Tidal Influnced Eocene Deposits of Dur At Talah (Libya) Compared with Present Day Tidal Sediments from the Bay of MT St Michel (France)

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Abstract: Dur At Talah escarpment is located in south central Libya, the southern peripheries of Sirt Basin. The escarpment (height ≈ 130m and length ≈ 150 km.) can generally be considered as the exposed part of Abu Tumayam Trough. The outcrop is built up with marine to deltaic clay, silty clay and various sandstones, it is attributed to the Upper and uppermost Eocene time. Only a few field studies have previously been carried out to this area, those were mainly attracted to its vertebrate fossil-content. For the moment, sedimentology and depositional environment are poorly documented.

Taking into consideration the importance of Dur At Talah escarpment outcrop, at the southern fringes of the large hydrocarbon bearing Sirt Basin, this paper aimed at defining the main facies, encountered in the exposed sequence. Sedimentological investigation suggested that the greatest part of the outcrop, which is the lower and the middle (approx. the lower 100 m.) parts, are strongly tidal dominated. The upper part therefore, appears to show smooth changing from tidal to 'pure' fluvial, probably includes mouth bar environments. In order to compare the Libyan tidal facies exposed in this outcrop, to modern ones, several field trips were conducted to the modern "macrotidal" environment of the Bay of Mont St Michel, France. The comparison would contribute to the understanding of the sedimentological sequence encountered in Dur At Talah area. Main results, especially the comparison between fossil and modern environments are presented in this paper.

Keywords: Macrotidal, tide-dominated facies, comparing sedimentary structure, Mont Saint Michel, Dur At Talah Escarpment

INTRODUCTION

Present is the key to the past is a principle (e.g. Charles Lyell) used among geologists since about two centuries. This principle has been applied to study the ancient sediment compared with the present analogs. In this article, the ancient example is Dur At Talah Formation, that is exposed (Fig. 1) as a large E-W stretching escarpment, of about 130 m in thickness located in the southern fringes of Sirt Basin, south central Libya. Particularly, the study involves a comparison of sedimentary structures and features from ancient deposits of Dur At Talah, with the active present day tidal-environment's sediment, as a modern analog. The Dur At Talah is attributed to the Late Eocene (Jaeger *et al* 2010a,b). In the Bay of Mont Saint Michel (Fig. 2), the tidal rang which is the difference between highest and lowest sea level of two successive tides, reaches a vertical distance of 15.5 m between the low sea level (low tide) and the successive high sea level (high tide).

Field work has been conducted to the Bay of Mont Saint Michael, Western coast of France, and to Dur At Talah escarpment, the southern periphery of Abu Tumayam trough (Vasic and Sherif, 2007). The escarpment is striking along latitude ≈25° 45′ N for approximately 150 km. To the west it interrupted by the southwestern corner of Al Haruj Basaltic complex. Best access to the escarpment is from the North that permits a direct access to the top of the cliff and from there to a multitude of small thalweg and Wadis. Access from the base as well as prospection on the foot of the escarpment is especially difficult because of the occurrences of soft, powder-like soil called "Fesh- Fash" composed of windblown clay and fine sand (Wight 1980). Previous geological field studies to the area were mainly attracted to the presence of interesting varieties of continental and marine fossil-vertebrates (Savage 1971; Wight, 1980; Rasmussen *et al* 2008; Duringer *et al* 2008; and Jaeger *et al* 2010a,b) embedded in their sediments.

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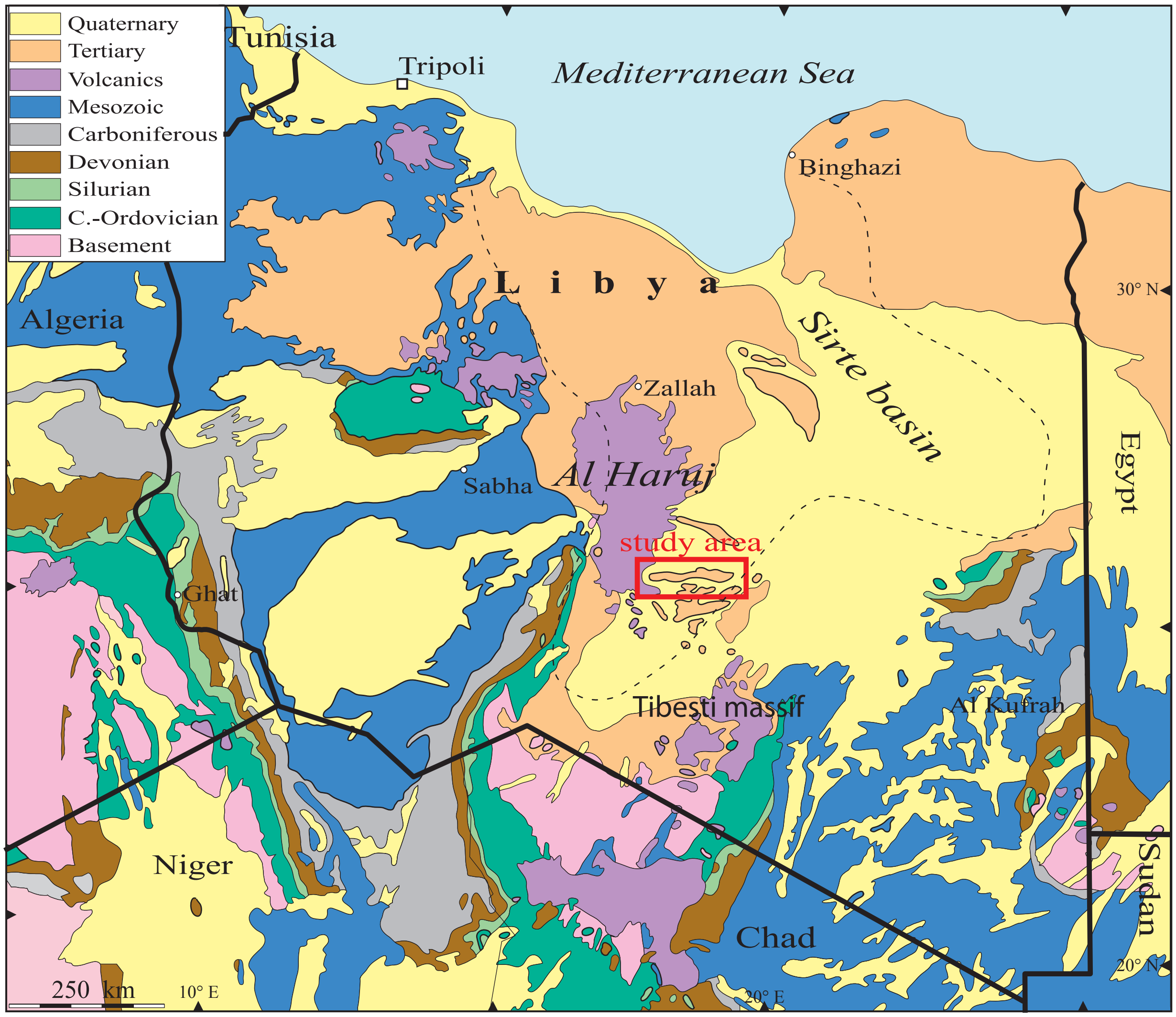

Fig. 1. Location map of Dur At Talah escarpment (red rectangle) south western flanks of Sirt Basin; the escarpment stretches east-west, to the west of Haruj basaltic complex, and to the north of Sarir Tibisti.

The Importance of the area increased in response to the continuous exploration activities devoted to discover more hydrocarbon occurrences in Sirt Basin. Late Cretaceous and Early Tertiary rocks of Sirt Basin contain large accumulations of hydrocarbon which have been the target of numerous exploration wells drilled in the region since oil discovery up to date. The study area can be considered as one of the best outcrops located in the southern Sirt Basin, the Abu Tumayam Trough. Understanding geology of this outcrop therefore, is of vital importance to understanding counterparts in the subsurface of the basin center to the north.

In the year 2007 Industrial Research center (IRC; Vasic and Sherif, 2007) produced the first 1: 250,000 general geological map with explanatory guide booklet (named ″Dur At Talah Sheet″) covering the study area and utilizing its name. By accepting the name “Dur At Talah” IRC puts an end to the differences in the spelling concerning the name of this area, and introduced the name to their new ″Dur At Talah″ Formation. Sediments exposed in this sheet area are dominantly marine carbonate in the south, located beneath the clastic deposits that dominate the northern parts including the escarpment.

During their mapping campaign, Vasic and Sherif (2007) established an overall geological description of Dur At Talah escarpment area; subdividing sedimentary rocks exposed in the sheet area including the escarpment, from older to younger (south to north) into three formations: (i) Al Jir (Gir) formation, (ii) Wadi Thamat and (iii) Dur At Talah Formations. The former two formations exposed south of the escarpment, the later (Dur At Talah Formation, which is the main objective of this study), occupies the whole body of the escarpment.

