in open-coast intertidal flat, theHCS become smaller in a landward direction because of a decrease of wave size (Yang et al.2006). Quasi planar laminated tabular sets are considered as proximal tempestites deposited from storm wave-generated oscillatory flows or oscillatory-dominated combined flows (Jelby et al.2019).

Evidence of tidal current action is expressed by the existence of typical facies and structures aslayers of sediments, periodically deposited in relation to daily and monthly tidal cycles and signature of reversing currents (Boersma 1969; Dalrymple et al. 1978; Visser1980; Terwindt 1981; Allen and Homewood1984; Mowbray and Visser1984; Kreisa and Moiola 1986; Dalrymple and Makino 1989; De Boer et al.1989; Tessier et al.1989;Nio and Yang1989;Dalrymple, 1992). Tidal bundle ormud couplet (F1, F11, F15, F16,and F21)indicates changes in current velocity and flow reversalsrelatedto daily tidal cycles.Sand laminareflectalternating ebb and flood episodes known as diurnal inequality, coarser lamina are deposited by dominant tide current (thick lamination) and subordinated tide current (thin lamination) andmud drapes are formed during slackwater stages by deposition of suspended mud. Alternation ofthick and thintangential laminae (F4, F9, F16) orsigmoid laminae (F7, F11, F15, F16, F22) limited each one to its upper surface by very thin mud layer (F3, F8, F12, F20) correspondsto atidalbundlerelatedto daily tidal cycles. Sigmoid-shaped sets separated by reactivation surface or mud drapes and made up of successive mud couplets (F8) result of tidal lateral accretion of a large-scale bedform such as megaripples or sandwavesduring a dominant tide. Stacked sets of thin laminae which thicken progressively from the bottom to the top and sets of thick laminae which thin progressively from the bottom to the top (F1, F6, F7, F10, F11, F12, F15, F16, F21) are considered as a tidal rhytmites. These microsequences, represent a vertical record of neap/spring tidal cycles fluctuations that occur during a lunar cycle. During spring tidal excursion is at maximum and during neap tide, tidal excursion is at minimum.Successive intervals exhibiting sigmoidal or tangential cross laminated cm-bundles, dipping in opposite directions (F11, F12) are generated by the reversing currents which can be developed in tidal environment. The cross laminated beds deposited during ebb tide dip in opposite direction of those formed during flood tide. Reactivation surface (F1, F7, F15, F19, and F22) is a minor erosion surface between cross-strata which results frompartial erosion by reversing current during an asymmetrical tidal cycle. The lower bedform is eroded back by the reverse current and buried by a new advancing bedform.

Interbedded layers of fine sandstone and mudstone expressed by: 1) ripples with small lenses of mud preserved in the trough (F1, F2, F15), 2) Interbedded rippled sandy layers andcontinuous mud drapes overlapping the ripple troughs and crests (F1,F2) and 3) well preserved micritic siltstone or sandstones lenses, embedded within muddy layer (F2) are respectively flaser bedding,wavy bedding and lenticular bedding. These sedimentary structures are characteristics of tidal deposits in intertidal zone and are related to tidal cycles,mud deposition is favored by the existence of slack tides (Reineck and Singh 1980; Dalrymple and Makino 1989). In the flaser bedding facies, ripple beds are deposited during periods of current activity and mud lenses result from mud in suspension when energy of currents decreases. Wavy beddings develop when preservation of mud is possible and lenticular bedding reflects more favorable conditions for deposition and preservation of mud than sand. Linguoid ripples (F5) and straight-crested ripples (F3 and F6) are generated in tidal flat by unidirectional current (Reineck and Singh1980). Mud drapes (F1, F4, F6, F7, F10, F11, F12, F16, F19 and F21) may be found in various environments, their occurrence with typical tidal structures and facies is in favor of tidal origin.They result from deposition of concentrated suspended mud during the slack-water stage

Sedimentary structures related to fluvial currents are: asymmetric ripples characterized by a planar base and planar cross-lamination (F2, F5 and F8), flute casts (F10, F11, F12, F15, F16) and tool casts: groove casts (F9, F10, F11, F12),bounce cast (F9) and prod casts (F9, F10, F11). Flute casts is the molding of a flute mark, which is a tongue-shaped scour produced into mud by a turbulent flow of water. Tool casts are molding of tool marks which are produced by larger particles (e.g., pebbles and shell) on soft sediments under action of turbulent flow. Groove marks are caused when fragments are dragged along, prod casts and bounce casts are produced when fragments bounced along or hit the substrate. Flute casts and tool casts are commonly linked to turbidity currents in deep marine settings. However they can form also in the fluvial-to-marine transition zone under action of transitional flows whose turbulence results from the density differences between sediment-laden fresh and marine water. Fluvial current action is also demonstrated by the texture and the characteristics of the three conglomerate levels (Facies F17) such as the AB-plane type imbrications.

Post depositional and secondary sedimentary structures (Fig. 8) include desiccation cracks, water escape structures, load structures, soft sediment deformations and biogenic structures. Desiccation cracks (F1, F2, F3, F4, F5 F7, F9, F11, F13,and F22) are subaerial sedimentary structures which form when wet sediments dries up and contacts under evaporation processes. They occur in settings submitted to subaerial exposures: fluvial levees, shore of lakes, delta plain and tidal flat. Dish and pillar structures (F15and F19) are water escape structures that form in unconsolidated sediments during stages of rapid deposition in deep sea fan and/or deltaic and fluvial systems (Lowe 1975).

Load casts (F18, F19, F20, F21) and flame structures (F10), form in response todeposition of layer of denser sediments (sand) over on a less-dense hydroplastic layer (mud), especiallyduringhigh sedimentation rate. The overloading lead to the sinkingof the sand layer in the form of highly irregular protuberances and lobes (load casts) or projecting curved, pointed tongues of mudas wavy or “flame” shapedintothe overlying sand (flame structures). Convolute beddings (F8 F10, F11, F12, F15, F16, F18, F19, and F22) are centimetric crumpling and folding of parallel laminae or foreset laminae of ripple bedding.They occur in fine grained soft-sediment in various settings from deep- marine to nearshore and fluvial environments, and they occur frequently arein deltas and intertidal flats.They can be produced in more than one way (Reineck and Singh 1980 and reference therein): liquefaction, shearing action of currents, down-slope movement favored by the existence of a slope, high sedimentation rate, and seismic shaking.

Slump structures (Fig.8)observed in Sandstone-pelitic Formation and Si MoussaFormation, consist of a metric size, complex fold patterns often overturned. They result from movement and displacement of unconsolidated sediments induced by high sedimentation rate, sliding down a slope, faultingand seismic shaking. Balls and pillows (F18, F22), may occur as rounded masses of coarse sediments (pseudonodules) in fine grained matrix or as isolated pillows with curved and deformed internal laminations in a sandstone layer.They resultin unconsolidated sediment under a physical shock which causes instability and rupturing of the sediment layer, generally in relation with tectonics.

The trace fossils (Fig.9) observed includes *Ophiomorpha* burrows (F10, F15, F16,and F18) Skolithos burrows (F15), Cruziana (F8 andF9), Psilonichus Y-shaped burrows (F3),Zoophycos (F16)andPaleodyction tunnels (F8 andF9). Ophiomorpha is considered as a part of the Skolithos ichnofacies (Seilacher1967) and is produced by crustaceans such as shrimps (Frey et al. 1978) in nearshore and shallow marine depositional environments (Boggs1995; Buatois and Mángano2011), Skolithos belong to Skolithos ichnofacies (Seilacher1967) is produced by a variety of organisms and commonly associated with lower intertidal to shallow subtidalsettings in moderate to high-energy conditions. Cruziana burrow belong to Cruziana ichnofacies is considered typical of subtidalabove storm wave base, but was recognizedin intertidal zone (Pandeyet al 2014). Psilonichusmay be produced by: decapod crustacean, shrimp or crab, it occurs in estuary to backshore sedimentary settings (Nesbitt and Campbell2006).Zoophycos is considered as feeding or moving trace, it was associated for a long time with deep marine sediments, often turbidites. However it has been reported from shallow marine storm deposits (Zhang and Zhao 2016; Belghouthi et al. 2020)and nearshore settings (Knaust2004).Paleodyction burrows consist of a regular hexagonal orpolygonal network of tubular tunnels. They are commonly linked to deep -water Nereites ichnofacies (Seilacher1967) and were identified in many flysch successions and at present day abyssal environments. However they has been documented in prodelta environments, in relatively shallowepicontinental basin, and in mid -to -deep -shelf environments of Upper Triassic and Middle Jurassic inIran(Fürsich et al.2007), and in associationof trace fossils belonging to Cruziana ichnofacies in the Devonian of Pensylvania (Metz2012). Y-Shaped burrows (Psilochinus) indicate a shallow marine coast (Frey et al. 1978).

Sedimentary facies associations and sequences interpretation

The facies identified are grouped into three facies associations: Tide dominated estuary facies association, tide dominated delta facies association, and open-coast tidal flat facies association. (Fig.11).The estuary facies association is composed of a tidal flat sub-association (F1 F2, F3, F4,) and an estuary channel sub-association (F5, F6,F7). In the tidal flat sub-association, FaciesF1 exhibits mud couplets, wavy bedding, flaser bedding, mud drapes and wave ripples. These sedimentary structuresindicate deposition from tidal current and waves. Mud couplet reflects daily tidal cycles andmud drapes result from deposition of concentrated suspended mud during the slack-water stage. Occurrence of wavy bedding and flaser bedding is frequent in tidal setting where the slack tides favors mud deposition (Reineck and Singh1980; Dalrymple and Makino 1989).

Facies F2 shows a vertical evolution from flaser bedding to lenticular bedding through wavy bedding which is considered as diagnostic of strongly tide influenced interidal flats. Facies F3 comprises a slightly deformed interval and asymmetric ripples related to wave and tidal currents. Combined- flow and wave –induced structure and bedding characterize exposed tidal flat setting. The slight deformations of the lower interval may suggest a high sedimentation rate. Facies F4 represents deposition in a tidal creeck or gullie illustrated by erosively undulating base and tidal current induced structures such as: sets of parallel plane laminae, tangential cross laminated cm-bundles, reactivation surfaces and mud drapes. Successive tangential bundles and reactivation surfaces are related to diurnal inequality of tides.

In the estuary channel sub-association,Facies F5 consists of an erosionaly based succession displaying a basal lag rich inmud pebbles, passing to silty micrite interval with unidirectional flow ripples which in turn is overlain by an interval with wave ripples. The top shows linguoid ripples and centimetric to decimetric desiccation cracks. This facies results from deposition within a distributary channel under the interplay of tide currents and waves. Mud pebbles form at least in two stages: 1) a breakage of muddy bed by desiccation during a dry periods, bioturbation or erosion by currents which results in the formation of muddy chunks and flakes, and 2) reworking of the intraformational clasts by storms or tidal currents and accumulation on the erosional surface as lag deposits.Linguoid ripples occur in tidal flat under unidirectional current (Reineck and Singh1980).

Facies F6 comprises neap/spring tidal rhythmites muddrapes, wave ripples and desiccation cracks at its top. This facies is interpreted as a tidal pointbar deposit under the interplay of tide currents and waves. Tidal point bar forms within active distributaries of the estuary and extends from shallow to supratidal settings, thus desiccation cracks occurduring subaerial exposure stage.

Facies F7 displays neap spring tidal rhythmites, sigmoid-shaped sets made up ofsuccessive mudcouplets,mud drapes,reactivation surface and desiccation cracks. It s interpreted asdistributary channel fill,where tidal action is expressed by the most diagnostic structures of tidal origin: neap /spring tidal rhythmites, sigmoidal bundles,mud drapes and reactivation surface. The desiccation cracksresult from subaerial exposurerelated to shallowing due to sedimentation and channel abandonment.Combined-flow and wave-induced structures and beddings suggests sedimentation in a tide dominated and wave influenced mixed tidal flat. The presence of desiccation cracks indicating repeated emergence. The existence of distributary and tidal channel fill is also supported by the existence of marine and littoral organisms such as benthic and planktonic foraminifera, Calpionella and bioclasts of: gastropods, bivalves, echinoderms, bryozoans and algae. Tide dominated estuary receive sediments both from the river at the head of the estuary and from adjacent shelf by tidal currents.

The delta facies association includes a lower delta plain sub-association (F3, F4) a tide dominated delta front platform sub-association (F9, F10, F11 F12, F13 F14, F15, F16, and F17), and a prodelta (F8). In the delta plain sub-association, facies F3 suggests deposition in tidal flat under combined- flow and wave action and facies F4 represents tidal creek fill. In thefront delta platform sub-association, FaciesF9display an erosional base with tool casts (grooves casts, prod casts and bounce casts), Paleodyction tunnels,tangential cross laminationsanddesiccation cracks at its upper bounding surface. This facies result from transitional flows in the front delta slope. Tangential cross laminations are induced by unidirectional flow. Tool casts can form in such fluvial-to-marine transition zone where the interaction of sediment-laden freshwater river flux and tidal currents generates turbulent eddies and strong shears Paleodyctionhas been documented in deltaic environments, in relatively shallowepicontinental basin. The desiccation cracks at the top of the bed are related tosubaerial exposure episode due to swallowing of the setting.

Facies F10 and F11 hasan erosive base exhibiting prod casts (F10) and flute casts (F10, F11) induced bytransitional flows whose turbulence results from the interaction of fluvial and marine process. Gravity-driven transport may occurs when river are discharging peak sediment loads onto an energetic marine environment. This mode of sediment transport has been highlighted in several deltas studies. (e.g.Wright and Friedrichs2006). Their internal structure which can be affected by flame (F10) andconvoluted beddings (F10, F11) is made up of alternating wave ripples and tidal sedimentary structures such as: neap spring tidal rhythmites, wavy bedding, sigmoidal cross laminations, opposite directions of fore set laminations in adjacent layers, reactivation surfaces. The upper surface of thesefaciesmay shows mud pebbles (F10, F11) and decimetric-scale desiccation cracks

(F11) and the base of F10 base exhibits Ophiomorphaburrows (F10). The presence of mud pebbles indicates an accumulation at the top of beds during episodic storm events. F12 displays alternatingwave ripples which may be disturbed by convolutes bedding and tidal structures: neap springtidal rhythmites, tangential cross laminated cm-bundles dipping in opposite directions in adjacent layers and mud drapes. This facies result from the interplay between tidal currents and waves.

Facies F10, F11 and F12 are interpreted as tidal sand ridges deposits which developed in the delta front platform. This part of the deltaic system is controlled by the interplay between river discharges and fluvial sediment load and marine processes: tides, waves, and episodic storms. The vertical succession of sedimentary structures indicate rapid transition from subtidal to intertidal setting,desiccationcracks are related to subaerial exposure period due to swallowing of the setting. The presence of Ophiomorpha burrows is also indicativeof a high energy sublittoral or shoreface environments. This trace fossil occurs from littoral to shallow-marine paleoenvironments (Buatois and Mangano2011).

Facies F13 corresponds to a storm event deposit as indicated by itsgeometric characteristics: erosional undulating base and erosive top exhibiting metric scale wavelength hummocks, and its internal structures expressed by metric scale hummocky cross stratification. Decimetric desiccation cracks and soft pebbles at the top indicate period of subaerial emergence.

Facies F14, F15, F16 and F17 represents channel fill depositsat the mouth area of front delta.Facies F14, F15, F16 have in common a highly erosive base with flute casts and aninterval corresponding to a lenticular fining upward microconglomerate which may comprise tangential cross-stratification. In Facies F15 and F6, this interval is surmounted by a finning upward sequence showing grading from allochemic sandstones which may be affected by dish and pillar structures and convolutes bedding (F15) into micritic siltstone or silty micrite. The sequence in F15 exhibits waves rippled and tidal structures: mud couplets tidal rhythmites reactivation surfaces, sigmoidal tidal bundle and flaser bedding as well as mud pebbles, and Ophiomorpha and Skolithos burrows at its top. The sequence in F16 displays only tidal structures: neap spring tidal rythmites, sigmoidal bundle, mud drapes and reactivation surface and Zoophycos, Ophiomorpha and Skolithos burrows traces at its top.

Facies F14 is interpreted as being a channel fill deposit from unidirectional turbulent flow. Facies F15 and F16 record different stages of channel initiation and fill, scouring, flute caste and normal grading of the lower interval are related to unidirectional turbulent flow. The filling of the F15 channel was made first under action tidal current and with shallowing upward due to sedimentation, the filling continued with waves. In the case of F16 filling was made only by tidal currents. The existence of nearshore to marine organisms and shell fragments in facies F14, F15, and F16 confirms the intrusion of marine and coastal currents in the channels. Ophiomorpha and Skolithos burrows belong to skolithos ichnofacies (Seilacher1967) which is diagnostic of nearshore and shallow marine depositional environments.Zoophycos has been reported from shallow –marine storm deposits (Zhang and Zhao2016; Belghouthi et al.2020) and nearshore settings (Knaust 2004). Dish and pillar structures consist of fluid escape structures which results of quick packing due to high sedimentation rate. Convolutes bedding are common in front delta and prodelta settings, they may form during gravity-driven flows or tectonic events.

Facies F17 is interpretedasfluvial deposits based onthe dimension, the lithology, the composition,the texture and the sedimentary structures thatcharacterizefluvial facies(Miall1992).The shape of the clasts underlines a short transport distance. The absence of sedimentary structure and fabric as well as the poor sorting ofthe massive polymictic, texturally immature matrix supported conglomerate(Subfacies F17a), suggest deposition by gravity flow. Fine -grained sandstone bed (Subfacies F17b)might haveresultedfrom deposition by vertical accretion on the top of channels sand bars during low flow régime. Clasts-supported conglomerate unit (Subfacies 17c) isinterpreted aschannel lag deposits, based onits highly erosive base, lenticular shape,and texture especiallythe AB-plane type imbrications of the clasts. The coarse sandstones exhibiting planar and cross-stratified beds separated by erosional surfaces may be attributedtovertical accretion during lower flow regime, or to the migration of sand dunes and transvers barsin shallow water stream channel.These subfacies result from fluvial discharges in responseto flooding stages and reactivation of detrital inputs due to tectonic events and uplift of the source area. Marine to nearshore bioclasts such as bivalve shells of the matrix of the clast supported conglomerate and the coarse sandstone, confirm deposition at the mouth of delta submitted to flood tides.

Facies F8 consist of predominant muddy deposit with centimetric alternation of silty micrite displaying planar parallel laminations or tabular cross-laminations that may be disturbed by convolutes bedding, and intense bioturbation.This facies can be formed in an offshore or in a prodelta this last hypothesis is the most probable because of its association with deltaic facies at the base of upward coarsening sequence. Convolutes bedding are frequent in such setting and may be induced by gravity driven transport in the delta slope or under high rate of sedimentation. Intense bioturbation indicates a low-energy setting with normal oxygenated conditions. The presence of Paleodyction tunnels has been documented in prodelta environments (Fürsich et al.2007).

In the open-coast tidal flat facies association, Facies F18 is interpreted as nearshore sand bar based on low-anglecross laminated sets separated by erosional surfaces. Low-angle cross laminated result from mega ripples migration and may be generated by waves processes during fair weather periods (Wright and Short1984).

Occurrence of Ophiomorpha trace fossil is consistent with nearshore environments.Load casts may results from high sedimentation rate.Convolutes bedding, ball and pillow and slumps may be inducedbytectonics.

Facies F19is interpreted asproximal tempestite deposited from storm wave-generated oscillatory-dominant combined flows (Jelby et al.2019)and tidal currents, based on the existence oferosional limits, quasi planar laminated tabular sets, reactivation surfaces andmud draps. Association ofproximal tempestites and tidal structures are in favor of a cyclic deposition by storm and tide currentsin an open coast tidal flat. Water escape structures and convolutes bedding which may affect this facies, might have beeninducedby a high sedimentation rate or storm waves. Soft -sediment deformationstructures are well documented in tempestites and interpreted as the result ofliquefaction triggered by the stress induced by storm waves (Jelby et al., 2019 and references therein).

Facies F20is considered as storm deposit in intertidal flat based on the existence of erosional bounding surfaces, planar parallel lamina and micro-hummocky cross stratification. Micro-hummocky cross stratification occurs in open-coast intertidal flat, theHCS become smaller in a landward direction because of a decrease of wave size (Yang et al.2006). Load casts express a high sedimentation rate.

Facies F21 consist of coarse-sandy micrite bed displaying mudcouplet, wave ripples passingto megaripple cross bedding and micro-hummocky cross stratification. This facies is generated in the intertidal zone under the tide, waves and storm action.

Facies F 22 corresponds to anearshore sand bar generated by fair weather wave and ebb or flood delta which developed in tidal inlet by tidal current. Waves signature is expressedbythe existence of low angle cross-stratified (less than 10°) laminations.Influence of tidal currents is recordedby the sets of sigmoidal cross laminations delimited by reactivation surfaces. Occurrence ofdecimetric desiccation cracks at the top of beds suggests sedimentation in nearshore setting submitted to subaerial exposure. Convolutes bedding, ball and pillow and slumps are probably inducedbytectonics.

Open-coast tidal flat recorded byFacies association (F18F19, F20, F21,and F22) developedunder action oftides,fair weather waves and storm action. It corresponds to a sandy open coast tidal flat in the classification of Daidu (2012) which is characterized by:1)abundance of storm-generated structures, 2)scarcity of tidal-channel deposits and 3) abundance of structures created by combined flows or the interactions of waves andtides. According to this author, such depositionalenvironment is common in the open-mouth estuaries of small river and the adjacent strand plain.

Discussion

The Mrayt Group deposits have been previously described as siliciclastic sediments: quartzarenite and sublitharenites (Tejera de Leon 1993) the petrographic analysis of thin sections performed in this study, has shown that the sediments are not siliciclastic deposits but rather mixed siliciclastic/carbonate components. The petrofacies recognized according to Mount classification (1985) are: silty micrite, micritic siltstones, micritic sandstones, sandy micrite, and allochemic sandstones. They are very similar to those observedwithin the Eocene to Miocene sedimentary series outcropping in the North Western Rif (Hamoumi 1995b; Hamoumi et al. 1995; Ouldchalha et al. 1995; Salhi et al. 1995). Furthermore, such mixed deposits are quite common in ancient and modern depositional environments (see references in Chiarella et al. 2017).These new findingsare even more important thanmixed siliciclastic / carbonate rocks in the Rif belt are not well encoded. The tendency has beento ignore the mixed composition andto consider them as pure siliciclastic which results in wrong nomenclatures.Precise petrographic analysis and classification are necessary for accurate naming and classifying sedimentary rock which is in turn essential to reconstitute provenance(nature and composition of the sediment source, relief and climate in the source areas),as well transport and sedimentation processes, and diagenetic history. They are also fundamental tools inhydrocarbon exploration and engineering, according to Chiarella et al., (2017), a correct identification of different types of mixing and the scale of their occurrence is essential for petrophysical properties (porosity, permeability) identification and reservoir models reconstruction in hydrocarbon exploration and exploitation.