Most previous studies focus mainly on

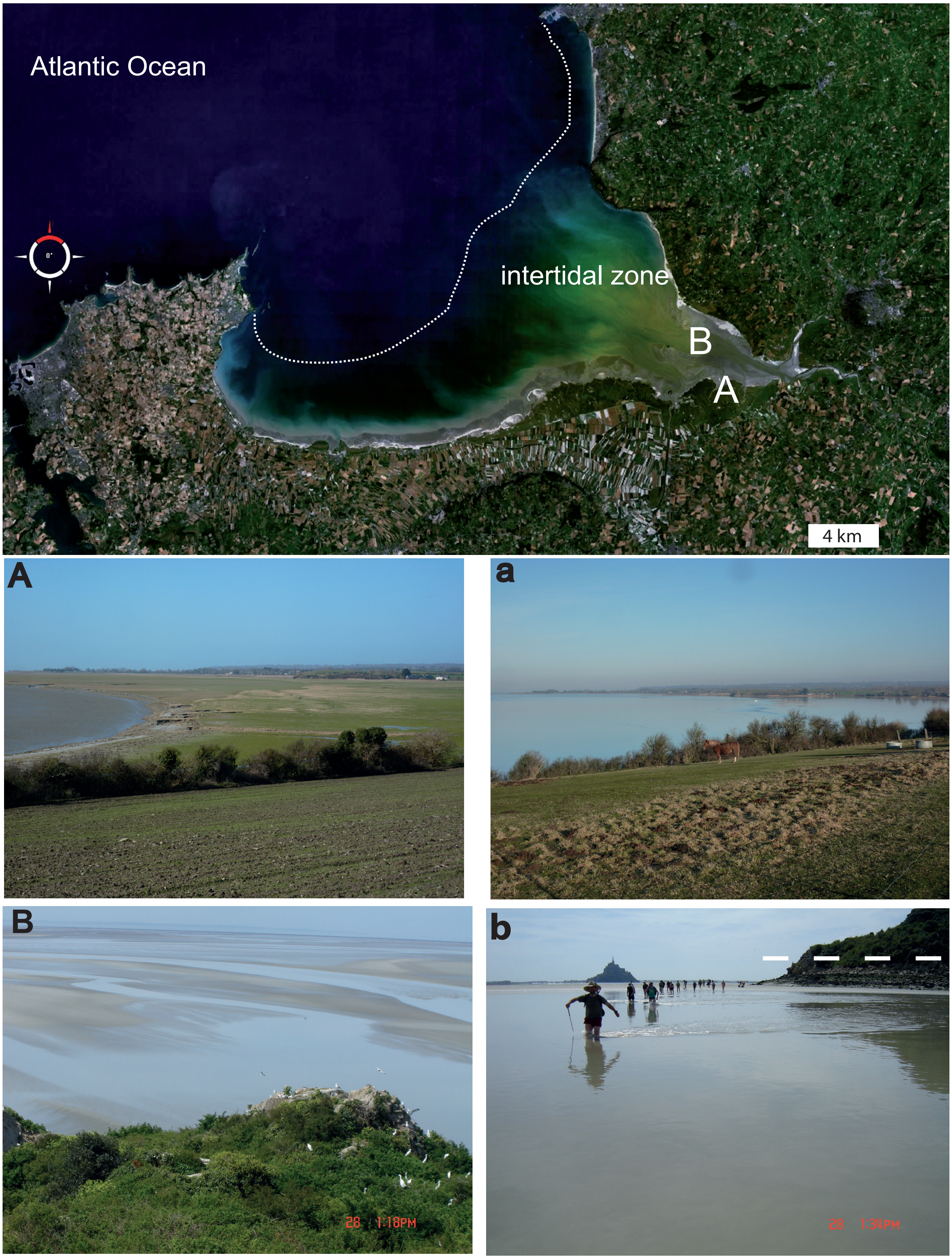

Fig. 2. Satellite image of the Mont Saint Michael Bay, the western coast of France. Dashed line refers to the low-tide limit, characters (A and B) on the image show the locations of the photos: Example from the supratidal zone during ebb (A) and flood after 6 hours (a) in the same location, (B) large size tidal channels as appear during low-tide and (b) closer view of the tidal channel observed in (B), dashed line marks water level during high tide.

paleontology. The present work attempts to consider sedimentological aspects of Dur At Talah escarpment succession. Special attention is given to the tidal sedimentary features, and the comparison of those features and structures with the ones from the present day macro-tidal environment operating today in the Bay of Mont Saint Michel, France.

During our last field work carried out in 2009, field observations and data (paleocurrent measurement) were collected, in order to define and describe the main facies successions encountered in Dur At Talah escarpment. Several locations have been investigated and described, including review of some sites mentioned by previous workers, such as Wight (1980) and Vasic and Sherif (2007).

Four major (large scale) facies successions (Fig. 3) have been recognized, each of those successions are genetically related.

1 The lower most facies of these are clay-dominated facies intercalated by several horizons of oyster shell accumulation (oyster bank).
2 The second facies succession is the thickest constitute of bioturbation-dominated, heterolithic, argillaceous succession, manifested with tidal characteristics, it occurs in the gently sloping, lower part of the escarpment
3 The third facies succession is of medium to coarse grained cross bedded sandstone intercalated by subordinate amount of mudstone, this succession forms the main part of the ledge of the cliff, and it displays less tide characteristics than the underlaying bioturbation-dominated facies.
4 The uppermost facies which shows absence of tidal criteria, is represented by very coarse to microconglomeritic sandstone, contain variable occurrences of fossil roots and large silicified wood trunks.

Sedimentary structures which are known to be tide generated are presented by the middle two facies successions. Therefore, they will take the greater attention of this article.

IMPORTANT ASPECTS OF TIDAL FACIES

Tidal current commonly have sufficient velocity to move sand and gravel on the bed, and silt and clay in suspension (Bridge and Demicco, 2008). Tidal currents are known to be generated as a result of the gravitational force acted on the earth by mainly the moon and, to a lesser extent by the sun (Reineck and Singh, 1980). As result water on the oceans and seas moves forward (flood) and backward (ebb) in a harmonic motion one time, twice times a day, or more complicated according to geographic area. Due to the increasing volume of water tidal range and therefore energy increases, as the water passes into narrow areas such as bays (embayment; the Bay of Mont Sainte Michael is a worldwide example) and funnel shaped coastal regions. This fact explains why tidal range is specifically high in relatively restricted areas.

In tidal environments, traction currents are commonly bidirectional. Maximum flood and ebb currents commonly follow different pathways; result in characteristic sediment transport path for which there is net sediment transportation in a given direction (e.g. Harris *et al* 1995). In many cases, only one water directions is recorded, though, It is usual to observe a high asymmetry in recording of the sedimentary features. Thus, tidal megaripples are often associated with reverse small ripples, each representing one direction of water flow (Ashley, 1990). Tidal deposits therefore is known by its systematic (rhythmic) variations in the thickness of lamina, this have been related to periodic variations in current strength and deposition rate over tidal cycles Dalrymble (1992).

Tidal flat in the Bay of Mont Sainte Michel are flooded and exposed at regular intervals twice times a day. Reshaping of tidal bars and tidal channel can be visualized within several hours. The objective of the field work to the Bay was to practically understanding tidal processes and to find a set of criteria within the recent sediments, that can be applied to compare with the fossil counterpart of Dur At Talah deposits. The tidal flats of Mont Saint-Michel Bay, in France belong to the macro-tidal flat of very high tidal range (15.5 m.; Reineck and Singh, 1980; Bonnot-Courtois, *et al* 2002).

Tides in this region are semidiurnal; two tidal cycle each 24 hours.; In each cycle the water flood landward up to (high sea level) the high tide level, then short period of stagnation (slack water period), followed by ebb back towards the sea until the low tide, short period of stagnation and so on. The horizontal distance of tidal flat between low sea level and high sea level exceeds 15 Kilometers, and water speed is capable of transporting sand-size and even coarser sediments several meters per second.