The compositional mixing indicates contemporaneous accumulation and sediment supply from both intra-basinal and extra-basinal sources. The intra-basinal components:shell fragments, algae glauconitic peloids rhombohedral crystals of dolomite and mudclasts, suggest nearshore to shallow marine depositional settingsubmitted to flood tides. The extra-basinal source that provides the siliciclastic components and detrital carbonates, may corresponds to the geological sections outcropping along the African margin which consists of Paleozoic basement of detrital dominance, folded, metamorphosed and granitized during Hercynian orogeny and its cover, the Meso-Cenozoic terranes, which are essentially carbonates. The presence of Cretaceous benthic foraminifera of the genus *Orbitolina* and other micritized foraminiferal test argues their provenance from the Meso-Cenozoic sediments.This hypothesis is supported by the results of palaeocurrents analysis carried out in this work that indicate a transport path from SSE to NNW, and those of previous works (Cazzola and Critellis 1987; Morley 1992; Tejera de Leon1993).

Previous works have proposed deposition of the Mrayt Group successions in marine (distal shelf and continental slope) of foredeep basin. They interpreted as a sedimentary prism adjacent to the outer edge of a storm dominated platform, which passes to deep sea fan system (Raissouni et al. 2008), or as synorogenic turbidites referred to deep sea fan and reworked and redeposited slope flows in an abyssal plain (Morley 1992; Tejera de Leon1993). Sedimentary facies reconstruction and interpretation performed in this work indicates that deposition of Mrayt Group sediments was realized in littoraland shallow marine environments: tide dominated estuary, tide dominated delta and open-coast tidal flat.

In these depositional environments, sedimentation took placeundercomplex hydrodynamics strongly influenced by river discharge, tidal currents, waves and storms action. Evidence of tidal current is expressed by unique sedimentary structures and facies that can only be produced by tides such as: layers of sediments, periodically deposited in relation to daily and monthly tidal cycles and signature of reversing currents (Boersma 1969; Dalrymple et al. 1978; Visser 1980; Terwindt 1981; Allen and Homewood1984; Mowbray and Visser1984; Kreisa and Moiola 1986; Dalrymple and Makino 1989; De Boer et al.1989; Tessier et al.1989;Nio and Yang1989;Dalrymple1992). The waves action is indicated by typicalwave-generated symmetricand asymmetrical ripples (De raaf et al. 1977) and low angle cross stratification (Shahin et al. 2009). The storm signature is expressed by hummocky cross stratification(Harms et al.1975), micro-hummocky cross stratification, (Yang et al.2006) and quasi planar laminated tabular sets (Jelby et al.2019).The fluvial action is recordedby current asymmetric ripples, flute casts and tool casts(groove casts, bounce casts and prod casts) and the the AB-plane type imbrications of the pebbles of the conglomerates. Nearshore environments are also suggested by: i)the presence of Skolithos and Ophiomorpha burrows considered part ofthe Skolithos ichnofacies (Seilacher1967), ii) Psilochinus Y-shaped burrows whichindicatea shallow marine coast (Frey and Pemberton1978), iii) desiccation cracks indicating repeated emergence and iv) the presence of shell debris and abundant mud clasts in the floor the channels.

Sedimentation occurred in “the Maghrebian basin” defined by Bouillin (1986), extending between the North African margin and the Internal zones domain during the Mesozoic-Paleogene interval (Wildy1983), under the interplay oftectonics and subsidence, eustacy,climate and sediment suplies. Evolution of the tectonic regime was guided by the complex subduction events and associated collisions between the African and Eurasian continental plates during the late Mesozoic and Cenozoic (Dewey et al. 1989; Srivastava et al. 1990; Leprêtre et al.2018 and references therein). After the Early Eocene Climatic Optimum (EECO), the evolution of the Cenozoic climate recorded gradual trends of warming and cooling (Zachos et al. 2001). Following the Ypresian high sea level, Cenozoic period was marked by short-term sea level fluctuations due to the increasing influence of glaciation. (Haq et al.1987).

Three depositional system intervals are recognized in the Mrayt Group successions from Early Eocene to Mid Miocene: tide dominated estuary, tide dominated delta and open-coast tidal flat. The first interval extended from Early to MiddleEocene, itrecords a tide dominated estuary system composed of a tidal flat and estuary channels. The tidal flat is characterized by tidal rhythmites and fining upward heterolitic successionsshowing regular changes vertically from flaser bedding through wavy bedding and lenticular bedding, (F1 and F2), surmounted by tidal creeck or gulley (F3 and F4). The estuary channel sub-association comprises, distributary channel fill (F5 and F7), tidal point bar (F6).

The Mrayt Group Eocene estuary system is a coastal plain estuary type where tidal action is expressed by the most diagnostic structures of tidal origin. Tide dominated estuaries are those in which tidal currents play dominant role at the mouth(Dalrymple et al.2012). They form generally in shelves that are large enough to amplify the oceanic tidal wave. Initiation and development of estuarine system depends on three principal factors: rise in sea level, climate and subsidence. According to Dalrymple et al.(1992) an estuary is a transgressive coastal environment at the mouth of a river, that receives sediment from both fluvial and marine sources and that contains facies influenced by tide, wave and fluvial processes. The climate controls the amount of precipitation and therefore the fluvial flow regime as well as the nature and quantity of the sediment supplies. Recent estuaries occur in temperate and tropical regions which are characterized by frequent and abundant rains and the existence of large rivers. Subsidence is necessary for the preservation of tidal deposit in as much as a part of the sediments deposited by a tidal current if not all maybeeroded by the opposite tidal current.

The Mrayt Group estuary system was initiated by the drowning of an existing river valley during theEarly Eocene (Ypresian) sea level raise (Haq et al.1987). Development of this estuarine system was favored by the subsidence and a warm and humid climate. After the end of the Paleocen-Eocene Thermal Maximum (PETM) at 56 million years ago, the Eocene climate began with a warming(Zachos et al. 2001).According to Brinkhuis et al. (2006) the warm greenhouse conditions of the Early Paleogene period (55-45 Myr ago) probably increased precipitation. Moreover, the climate in the Sahara during the Eocene would have been humid and warm (Swezey2009).

The Mid-Upper Eocene gap in the Mrayt Group successioncould be explained by erosionor by an interruption in deposition.This last hypothesis seems the most plausible. Non deposition may be attributed tothe combination of the effects of lowering in eustatic sea level andtectonic uplift.Major sea level falls occurred at the latest Ypresian and thelatest Bartonian (Haq et al.1987). Moreover, the Middle Late Eocene kinematic reorganization related to the strong coupling between the Eurasian, Iberian and African plates resulted in the development of intracontinental belts and compressive deformation at the scale of the west Mediterranean region (Leprêtre et al.2018 and reference therein).

The second interval records the development of a tide dominated deltas during Early Oligocene to Early Miocene period. Recognition of these depositional systems is based on the existence ofthreegenetically linked facies and facies association in the same succession: lower delta plain facies association, delta front platform facies association and prodelta facies. The lower delta plain sub-association includes tidal flat (F3) and (tidal creek or gulley (F4). The tide dominated delta front platform sub-association includes: deposit of transitional flows in the front delta slope (Facies F9), tidal sand ridges (Facies F10, F11 and F12), channel fill deposits at the mouth area of front delta (Facies F14, F15, F16 and F17) and a prodelta facies (F8).

Recognition of tide dominated delta is alsobased on the typicalcriteria commonly admitted for delta identification and the type of delta discrimination. 1) Coexistence of sedimentary structures and faciesindicating a combination of the effects of river discharge, wave, storm and tidal processes 2) Thick predominately clastic successions which pass from subaqueous (offshore and shoreface) facies upwards into subaerial (intertidal flat and fluvial channel). 3) Typical coarsening upwards sequence from prodelta to distributary channel and sand bars interfingered with interdistributary muds. 4) Repeated progradation within a depocenter. 5) Occurrence of the coarsest sediments in the boundary zone between the delta -front platform and slope and in the prograding, distributary -mouth channel bars.

Tide dominated delta are those where tide currents are the dominant process controlling sediment dispersal (Galloway1975). The criteria which serve to distinguish tide dominated delta from the other deltaic systems are: the existence of typical tidal sedimentary structures, sedimentary facies and sequences in the mid to upper part of the delta front, the distributary tidal mouth bar and the lower delta plain successions. These tidal indicators are:mud couplets, neap spring cycle, tidal rhythmites, bidirectional structures, reactivation surfaces, upward finingsuccession, regular changes vertically from flaser bedding through wavy bedding and lenticular bedding, tidal creekfill, distributary channel fills, tidal sand ridges, The criterionwhich serves to distinguishestide dominated delta from other tidally influenced settings is the “S” shaped sedimentary succession that tends to be heterolytic and both coarsening and fining upward (Goodbread and Saito, 2012). Additional criteria in favor ofdeltaic interpretation are: 1) decimetric desiccation cracks and soft pebbles which indicateperiod of subaerial emergence, 2) convolutes bedding which may be induced by gravity driven transport in the delta slope or under high rate of sedimentation. 3) Intense bioturbation which indicates a low-energy setting with normal oxygenated conditions, 4) mixing of marine to brackish fauna with detrital sediments from hinterland due to saltwater transport by flood tides.

The direction of flow in this delta has been reconstructed based on by the paleocurrent measurements of 48 flute casts identified in all the studied outcrops. The paleocurrent flow as revealed by the rose diagram indicates a transport path from SSE to NNW (Fig. 10) and is consistent with that proposed by the previous works (Cazzola and Critelli1987; Morley 1992; Tejera de Leon 1993). Other deltaic systems have been recognized insections of the same age in the North Western Rif (Hamoumi et al. 1995; Oueldchelha et al. 1995), which was considered by previous workas deep sea fan deposits.

The initiation and the development of the Mrayt Group deltaswere favored by the combination of major factors: tectonics and subsidence,sea level fluctuations, climate and sediments supplies. Delta construction was favored by the creation of depocenters induced bytectonics and subsidence. AnOligocene to Early Miocene extensional phase representing one of the two periods of strong mechanical coupling between Africa and Europe/Iberia plates, is recorded (Leprêtre et al.2018 and references therein). Evidence for the tectonic control during sedimentation is revealedby:synsedimentary faults and soft sediment deformations (slumps,ball and pillow). Tectonic activity and uplift in the drainage basinis attested bylarge amount of detrital sediment supplies induced by rejuvenation of the source areas following the end Eocene tectonic uplift in relation to the major pre-oligocene compressional event (Leprêtre et al.2018 et references therein). It's also confirmed by the presence of sedimentary structures induced by rapid deposition and increase in sedimentation rates (water escape structures, load structures). Most present day tide dominated delta is situated in tectonically active regions(Goodbread and Saito 2012).