Small and large scale sedimentary processes have been observed operating on the sediments of the Mont Saint Michael Bay, large scale processes include: (i) active tidal channels (of straight and meander types; Fig. 2) cutting across muddy to

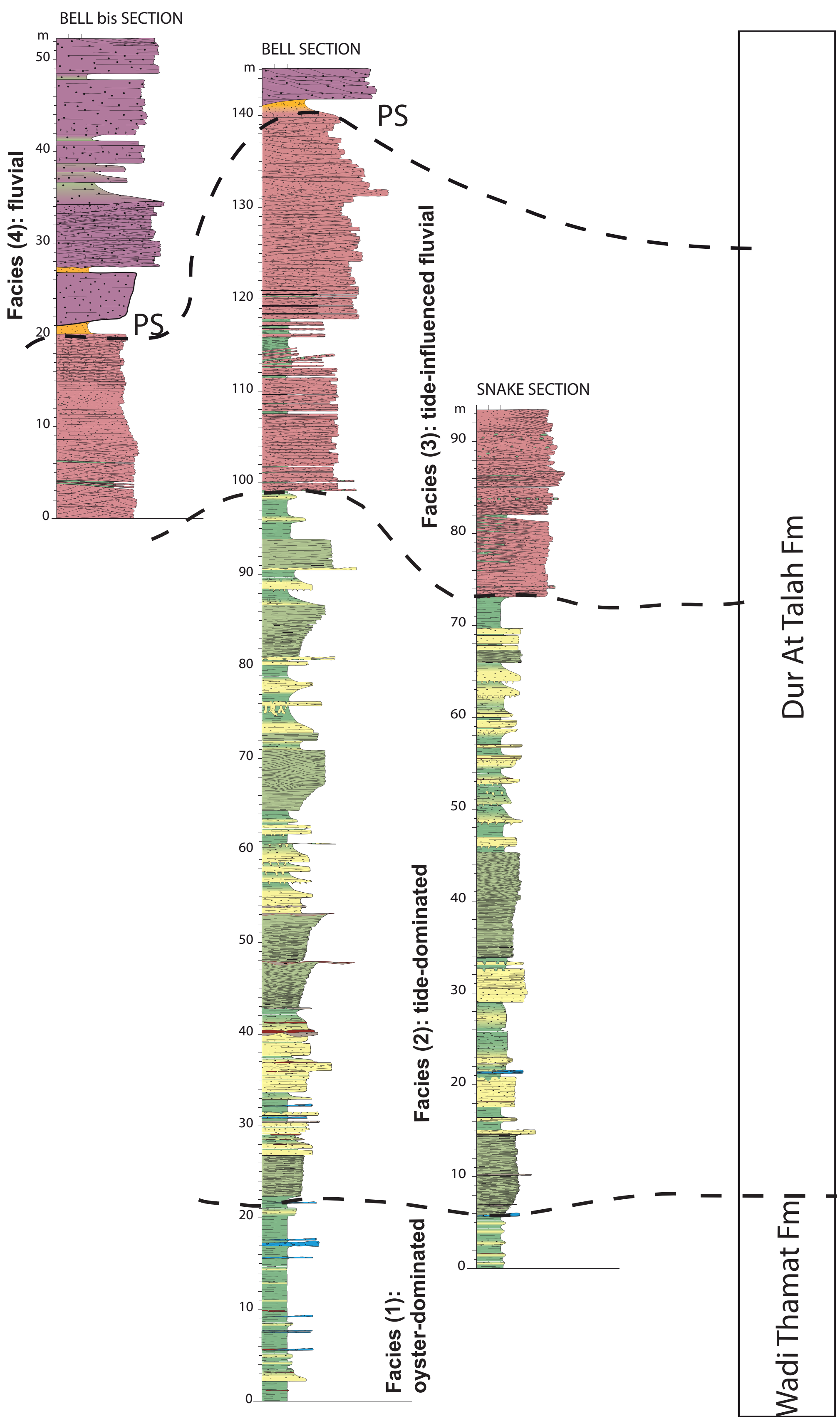

Fig. 3. Sedimentological log representing the main facies encountered in Dur AT Talah (escarpment) Formation. This section if pieced out from three adjacent (few kilometers apart) location at the western part of the escarpment. PS for paleosoil, and dashed line, separates the main facies.

sandy tidal flat, (ii) tidal channel lateral shifting and eroding previously deposited, unconsolidated sand and mud flats, (iii) mud deposition in abandoned channels, and (iv) landward sand transportation during flood tides and seaward sand transportation during ebb tides. The smaller scale features include but not limited to: deposition of mud from suspension during slack water periods to produce mud drapes on sand (e.g., Dalrymple and Choi, 2007), formation of ripple mark during ebb as well as flood, sediments burrowing by worms, crabs and bivalves.

DUR AT TALAH ESCARPMENT GEOLOGICAL SETTING

The Dur at Talah escarpment represents the southern extension of Abu Tumayam Trough of Sirt Basin. Sirt Basin or Embayment (Conant and Goudarzi, 1967; Goudarzi, 1980) has long been considered as part of the Tethyan rift system. The Basin reflects significant rifting in the Early Cretaceous and syn-rift sedimentary filling during Cretaceous through Eocene times, and post-rift deposition in the Oligocene and Miocene (e.g. Ahlbrandt, 2001 and Abadi *et al* 2008).

Geomorphologically, Dur At Talah area in general consists of three prominent morphological elements (Fig. 4): (1) the escarpment extends East-West around latitude ≈25° 45′ N; between 18° 00′ and ≈19° 30′ E; (2) the lower low- relief plain to the south; and (3) the upper, capping plateau to the north of the escarpment. Rocks forming Dur At Talah escarpment (equivalent to IRC's Dur At Talah Formation) are the main target of this study. These rocks are made up mainly of siliciclastic sediments shows coarsening and thickening up trend; clay, sandy clay, and fine sand at the base grads up into coarse to microconglomeratic sandstones at the top. The southern adjacent vicinity to the escarpment, represented by the lower plain, is occupied by sediments of uppermost member of Wadi Thamat Formation, and to which our lower facies (1) is included, Vasic and Sherif, (2007). This is composed of dominantly claystones, interbedded with oyster shell. The capping plateau has relatively lower

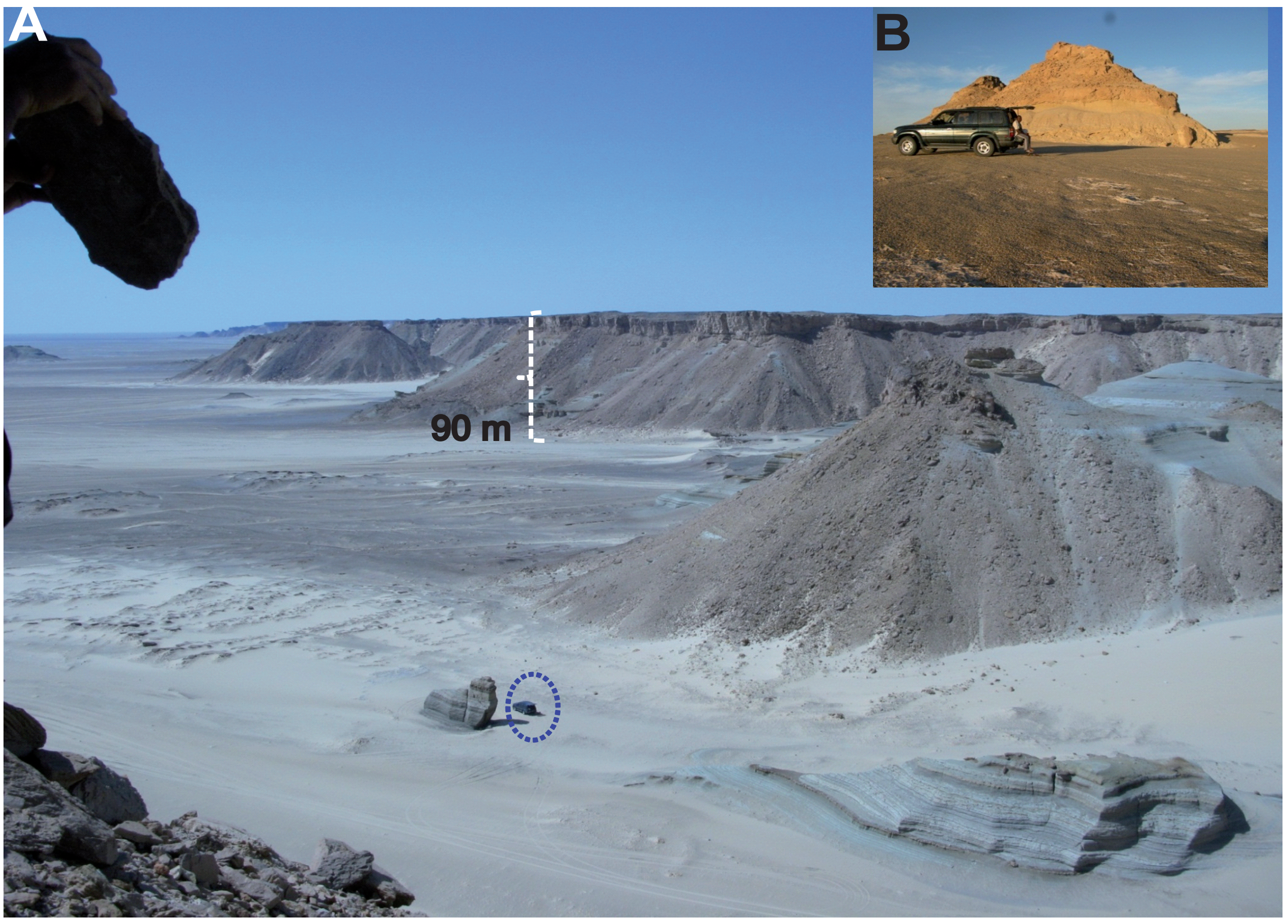

Fig. 4. Photo shows the major morphological elements of Dur At Talah Escarpment area. The escarp is stretching East-West for 150 km. total height about 130 m, starting from the footwall until the top of the hills on the capping plateau (the inset photo).

relief, it constitute scattered hills of maximum 20m high, composed mainly of very coarse to microconglomeratic sandstones.

The chronological framework of the Dur At Talah Formation is still in progress. Eocene to Early Oligocene ages have been first proposed in comparison with equivalent formations in the Sirt Basin, as well as to what thought to be equivalent outcrops adjacent to the area (e.g. Peregi *et al* 2003). Biochronology, based on large mammal fauna suggested a latest Eocene age (Savage, 1971 and Wight, 1980). Biochronology based on micromammals and paleomagnetic studies suggested an upper Eocene age (Jaeger *et al* 2010a,b).

There is a common agreement among local geologists that the source of clastic sediment supplied to the basin was the higher land to the south around Tibesti Massif. A major marine transgression in the Paleocene and Eocene times extended southward from the basin center south into its deep embayment, which by the late Eocene had reached the Tibesti area and possibly beyond (e.g. Barr and Wegeer, 1972; Benfield and Wright, 1980). Such transgression is well recorded by the marine fossil-dominated carbonate rocks, exposed to the south of the study area. Paleocurrent measurements from various locations, confirm that the main trend of sedimentary transport is from the South to the North. Nevertheless, as a result of tidal currents, many outcrops show local paleocurrent measurements.

Structurally, Dur At Talah rock sequence shows very low dip angle (1-2°), that is generally northward. Except of very widely spaced, typical normal and reverse faults, the area can be considered structurally undisturbed. The vertical displacement of those faults does not exceed one meter, with almost no horizontal displacement. Exceptionally, the western extremity of the escarpment, which is bordering the Haruj basaltic Massif (Pliocene to Late Pleistocene; Busrewil *et al* 1996) is displaying a small scale and localized folding, which might be attributed to doming effect during the generation of the basalt.

DUR AT TALAH FORMATION, GEOLOGICAL CONSIDERATIONS

Vasic and Sherif (2007) comprehensively described all the rocks exposed in Dur At Talah mapped area, starting from the rocks exposed in the lower plain (south of 25° 45′ N) extending north to the capping plateau into three formations, summarized hereunder.

Al Jir (Gir) Formation: Al Jir Formation Is the oldest (Lower Eocene, Ypersian-Lutetian), in the sheet area, it has more than 45 m thickness, and consists of marine carbonate rocks, occasionally contain concretions of silica. The Jir formation has a much greater thickness in the subsurface of Sirt Basin (Barr and Wegeer, 1972) the formation is oil-producing in Ed Dib and Facha fields.

Wadi Thamat Formation: The Wadi Thamat Formation (Middle Eocene, Lutetian-Priabonian), its thickness varies from160 m to-200m thick, and is divided into three Members: (i) Al Gata Member, the oldest, chiefly consists of bioclastic limestone with nummulites, (ii) Thmed Al Qusur Member, composed of limestone and chalky limestone, marlstone, gypsum, and dolomite varieties, and (iii) Qarart Al Jifah Member which is made up of sequences of green claystone, marly claystone, bioclastic limestone with frequent oyster (lumachelles) layers. Vertebrate bones have been mentioned (Vasic and Sherif, 2007) and observed in the top of Qarart Al Jifah Member. The Middle Eocene in the subsurface of the Sirt basin is represented by the Gedari Formation and its lateral equivalent Gailo formation, Wadi Thamat Formation is equivalent to the Gedari Formation (Tawadros, 2001).

According to our observations, the uppermost oyster bank is situated several meters above the foot of the scarp, that was considered as the boundary between Wadi Thamat Formation and the overlaying Dur At Talah Formation (Vasic and Sherif, 2007). Such boundary therefor is just an arbitrary, since the oyster banks are common in the lower part of the escarpment. It is worth mentioning that, up to date, there is no visible physical discontinuity separating the Wadi Thamat Formation from the overlying Dur At Talah formation.

Dur At Talah Formation: The name Dur At Talah Formation was first introduced by Vasic and Sherif (2007). The succession has been split into two members. The lower member is composed of alternation of fine sediments (mud, silt and fine sand), and is rich in marine vertebrates. The upper member is made up of coarse sandstone dominated with silicified tree trunks. Details about the major facies composing Dur At Talah Formation will be presented in the next section. In the subsurface of Sirt Basin the Oligocene-aged Arida and Diba

Formations described by Barr and Wager (1972) bears nearly similar lithological characteristics with the IRC's upper member of the Dur At Talah formation.

Dur At Talah Formation of Vasic and Sherif (2007), is equivalent to the Wight's (1980) three units: The Evaporite, the Idam, and Sarir units. The Evaporite unit therefore, is not primarily an evaporite, because the gypsum proportion is low compared with the clay and sand content, and in fact this gypsum is diagenetic rather than depositional (Duringer *et al* 2008). The term Idam unit was not suitable and shortly abandoned, as it is confusing with the Lidam Formation of Upper Cretaceous. Idam unit is included in the undifferentiated Eocene sediments in the geological map of Libya (1985). It can be inferred that Wight's Evaporite and Idam units is more or less equivalent to lower member of Dur At Talah formation of Vasic and Sherif (2007). Meanwhile the Sarir unit of Wight is, more or less, equivalent to the upper Member of Dur At Talah formation.

MAIN FACIES OF DUR AT TALAH FORMATION

Based on numerous field observations along and across the escarpment outcrop, and taking into consideration the outcrop scale sedimentological variations in the rocks composing Dur At Talah (Escarpment) Formation. This formation has been split (Fig. 3) into four vertical successions (or main facies), from bottom to top, these are:

1 Clay- oyster banks interbedded facies (marine-dominated facies)
2 Bioturbated fine sand to mud facies (Tide-dominated facies)
3 Cross bedded coarse sandstone facies (Transitional or tide-influenced facies)
4 Micro-conglomeritic sandstone facies (Fluvial facies)

In this study special attention has been given first two facies (1 and 2) as they own a characteristic sedimentary structures and features which are directly related to tidal sediments and processes. these structures are analogous to the one observed in the Bay of Mont Saint Michael tidal flat, which represents one of the best modern environment showing tidal dynamics. In other word, the sediments of facies (2 and 3) possess numerous features and sedimentary structures that are common and highly similar to the one occurring today in the Bay of Mont Sainte Michael. Meanwhile the Fluvial facies shows characteristic sedimentary structures which have not be observed in the Modern tidal Bay. The next section will illustrate the main characteristic features of each facies in correlation with their modern counterpart.

Clay-Oyster Banks Interbedded Facies (Marine-Dominated Facies): This facies is composed of green clay interbedded with shell accumulation known as oyster bank (wight, 1980; Vasic and Sherif, 2007). It is occurred in the lowermost part of the escarpment and extends far to the south, with a very gentle sloping terrain, where it is generally poorly exposed and covered by ″Fesh-Fash″. The topmost few meters of this clay-dominated facies, show better outcrop at the foot of the escarpment. This interbedding facies has a minimum thickness of 15 m, and was considered as the upper part of Wadi Thamat Formation (Vasic and Sherif, 2007)

Bioturbated Facies (Tide-Dominated Facies): This facies occupies the lower (65-70 m; Fig. 3) of the section; it displays a thinly stratified, commonly heavily bioturbated succession, forming the gentle to moderate sloping, lower part of the escarpment. Compared to the sediments in Mont Saint Michael Bay, this facies embraces characteristic tidal features very similar and sometimes identical with those observed operating today, in the tide-dominated Bay of Mont Saint Michel tidal. For this reason it named ″Tide-dominated facies″. A very prominent, easily distinguishable oyster bank of 50 cm thick (Fig. 5) can be considered as the lower contact with the

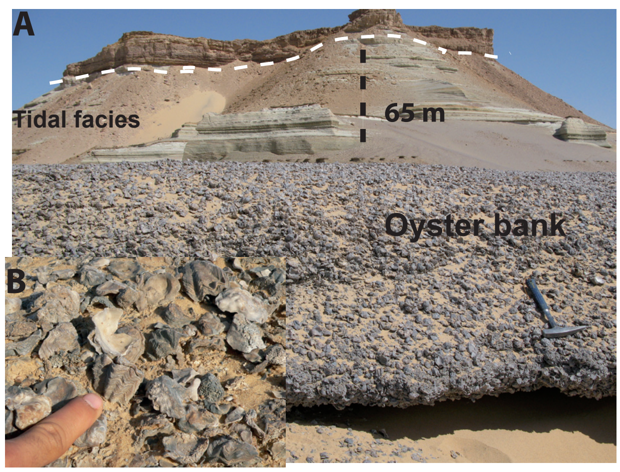

Fig. 5. composite photo from Dur At Talah, illustrates an example of the oyster bank occurrences, at the base of the bioturbated (tide-dominated) succession. The solid white line shows the location of the contact with the overlying cross bedded sandstone facies. Small photo in the corner (B) shows closer view of the oyster bank.

underlying clay-oyster bank dominated facies. This contact marks the onset of typical tidal sedimentary structures. It is important to mention that this bank is not a chrono-stratigraphic marker. Similar oyster banks (shell accumulation) are currently occurring in the Bay of Mont Saint Michel (Fig. 6) and interpreted as a wash over fans.