Delta formation was also favored by the relatively higher sea level recorded atthe Early Rupelian (Haq et al.1987). Delta confined to the shelf in shallow water is deposited during times of relatively high sea level. In addition,tide dominated delta are more generally highstand features as adequate tidal energy is less well developed during lowstand (Goodbread and Saito 2012).The climate plays a major role in both the catchment-based forcing of sediment production and fluvial transport. Tropical climatic conditions in the Eocene has changed warm subtropical in the Oligocene. The gradual cooling which occurred during the Eocene - Oligocene transition at 34 million years ago (Zachos et al. 2001), should be associated with humidity and precipitation as indicated by:i) the importance and quantity of detrital supplies and ii) alteration affecting feldspar and micas as well as small size and lower frequency of feldspar. Moreover, it appears that during Oligocene,north-flowing fluvial systems became a predominant feature across some parts of northern Africa during this time. (Swezey2009)and North Africa was closer to the equator (Guiraud et al.2005).

Described facies and facies association occur in three progradational vertically stacked stratigraphic units. Each unit shows an upwards coarsening succession from theprodelta mudstones,gradationnaly overlain by delta front tidal bars,followed by erosively baseddistriburtarychannels.The uppermost unit is overlain by lower delta plain deposits. Development and evolution of these stratigraphic units were realized by repeated progradation and abandonment within a depocenter dictated by fluctuations in sediment supply, subsidence and sea-level. In the first two units, deltaic deposition occurs during the Rupelian relatively high sea-level (Haq et al.1987). The higher stratigraphic unit is composed of three sub units, the lowers one is an upwards coarsening successionsimilar to the first units with prodelta deposits gradationally overlain by delta front channel fill and tidal bars. The second subunits is composed of stacked metric erosively baseddistributary channels and the third subunit is a lower delta plain succession.

Progradation of the first subunit was favored by tectonic and climate,the major sea level fall which occurred near the Rupelian-Chattian boundary (Haq et al 1987), was compensated by compressive tectonics. A significant compressional event was recorded in the tell Rif system during pre-Late Oligocene (Leprêtre et al., 2018 and references therein).In addition, the tectonics allowed the source reactivation. Deposition of the second subunit of the mouth areas is related to the development of an extensive fluvial systems which was favored by:i) the persistence of decline in sea level, forced regression of the shoreline drives delta progradation and potentially downward incision, ii)continued tectonic uplift of the hinterland and iii) enough rainfall, north-flowing fluvial systems wasa predominant feature northern Africa in during the Oligocene (Swezey 2009). The third subunit correspond to the lower delta plain reflect deposition during rising relative sea level and creation of accommodation space behind the delta front.This transgression would have been coincident with the higher eustatic sea level (Haq et al.1987) and generaly warm climate that characterized the late Middle Miocene (Zachos et al.2001).

The third interval is a sandy open-coast tidal flat during Early Mid Miocene. Recognition of this depositional system is based on the existence ofrhythmic alternation of nearshore sand bars generated by fair weather waves (facies F18 and F22), storms (facies F20) storms and tidal currents (facies F19) and wave and tidal current (facies F21). Nearshore environment is also indicated by centimetric to decimetric desiccation cracks and Ophiomorpha burrows.Sandy open-coast tidal flats are common in the open-mouth estuaries of small river and the adjacent strand plain (Daidu 2012). This stratigraphic unit expresses the abandonment of the deltaic sedimentation and the installation of a wave storms and tide dominated open tidal flat. It coincides with relatively high sea levels recordedduring Aquitanian, Burdigalian,Langhian and Lower Serravallian(Haq et al.1987).

Sedimentation was favored by enough rainfall to support the development of extensive fluvial systems in the hinterland. The global cooling induced bythe establishment of the major ice-sheet on Antarctica (Frakes et al. 1992) was interrupted by warm intervals. A warming trend was recorded from the Lower Miocene to the Mid Miocene where the warm phase peaked in the climatic optimum (Zachos et al.2001). Sediment supplies have been ensured by continued tectonic uplift along the northern Africa margin, related to the change in motion of the African plate during Early Miocene (Leprêtre et al.2018 and references therein). The rate of sedimentation was probably important as demonstrated by the existence of water escape and load casts structures. Sedimentation was favored also by the fact that accommodation outpaces the sedimentation rates at the coastline. Tectonic was active during sedimentation as indicated by soft sediment deformations as slumps, ball and pillow and convolutes bedding.

Conclusion

This work presents new insight concerning the nature and composition of the sediments,the depositional environments and thefactors that have controlled sedimentationfor the Eocene-Miocene Mrayt Group in North-Western Rif (Morocco). The petrographic study reveals, for the first time, the mixed siliciclastic/carbonate composition ofthedeposits and their nomenclature:silty micrites, micritic siltstones, micritic sandstones, sandy micrite, and allochemic sandstones. They reflect sediment supply from an intra-basinal source that provides exoskeletons,glauconitic peloids, algae and rhombohedral crystals of dolomite and mud pebbles and extrabasinal sources, which correspond to the metamorphosed and granitized Paleozoic basement, and its Meso-Cenozoic cover outcroppinginthe northern African margin.Detrital fraction characteristicsindicate also rapiderosion from a young and high relief continental source and a short transport and rapid deposition.

Twenty two sedimentary facies that have never been described before are identified, and based on their succession and associationa new interpretation of depositional processes and depositional systems are proposed. The paleoenvironments of the Mrayt Group are interpreted as littoral andshallow marine settings: tides-dominated estuary, tides-dominated delta systems and open coast tidal flat,undercomplex hydrodynamics strongly influenced by river discharge, tidal currents, waves and storms action.Sedimentation occurred in “the Maghrebian basin” under the interplay of:i) tectonics relatedto the Cenozoic collision of the African and Eurasian continental plates, ii)Cenozoic alternation of warm climate and cooling due to the increasing influence of Antarctica glaciation, iii) sediments supplies induced by rejuvenation of sedimentary sourcesandiiii)sea level fluctuation related tothe advance and retreat ofice-sheet on Antarctica.

This work bringsalso additionalinsights such as the occurrence of Paleodictyon trace fossils in prodelta environment,Zoophycos trace fossils in nearshore settings andCruziana burrow in the intertidal zone. The firsttwo trace fossils are normally associated with deep-sea flysch settings and Cruziana is considered typical of subtidal above storm wave base.In addition to these new findings, this work is important for increasing our knowledge about ancient tides dominated deltas that is less investigated in comparisonto the other deltaic systems (waves or river dominated) and its responses to sea level changes and tectonics. Furthermore, this work is also important fordocumenting an example of mixed siliclastic/ carbonate in nearshore to shallow depositional setting.Last but not least, it consists an essential contribution for a better knowledge of North WesternRifbelt and the the peri- Mediterranean alpine chain.

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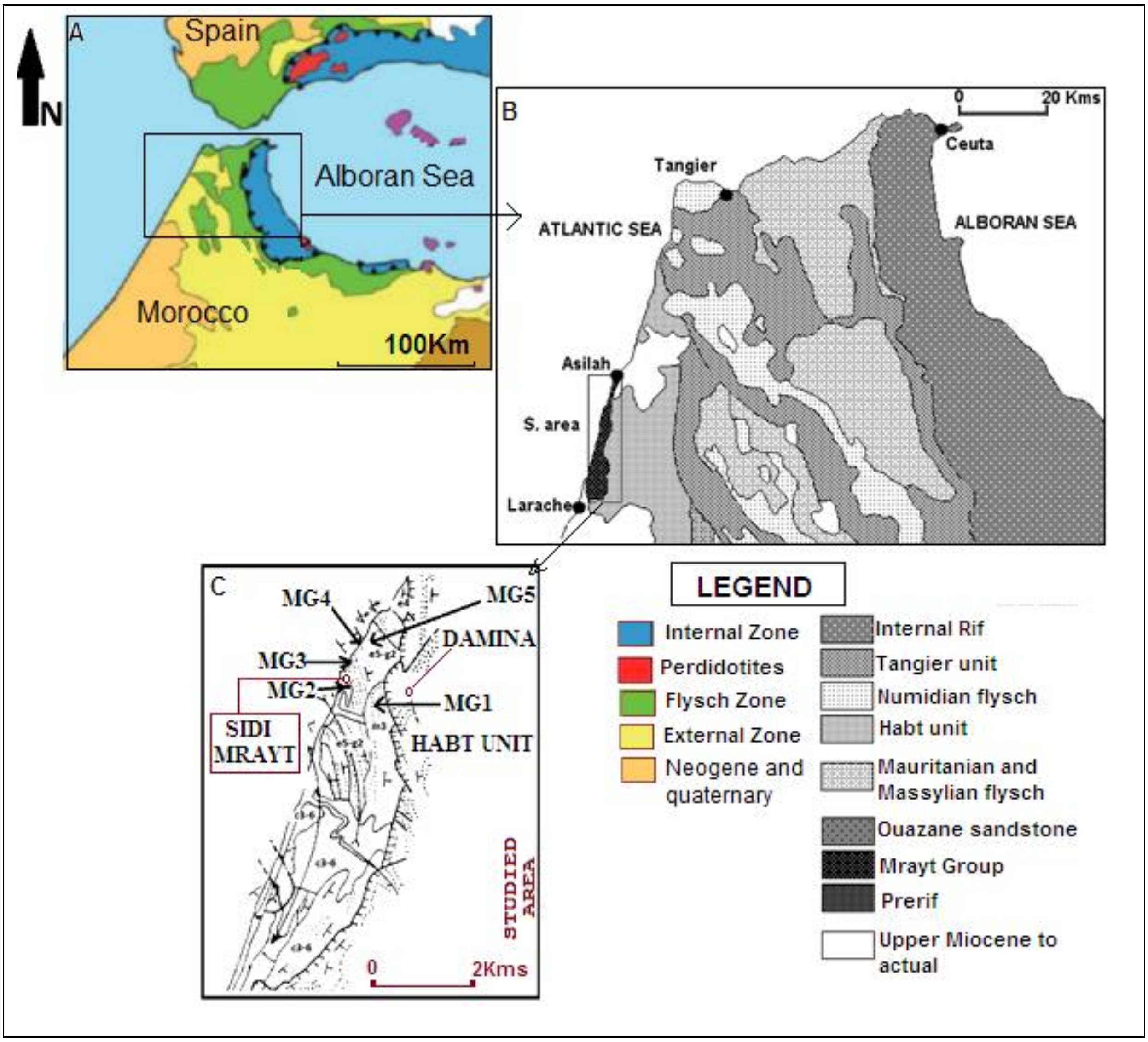
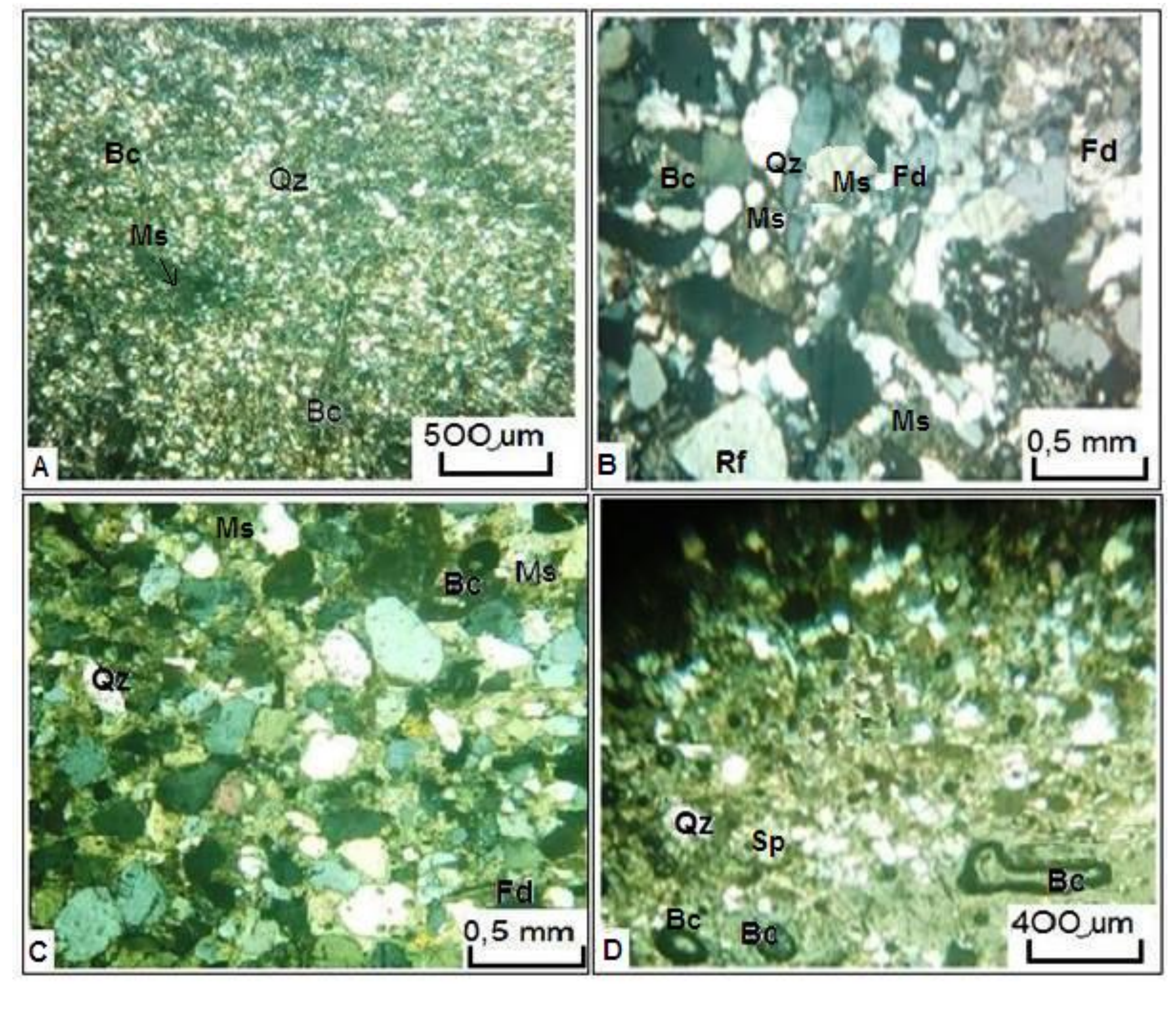
Fig. 1