Sedimentary structures of the bioturbated facies include but not limited to the biogenic (mainly bioturbation) structures, and the small scale intra-bed sedimentary structures, such as ripple laminations and mud-sand alternation, flaser-, wavy- and lenticular-bedding, climbing ripples, and occasionally bi-polar cross lamination. As well as, large scale structures such as tidal bundles, (Reineck and Wünderlich 1968; Dalrymple 1992) composed of systematic silt-mud alternations, and larger scale structured as channels and channel filling including frequent reactivation surfaces followed by rip up clasts. The small scale structures such as climbing ripples are well preserved and displayed within the large scale structures such as channels. The upper contact (Fig. 7) of the bioturbated facies are erosional and has a wide lateral extent along the escarpment. It is usually marked by well cemented ferruginous sandstone layer. Morphologically it is represented by a break in the slope, from gentle and moderate below to cliff and steep sloping above.

Bioturbated facies versus modern tidal flat: Apart from the various types of sedimentary structures preserved in the bioturbated (tide-dominated) facies succession, this succession has been split into three alternating subfacies, based on grain size variations. Accordingly, the tide-dominated facies succession can simply be described as an alternations of three interbedding (lithofacies) subfacies. All three lithofacies display characteristic sedimentary structures that are encountered today in the sediments of Mont Saint Michel Bay. In Dur At Talah therefore, the distribution of bioturbation content (Fig. 8) is not yet well elaborated, and bioturbation could be expected to occur in a variable

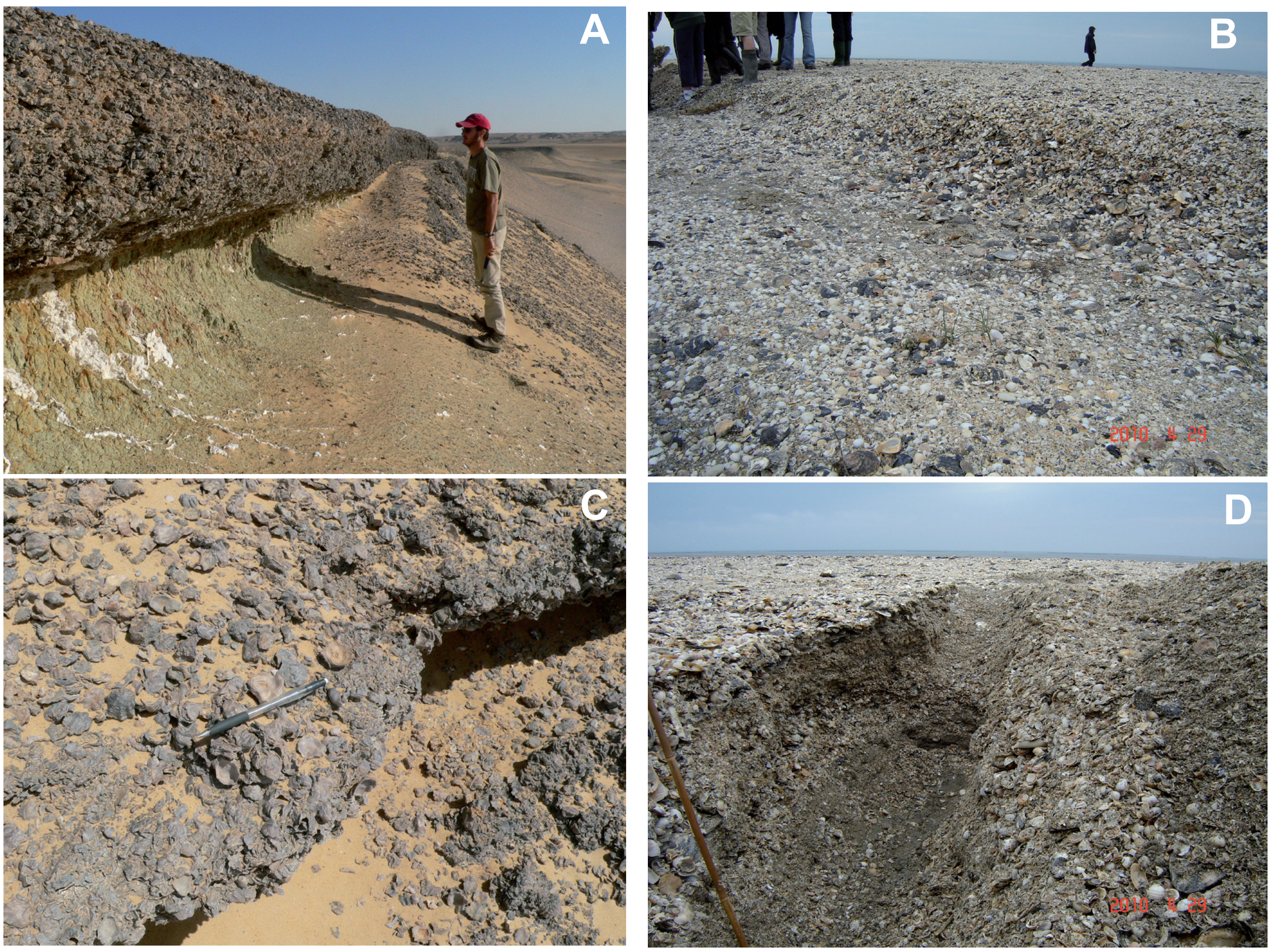

Fig. 6. photos (A to D) shows the comparison between the ancient (A and C, left side, from Dur At Talah) and the modern (right side, B and D, from the Bay of Mont Saint Michael) oysters accumulation or banks. Note the similarity between both ancient and modern oyster banks morphology.

Fig. 7. Photo from Dur At Talah formation shows the erosional contact between the bioturbated facies (gray mud) below and cross bedded sandstone facies above. The contact is usually marked by a ferruginous sandstone layer (above the dashed line), which indicated permeability barrier between muddy deposits below and sandy above.

intensity at any level, within these three lithofacies. The following section will define and describe each of these three lithofacies individually:

- Heterolithic (Mud-sand dominated) lithofacies
- Mud dominated lithofacies,
- Fine sand dominated lithofacies.

Sometimes the three lithofacies appear to be arranged in a set of finning up Parasequences. In fact they appear to be interbedding vertically, and interplaying laterally in a kilometric-scale distances.

Heterolithic (Mud-sand dominated) lithofacies: This lithofacies is made of packages of sand-mud interbedding bundles, arranged in a rhythmical sequence, which occasionally contain intraformational conglomerate lenses (Fig. 9). Individual beds of this facies has a thickness varies from 1m up to several meters. It exhibits two morphologies; the most common is horizontal parallel stratified appearance, and second is the inclined clinoform-like appearance. The latter is thought to be a cross sectional view of channel infill. Those are the most commonly observed features in the tide-dominated unit, and in both cases they are built up of alternating beds of fine sand, silt and clay layers. The thickness of each individual layer varies from less than one to five centimeters.

In correlation with the recent sediments in the Bay of Mont Sainte Michael, the heterolithic lithofacies possess many sedimentary structures diagnostic of tidal environment, these include but not limited to: tidal bundles (Fig. 10), represented by systematically organized sand-mud layers reflecting variation in tide energy attributed to semidiurnal and/or neap-spring variations. Visser (1980) suggested that tidal bundles associated with mud couplets are the best criteria of estuarine subtidal environment. Ripple lamination, cross lamination, and climbing ripples, as well as flaser to lenticular bedding of Reineck and Wünderlich (1968), and bipolar (herringbone) cross lamination are well preserved in the sediments of this lithofacies. Comparatively, the same structures are observed in modern intertidal sediments.

Mud dominated lithofacies: This lithofacies consists of beds of light gray to green mud (clay and/or silt). It varies in thickness from several decimeters to less than 3 m. in most cases internal (intra-bed; Selley, 1992) sedimentary structures are barely observed in this lithofacies, especially when the clay is dominating. Nevertheless, they occasionally appear as laminated and cross laminated when the silt is dominating. In many situations, small leave prints, as well as some Skolithos and other undifferentiated burrow are observed. Exceptionally, accumulation of plants (silicified wood fragments and fossil fruits) and a variety of fossil vertebrate bones are preserved in a level located in the middle of the bioturbated beds. Features, Such as tree trunks, fruits, and bones have been observed in the intertidal sediments of Mont Saint Michael Bay. Unlike the heterolithic lithofacies above, and fine sand lithofacies below, bioturbation are uncommon in mud dominated lithofacies.