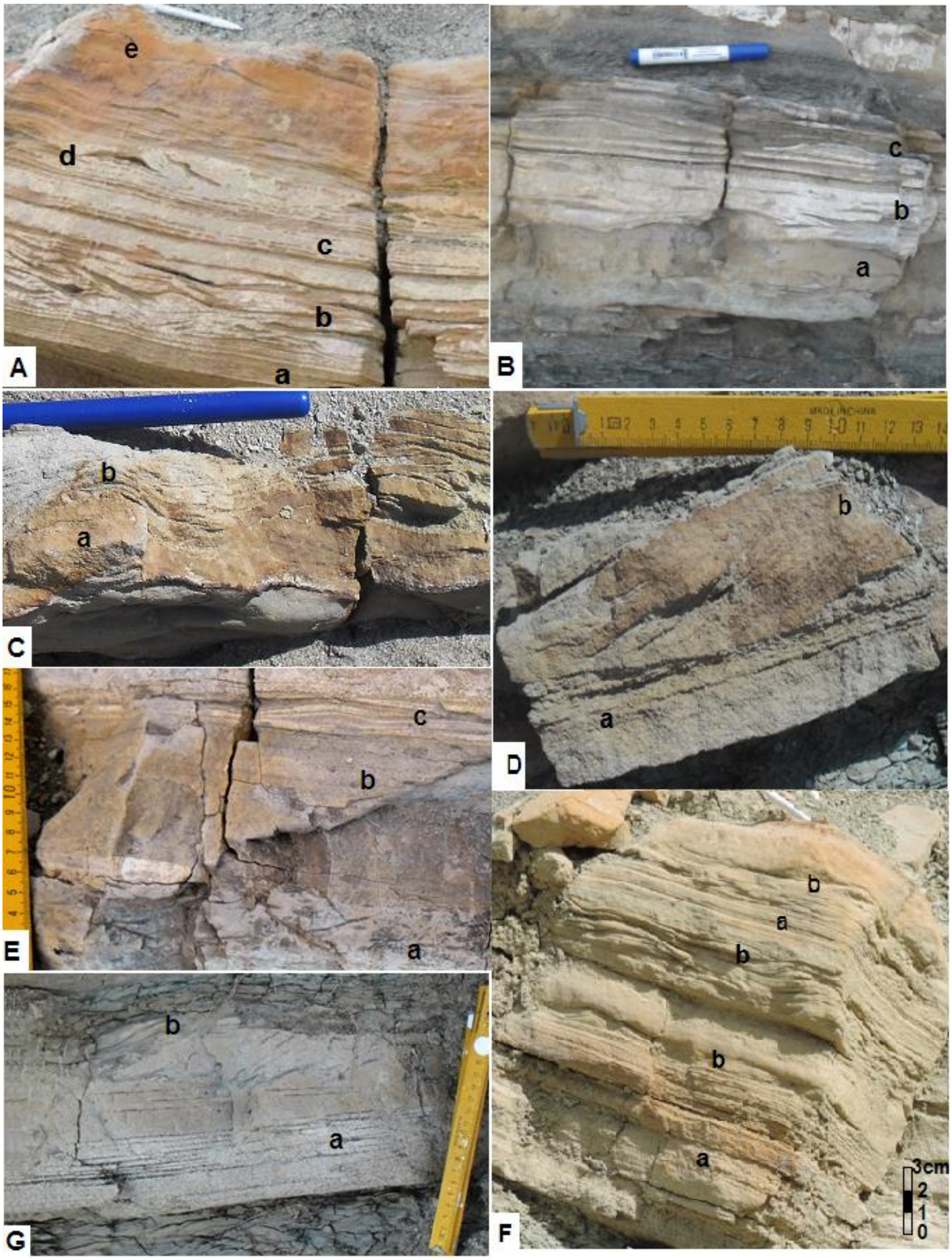
A geological map of the geological domains in the Betic–Rif orogenic system (after Platt and Vissers 1989); B Location of the Mrayt Group outcrops in the geological map of the North Western Rif (after Suter 1980); C Location of the studied outcrops in the structural map of Suter (1980): MG1- Damina section, 80m thick (X= 6.06; Y= 35.42), MG2- Marabout section, 750m thick (X= 5.85; Y= 35.36), MG3- Sidi Mrayt beach section, 200m thick (X= 5.85; Y= 35.41), MG4- Merja section, 520m thick (X= 5.96; Y= 35.43), and MG5- Merja ravine section, 280m thick (X= 6.05; Y= 35.44). S. area: Studied area

Fig. 2



Petrofacies of the Mrayt Group: A- micritic siltstone; B- sandy micrite; C- micritic sandstone; D- sandy allochemic sandstone. Bc- Bioclasts, Qz- Quartz, Sp- Sparite, Ms- microsparite, Fd- fedlspath, Rf- Rock fragment

Fig. 3



Sedimentary facies. A- Facies F1 (a and c- mud couplets, b-flaser bedding, d- wavy bedding, e-lenticular bedding). B- Facies F2 (a and c- mud couplets, b-flaser bedding, c- asymmetrical ripples); C- Facies F3 (a- slightly deformed level without visible bedding, b- asymmetrical ripples); D- Facies F4 (a- parallel undulated plane laminations, b- tangential oblique laminations); E- Facies F5 (a- mud pebbles, b- massive level, c- parallel undulated lamination); F- Facies F6 (a- rhythmic parallel laminations, b- tidal bundles); G- Facies F7 (a- tidal rhytmites, b- tidal bundles)

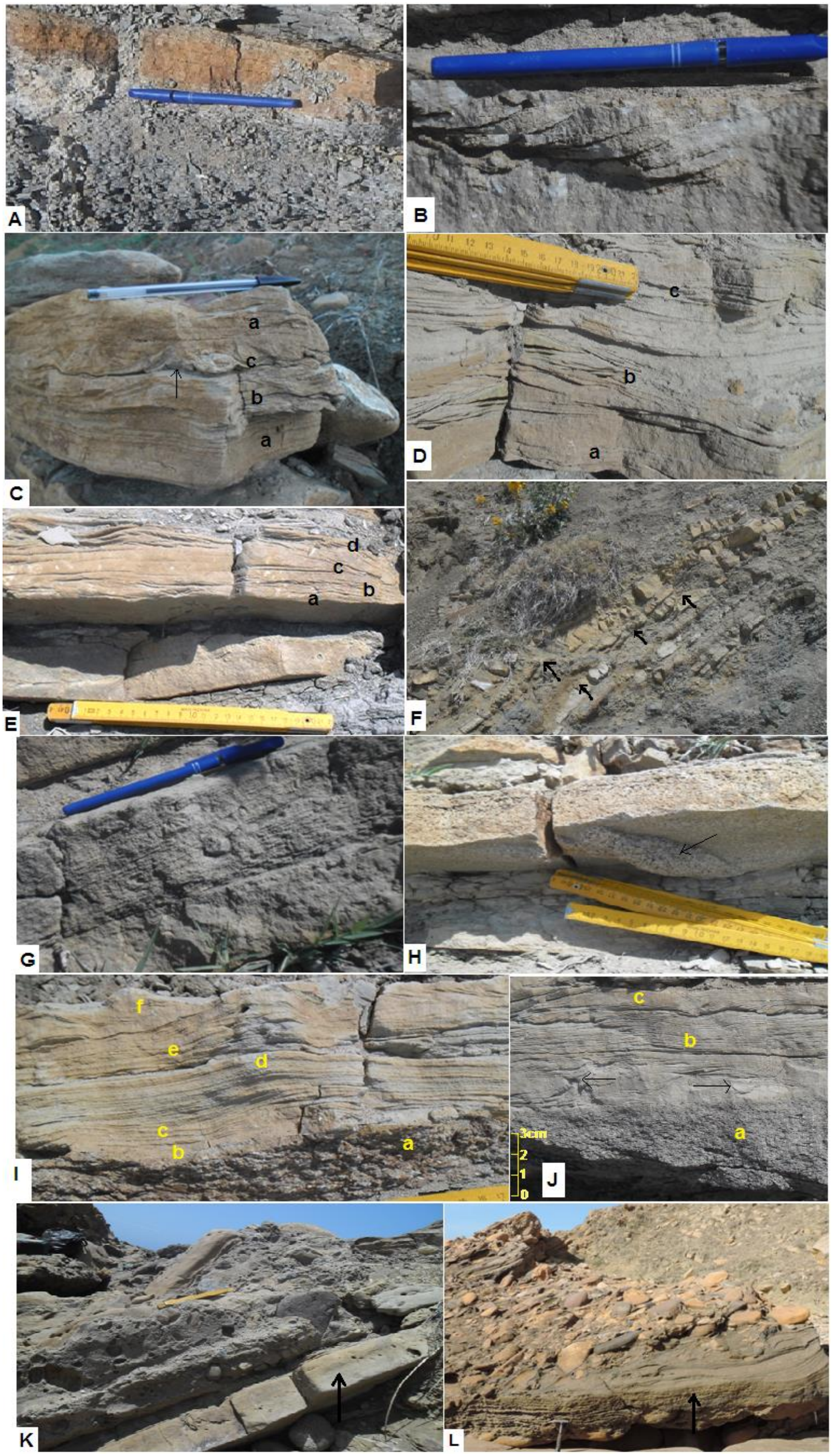
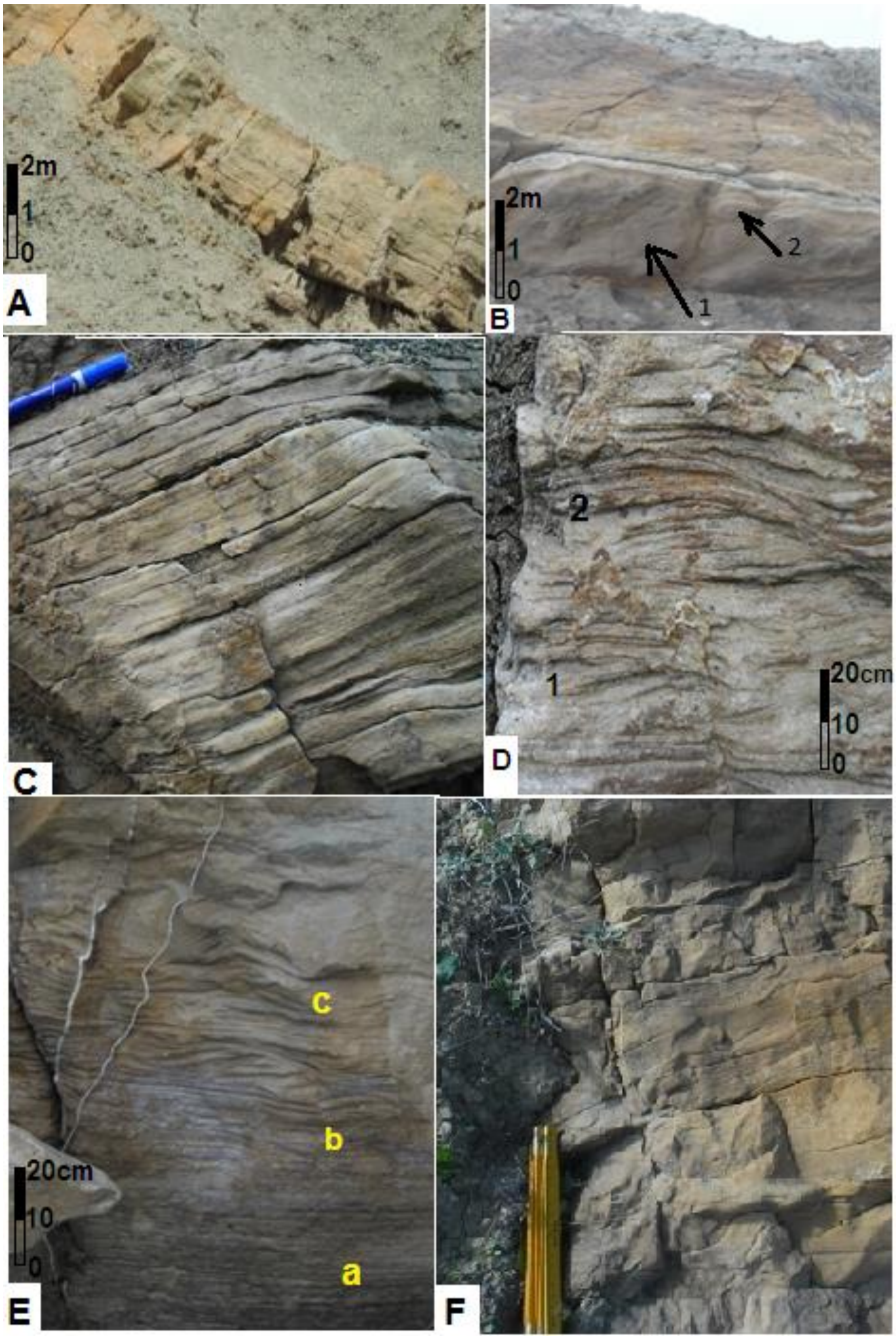


Fig.4 Sedimentary facies. A- Facies F8; B- Facies F9; C- Facies F10 (a- mud couplets, b- sigmoidal bundles, c- symmetrical ripples, arrows indicate flame structures); D- Facies F11 (a- tidal bindles, b-cross laminated beds, c- tidal rhytmites; E- Facies

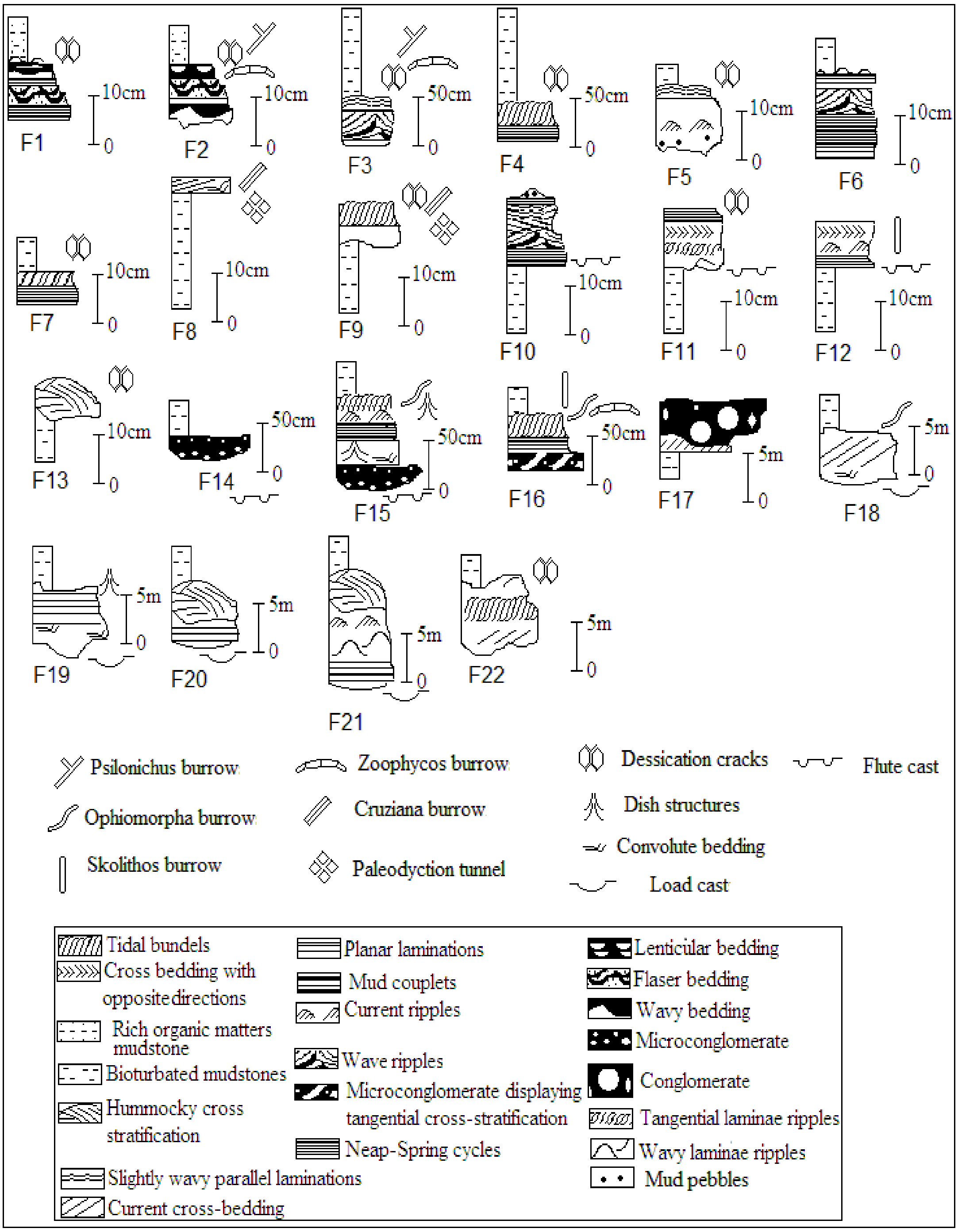
F12 (a- asymmetrical ripples, b- tidal rhytmites, c- cross laminated beds , d- tidal bundles); F- Facies F13 (arrows indicate hummocks); G- detail of F13: Hummocky cross stratification; H- Facies F14 (arrows indicate flute cast); I- Facies F15 (a- microconglomerate, b- massive level, c- asymmetrical ripples, d- tidal rhytmites, e- tidal bundles,   f- asymmetrical ripples); J- Facies F16 (a- microconglomerate, b- tidal rhytmites, c- tidal bundles, arrow indicate convolute bedding); K- Facies F17 a and b (arrow indicate medium to fine -grained sandstone bed); L- Facies F17c (arrow indicate coarse sandstone bed)