Fine sand dominated lithofacies: This lithofacies is composed of light gray to white very fine to fine grained, occasionally argillaceous sandstone. It has thickness range between few decimeters to two meters. Bioturbation of various shapes and sizes are abundant and well preserved in this lithofacies. Such abundance (Fig. 11) can also be compared with that occurring in the sand flat of the Mont Saint Michel. Frequently, bioturbation in this lithofacies is intensive, so that it obscures the primary sedimentary structures. Furthermore, bioturbation are sometimes large sized (up to 70 cm deep, 20 cm diameter; Fig. 8 A and B). This large bioturbation is thought to be a combination of both roots and fossil traces. Distinguishable sedimentary structures are laminations, centimeter scale cross laminations and climbing ripples (Fig. 12). Presence of fossil fish and crocodilian skulls and remains are confirmed in many beds of this lithofacies. Uncommon horizons of this sandstones display a green color which thought to be due to the presence of glauconite.

Cross Bedded Medium Sandstone Facies (Tide-

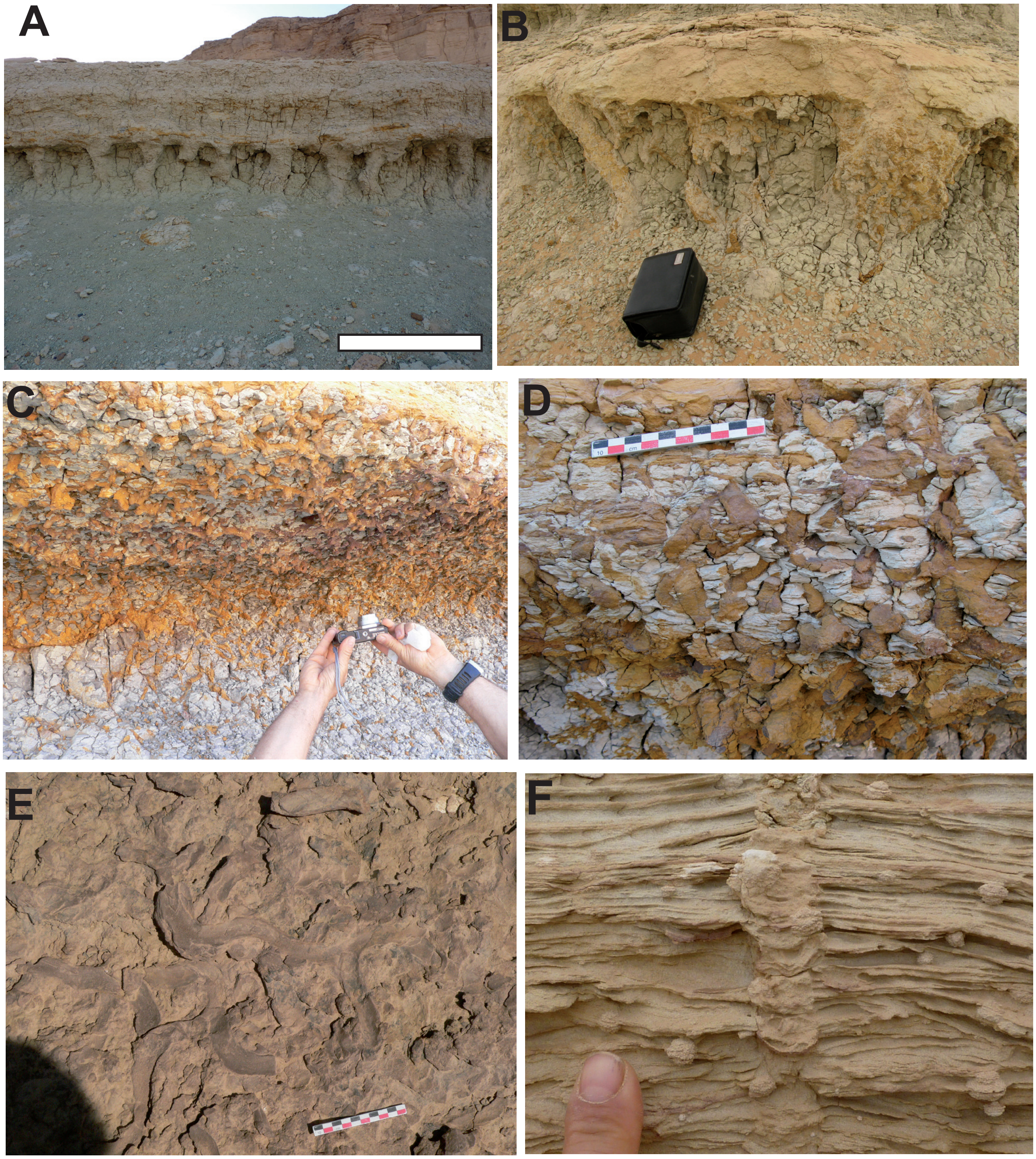

Fig. 8. photos A to F from Dur At Talah Formation, show various occurrences of bioturbation found in the bioturbated facies. In A (scale bar 1 m) and B the burrow are very intensive and shows multiple generations. Its morphology appears like a combination of roots traces and burrows. (B) is a closer view of (A); (C) shows domination of small size burrows, Thalassinoides in some levels, and to a lesser extent Skolithos; (D) a closer view of C, notes that sedimentary structures are no more distinguishable due such biogenic activities. (E) Shows plane view of fine sandstone with Teichichnus ichnospecies, and photo (F) shows Teichichnus cross-sectional view.

Influenced Facies):Unlike the bioturbated facies which is composed of fine sand and finer sediments, this facies (≈30 m.) is made up of yellow, medium to coarse, cross bedded sandstones. This sandstone is intercalated with subordinate amount of thin and irregular beds of light gray to white mudstones. Abrupt erosional contact separates this relatively large scale cross bedded sandstone from the underlying tide-dominated facies. In most locations where this contact is observed, it cuts (Fig. 7)

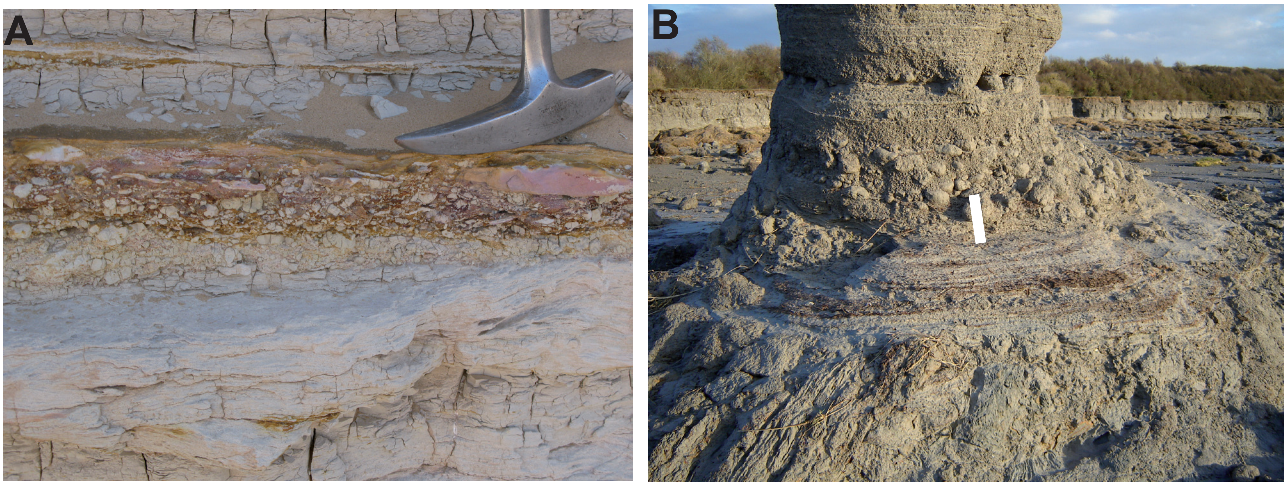

Fig. 9. photos (A) and (B) illustrate the comparison of intrabasinal conglomerate in the ancient (A; Dur At Talah) and the recent (B; Mont Saint Michel Bay, scale bar 10 cm), such conglomerate is resulted from the erosion when tidal channel cuts through mud flat.

into the mud of the underlying bioturbated facies, and it marks the end of all kinds of fossil fauna, ichnofossils intensity is also highly diminished.