Fig. 5



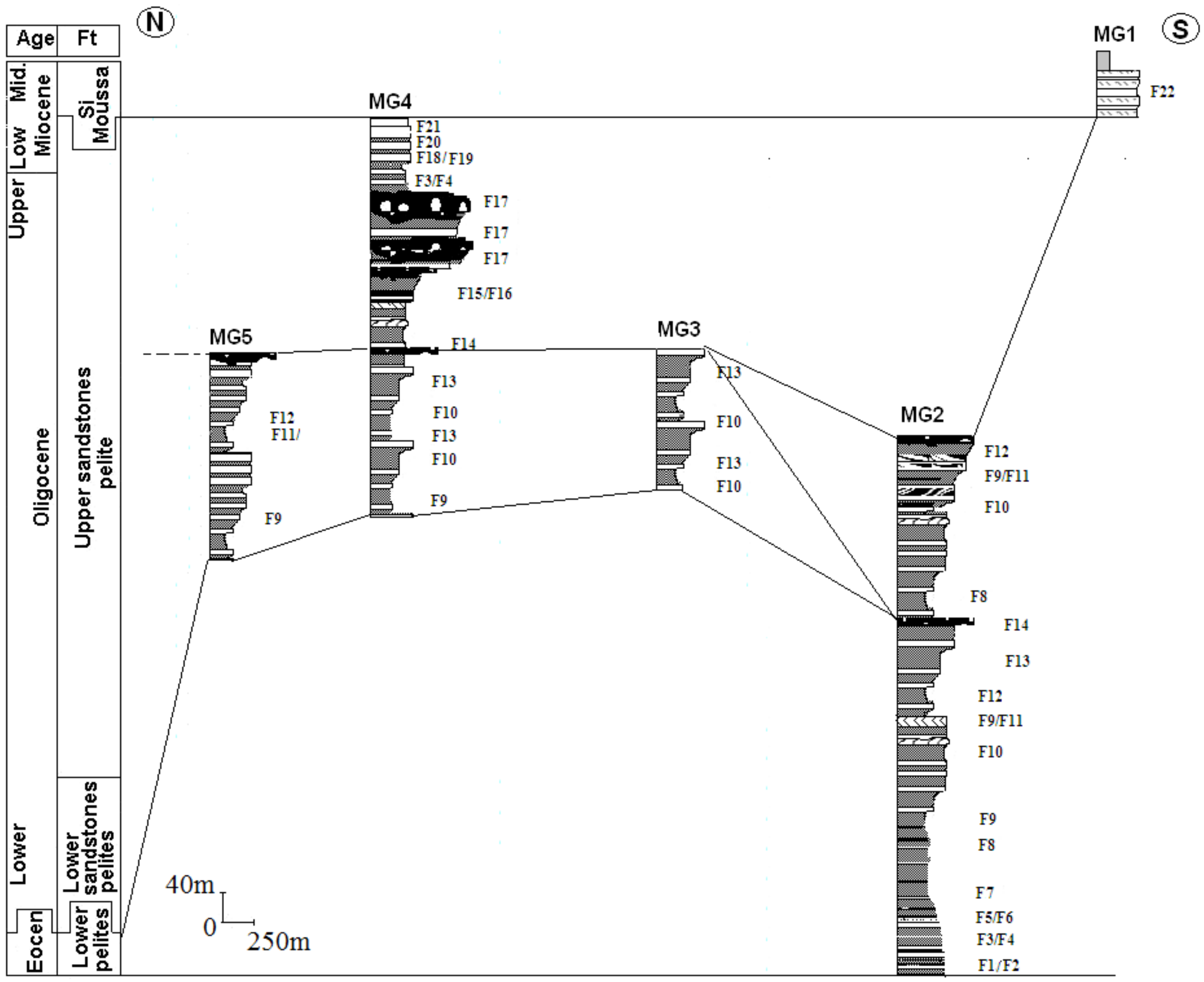
Sedimentary facies. A- Low-angle cross lamination in Facies F18; B- Load casts (arrows 1: large-scale and 2: small-scale) at the base of Facies F18; C- Facies F19; D- Facies F20 (1- planar parallel lamina and 2- Hummocky cross stratification); E- Facies F21 (a- tidal rhytmites, b- symmetrical wave ripples passing to megaripple cross bedding, c- micro-hummocky cross stratification); E- Facies F21 (a- tidal rhytmites, b- symmetrical wave ripples passing to megaripple cross bedding, c- micro-hummocky cross stratification; F- Facies F22

Fig. 6



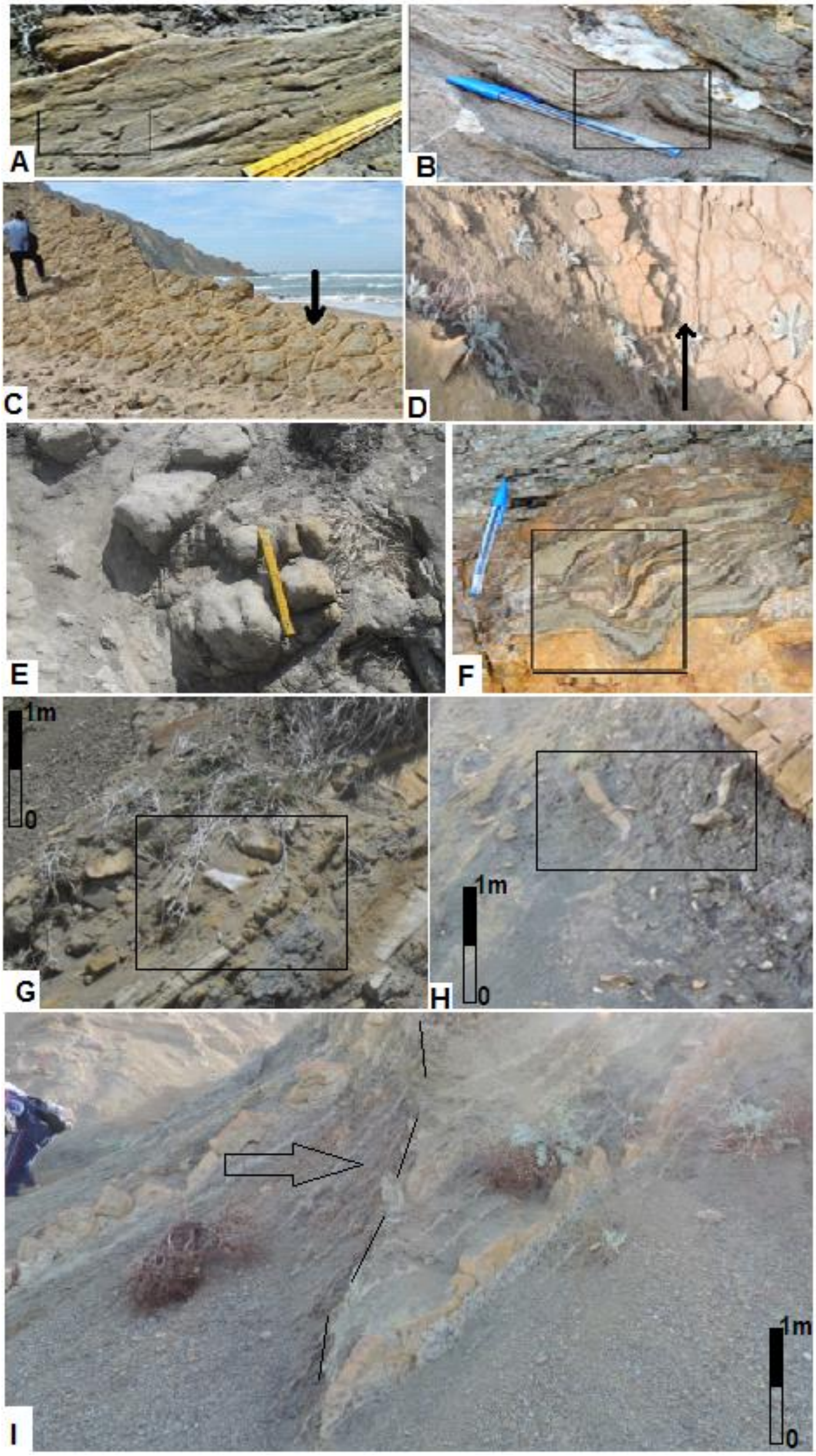
Facies of the Mrayt Group

Fig. 7



Studied outcrops from the Mrayt Group: MG1- Damina section, MG2- Marabout section, MG3- Sidi Mrayt beach section, MG4- Merja section, and MG5- Merja ravine section (See locationsin Fig.1C)

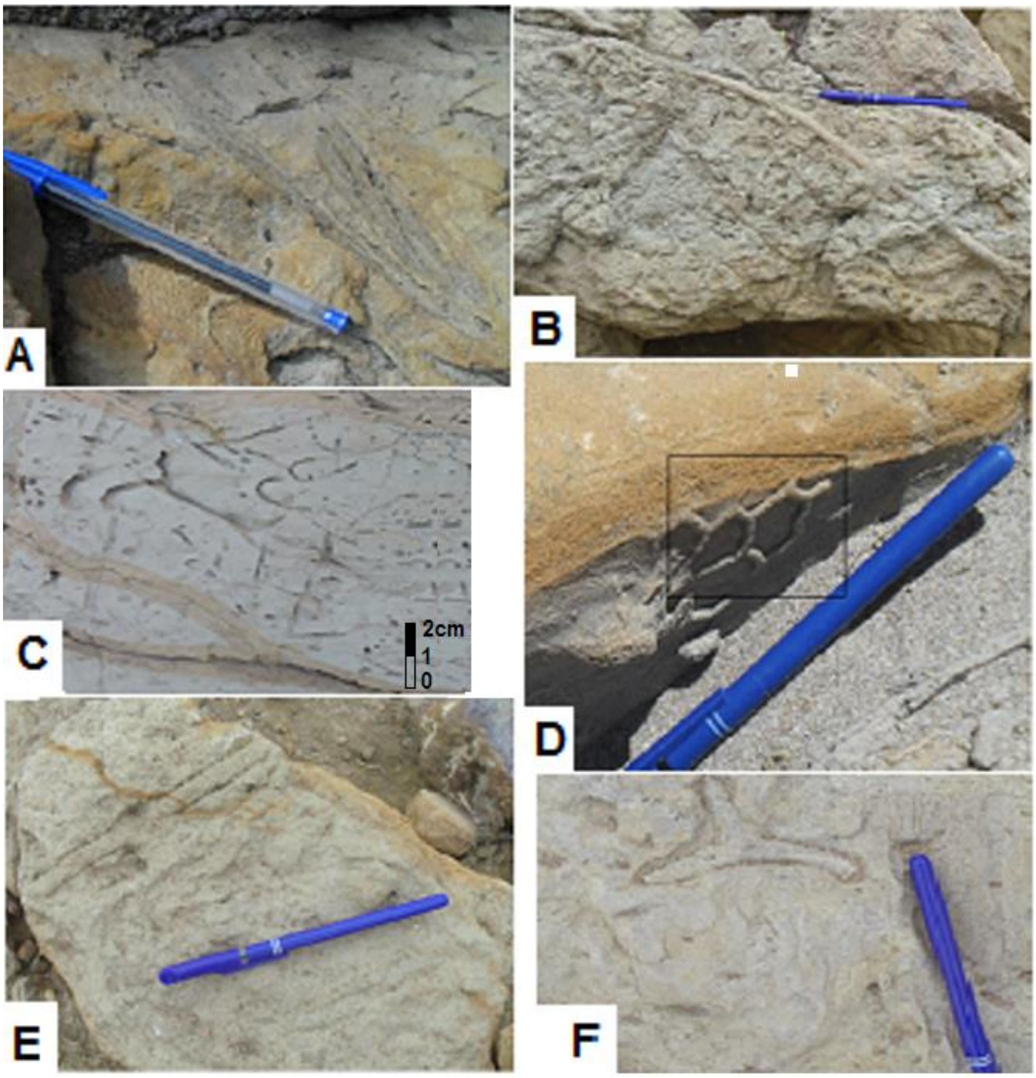
1 **Fig. 8**



2

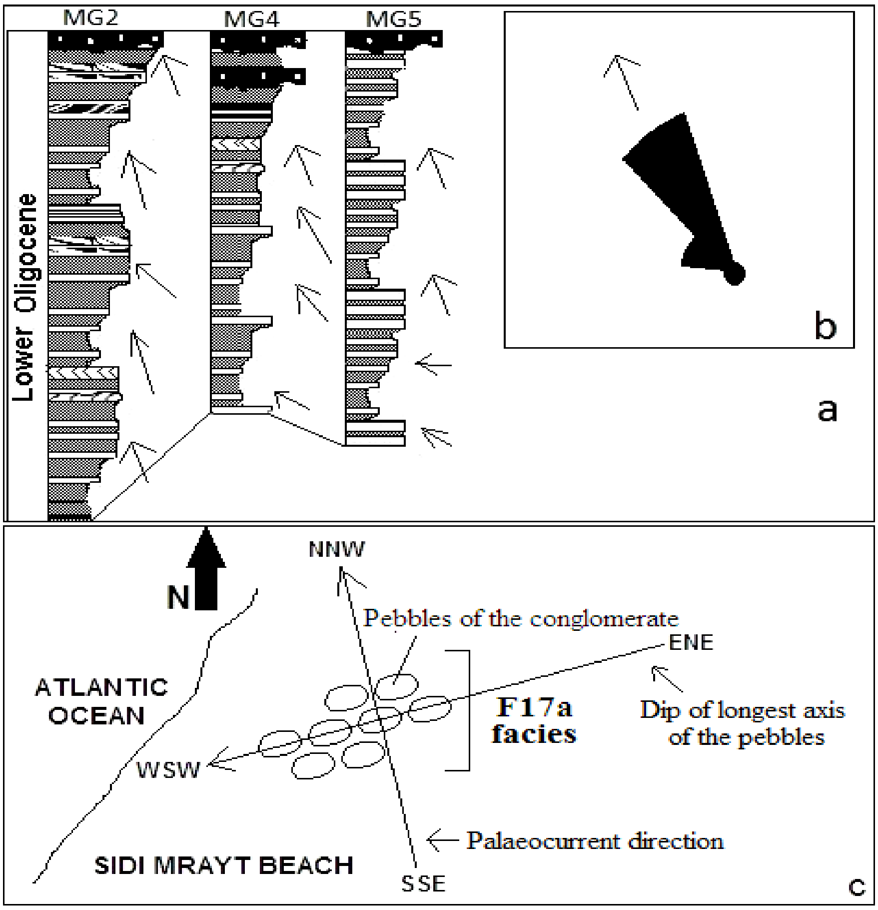
Sedimentary structures. A- Flute casts (F10, observed also in F1, F11, F12, F14 and F15); B- dish and pillar structures (F15, observed also in F19); C- large scale desiccation cracks observed in F3 in the upper pelites formation; D- cm to dm desiccation cracks (F11, observed also in F1, F2, F3, F4, F5 F7, F9, F13 and F22); E-ball and pillow (F16, observed also in F20); F- convolutes bedding (F15, observed also in F8, F16, F18, and F19); G-synsedimentary deformations in the lower pelites formation; H- synsedimentary deformations in the lower sandstones formation; I- synsedimentary deformations in the upper pelites formation (dashes show synsedimentary tectonics)

Fig. 9



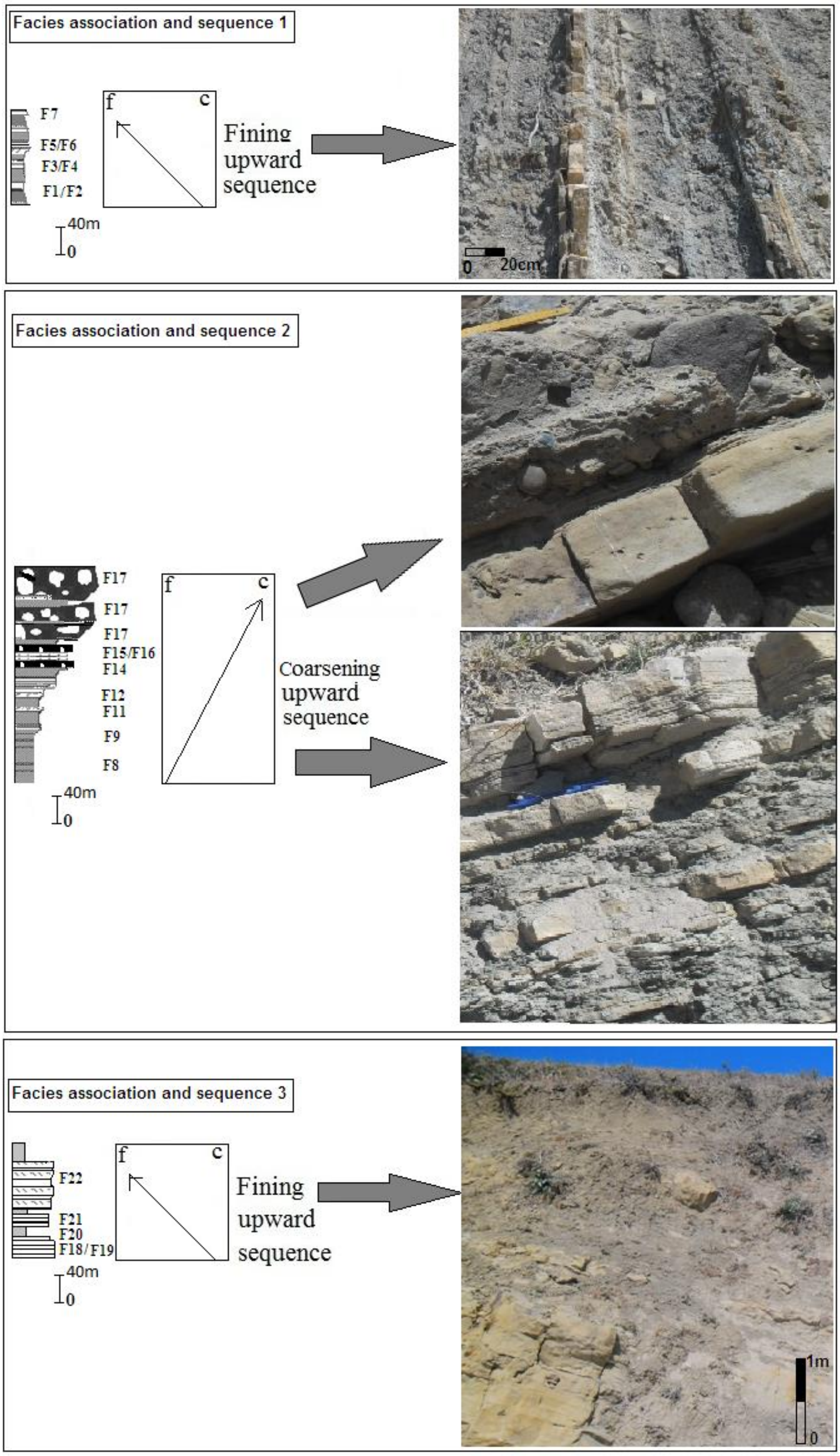
Trace fossils. A- Zoophycos burrow (F12); B- Ophiomorpha burrow (F10, observed also in F12, F13 and F16); C- Skolithos burrow (F12, observed also in F13); D- Palaeodictyon tunnel (F4); E- Cruziana burrow; F- Psilochinus burrow

Fig. 10



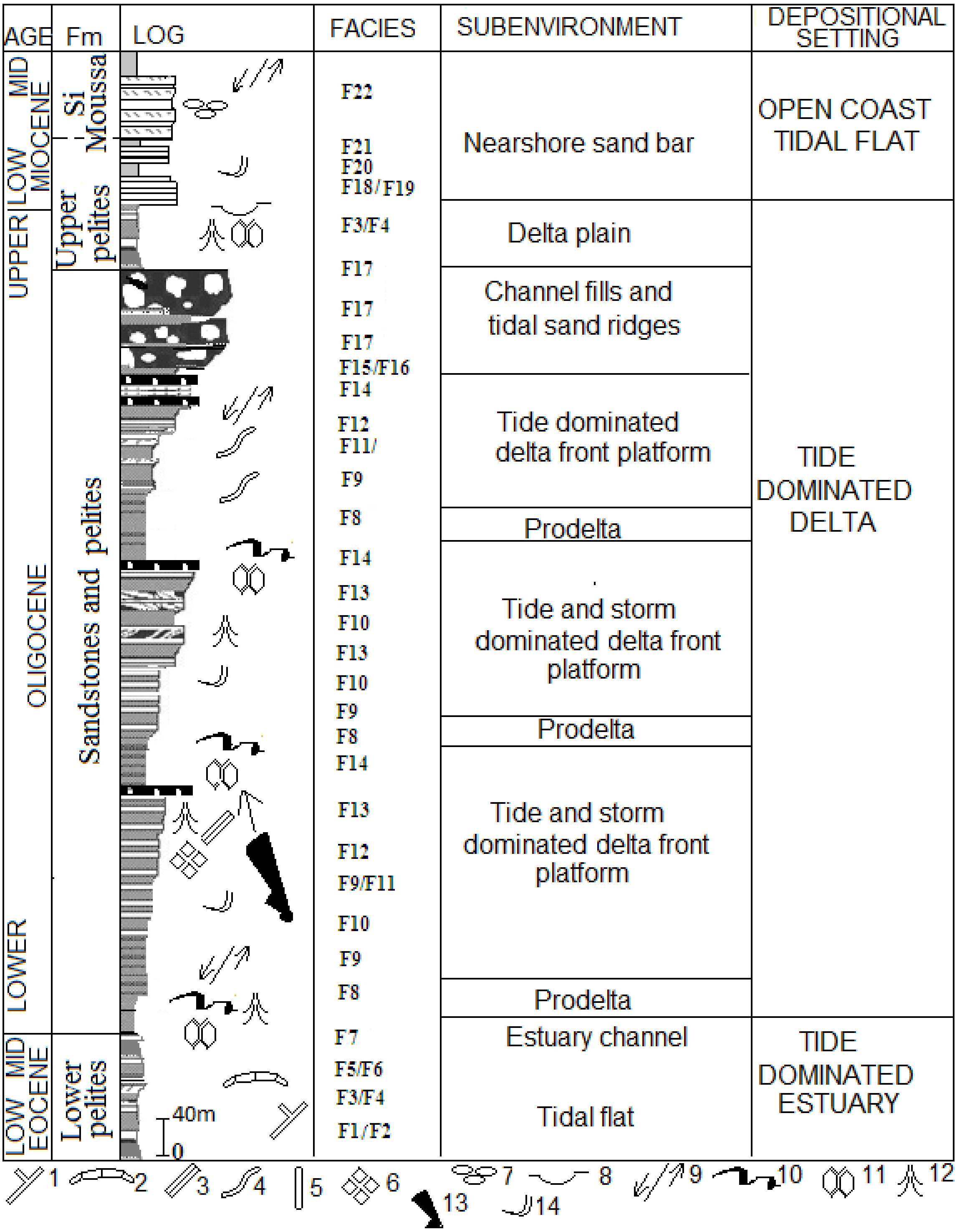
Palaeocurrent measurements (a) and the rose diagram (b) (main direction SSE to NNE, n=48). MG2- Marabout delta, MG4- Merja delta, and MG5- Merja ravine delta (locations in Fig.1C), dip of longest axis of pebbles **(c)**

Fig. 11



Facies associations and sequences of the Mrayt Group.f: fine grained sediment. c: coarse grained sediment

Fig. 12



Lithology, sedimentary environments and depositional sequences of Mrayt Group (1- Psilonichus burrows, 2-Zoophycos burrows, 3- Cruziana burrows, 4- ophiomorpha burrows, 5- skolithos burrows, 6- Paleodictyon tunnels, 7- ball and pillow, 8- load cast, 9- synsedimentary fault, 10- convolute bedding, 11- dessication cracks, 12- dish and pillar structure, 13- palaeocurent measurements), 14- slumps, Fm: Formation