In spite of this great change, typical signs of tidal influence are still preserved in this coarsely sandstone facies, especially within its lower part. The tidal influence compared with what has been documented in the present day tidal environment is well displayed by the presence of mud drapes (Dalrymple, 1992) between forests of the cross bedded sandstone (Fig. 13). In modern tidal environment, such drapes of mud are deposited from suspension during periods of slack water (Allen, 1990) culminating each tide cycle. Sometimes double mud drapes also preserved, recording (semi-diurnal) two tidal cycles per day. Superimposed cross bedding cosets display bipolar palaeocurrent directions is another evidence of tidal action, such diversity in current directions is uniquely documented in ancient and witnessed in modern tidal environments (e.g. Selley, 1992; Dalrymple and Choi, 2003).

The cross bedded sandstone of this facies can preliminarily be described as an amalgamation of prograding sand-bars complex, intersected by abandoned channel fill . In many locations distinctive large scale packages of fine sand-mud alternations (Fig. 14) occupied the abandoned channels. Small pieces of petrified wood is uncommonly scattered here. Understanding the sedimentary processes resulted in occurrences of such sand-mud alternations, requires more field investigations to be well elaborated. In the cross bedded sandstone facies therefore, tidal action appear to decrease gradually upward, in the contrary fluvial influence appear to be increasing, as suggested by the local abundance of cross stratified sandstone beds containing silicified tree trunks.

Microconglomeratic Sandstone Facies (Fluvial Facies): This facies occupy the uppermost part of the Dur Attallah Formation (or escarpment). It has a thickness that exceeds 30 meters. In the western side of the escarpment it is represented by an isolated hills and small outliers attached to the escarpment. This facies is more or less equivalent to the Sarir unit of Wight (1980). To the east, it has less thickness and (in part) disconnected far away to the north of the escarpment body. The decreasing in thickness is possible attributed to differential erosion. This facies is composed of very coarse, occasionally microconglomeratic sandstones. It lacks any kind of tidal sedimentary structures, and possesses features that are diagnostic of fluvial environment: large scale trough cross bedding, graded bedding, and the onset of sandstone bars with intensive roots network. The contact of this unit with the lower facies is not well defined, but there is a zone of several meters marks the first appearance of thick irregular beds of paleosoil. These paleosoil horizons are channelized with thick well cemented beds of microconglomeratic sandstone. Laterally, this zone is changed into sandstone probably with in situ vertically positioned silicified trunks. Above the contact zone, the sandstone is mostly very coarse and pebbly, poorly sorted, trough cross bedded occasionally with basal conglomeratic layers. This sandstone is gray to white in color, and intercalated with lenticular beds of green sandy mudstone.

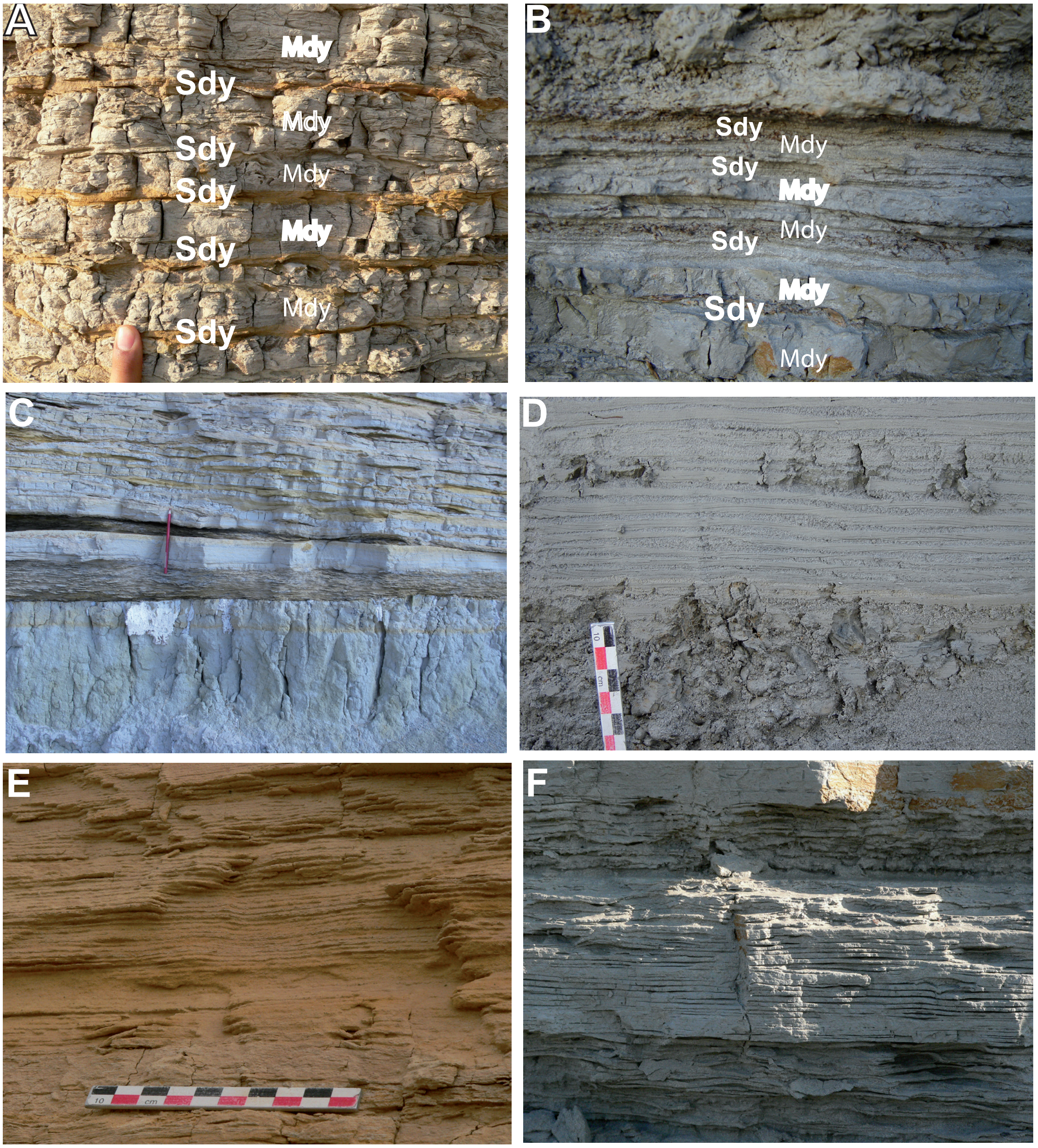

Fig. 10. photos (A to F) illustrate three different examples of tidal bundles from Dur At Talah deposits (left side photos: A, C, and E), compared with the modern analog in Mont Saint Michael Bay (the right side photos: B, D, F). Note the muddy (mdy)-sandy (Sdy) alternation of layers, resulted from diurnal and neap-spring variations in tidal energy.

DISCUSSION AND INTERPRETATIONS

In correlation with the modern tidal processes acting at the sediments of the Bay Mont Saint Michael in the present time, the 130 meter's rock sequence composing Dur At Talah escarpment (formation) is possibly interpreted to be deposited as a result of two major environments: (a) Tidal environment certainly acted in variable degrees on the lower 100 meters of the sequence; and (b) in the uppermost (30 m) a fluvial environment is evident, due to the presence of the in situ silicified wood and paleosoil horizons, supported by the absence of any tidal sedimentary structure.

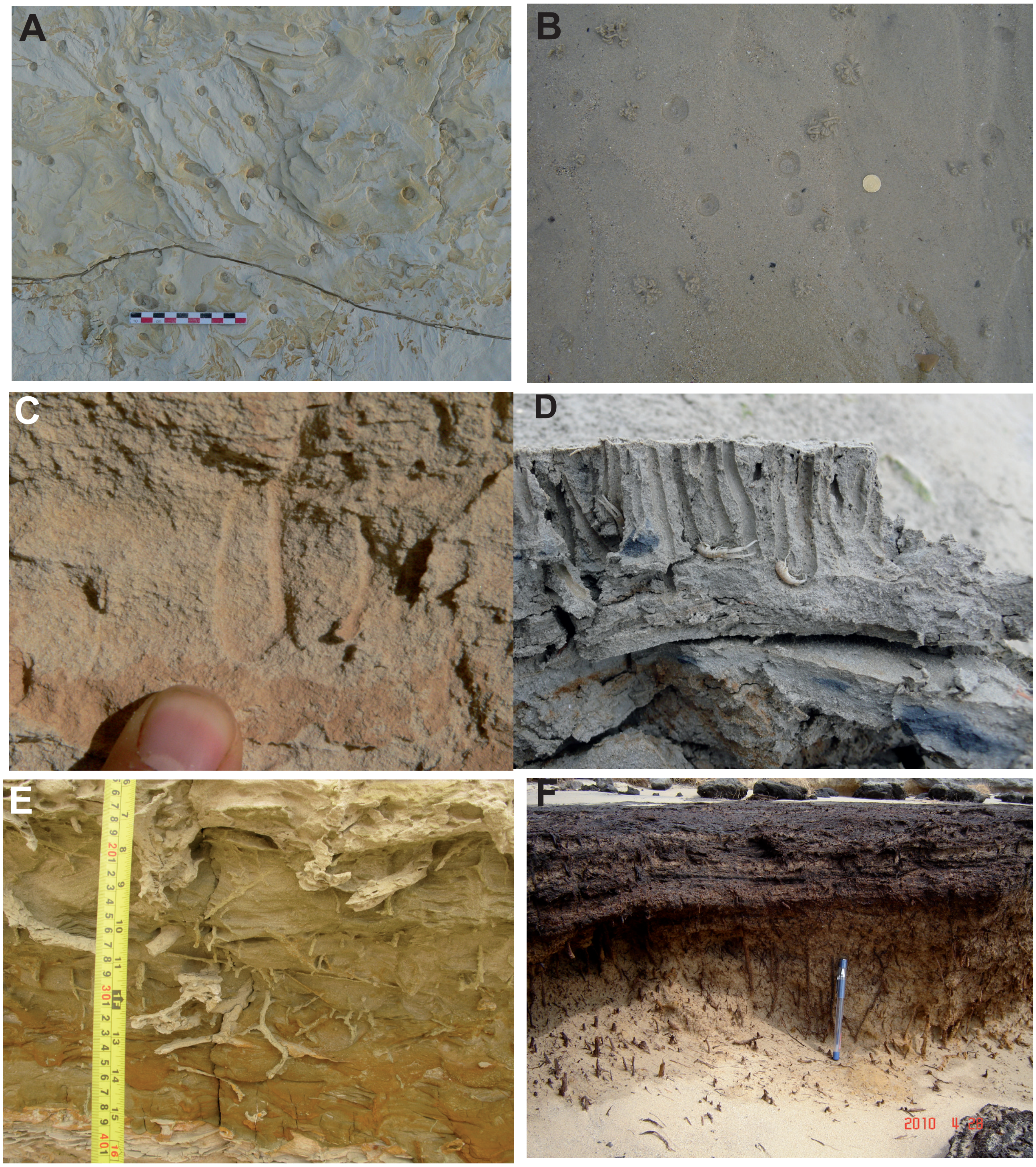

Fig. 11. plate show comparison of trace fossils from Dur At Talah (photos A, C, and E) with their modern counterparts from the Bay of Mont Saint Michael (photos B, D, and F). A and B are examples of burrowing worms. U-shaped trace in C and D is a burrows of crabs, the animal is still exist in D. in photos E and F sediments is roots dominated, with the presence some Skolithos?, sediments in photo F is several hundred years old.

Tide-domination: Tide dominance occurs if tidal currents are responsible for more sediment transport than river currents or waves and they determine the large geomorphology (Gallawy, 1975). The lower two facies namely the bioturbated facies, and cross bedded sandstone facies, (70) and (30) meters respectively possess a common characteristic sedimentary features which has been closely correlated with the currently active tidal settings. Numerous tidal features recorded in the

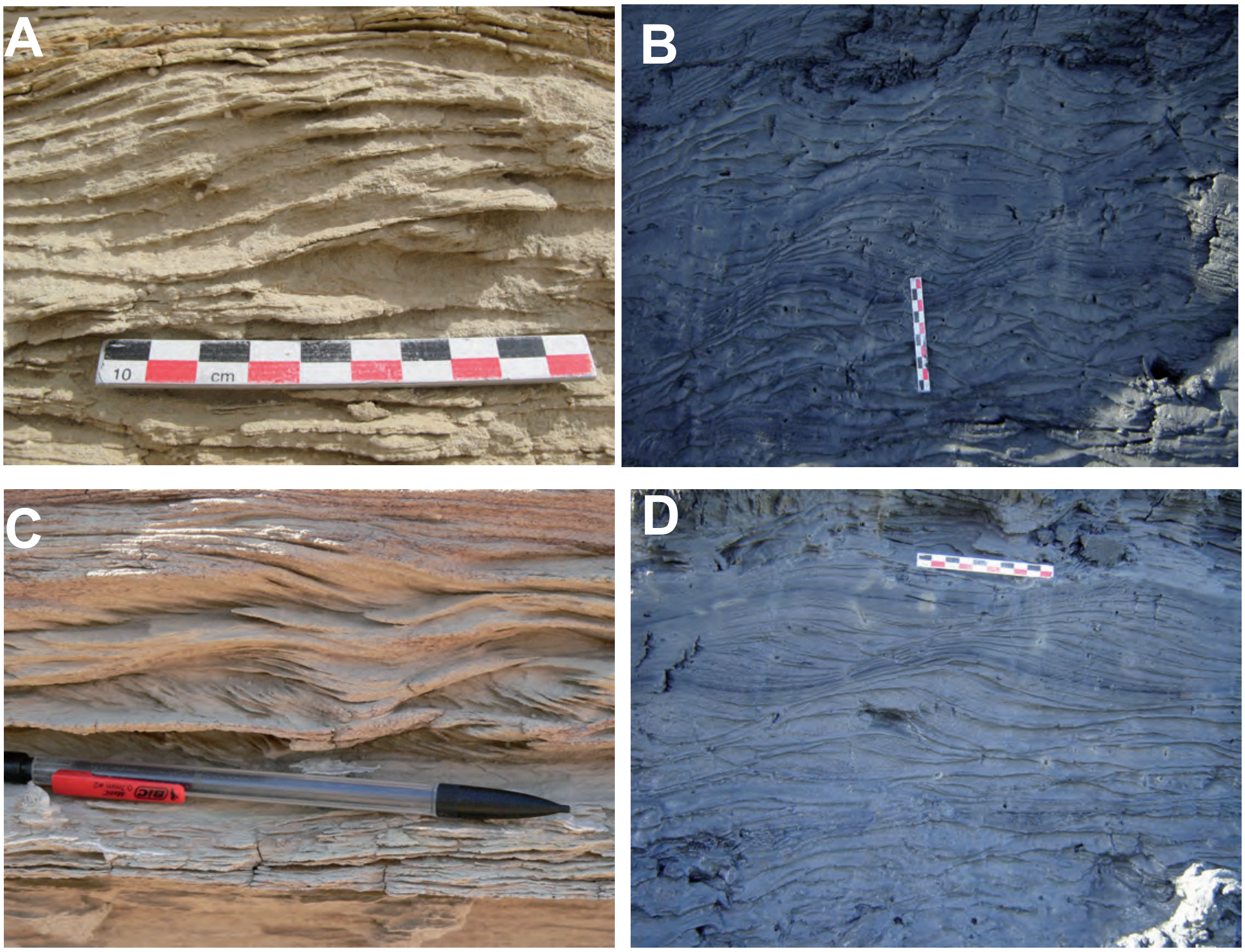

Fig. 12. photos A to D shows the occurrences of climbing ripple in ancient- (A and C, Dur At Talah) and modern- (B and D, Mont Saint Michael) tidal environments. Note, mud drapes (and double drapes as in A) separating successive sand ripples in both ancient and modern examples. The pencil head in C points to the current direction. The ripples in both modern and fossil examples are built upward in overlapping series rather than migrating in a forward direction, indicating rapid rate of sedimentation.

bioturbated facies of the Dur At Talah sequence, the most common of which are the rhythmic sand-mud layers alternation (e. g., Dalrymple and Choi, 2003; Fig. 15). Reactivation surfaces caused by tidal flow reversal (Klein, 1970; Allen 1973) are common as well. In addition, purely continental evidence is uncertain in this facies. Accordingly, it is termed ″ tide-dominated″ facies.

It can be concluded that tide-dominating succession is displayed as a lateral and vertical alternations of tidal (mud and sand) flat intersected/ amalgamated with a simple and complex tidal channels. Similar channeling features have been documented by Schumacher *et al* (2010) in the Eocene Green River Formation, Uinta Basin, within the Tide-dominated succession with certain evidence of tidal dominance. Moreover, there are many criteria that emphasize a continual, uninterrupted, and relatively rapid sedimentation rate, characteristic of tidal setting. Most important of those criteria are: (i) the presence of very common, well preserved climbing ripple structure. The development of climbing-ripple from ripples requires that abundant sedimentation is continually available to a current or wave so that the ripple are built upward in an overlapping series rather than merely migrating in a forward direction (e. g. Allen 1963); (ii) This interval possess a common similarity among the type of sediments which embraces identical trace fossil assemblages such as Thalassainoides and variety of Skolithos, and other fossil such as large skulls of crocodilian , intact part of fish skeleton and other vertebrate remains (e. g. Wight, 1980; Rasmussen *et al* 2008). Fig. 16 shows some examples of such fossil assemblages; and (iii) the common occurrences of well-preserved, soft sediment deformation. The tide-dominated succession, therefore, can be considered as an

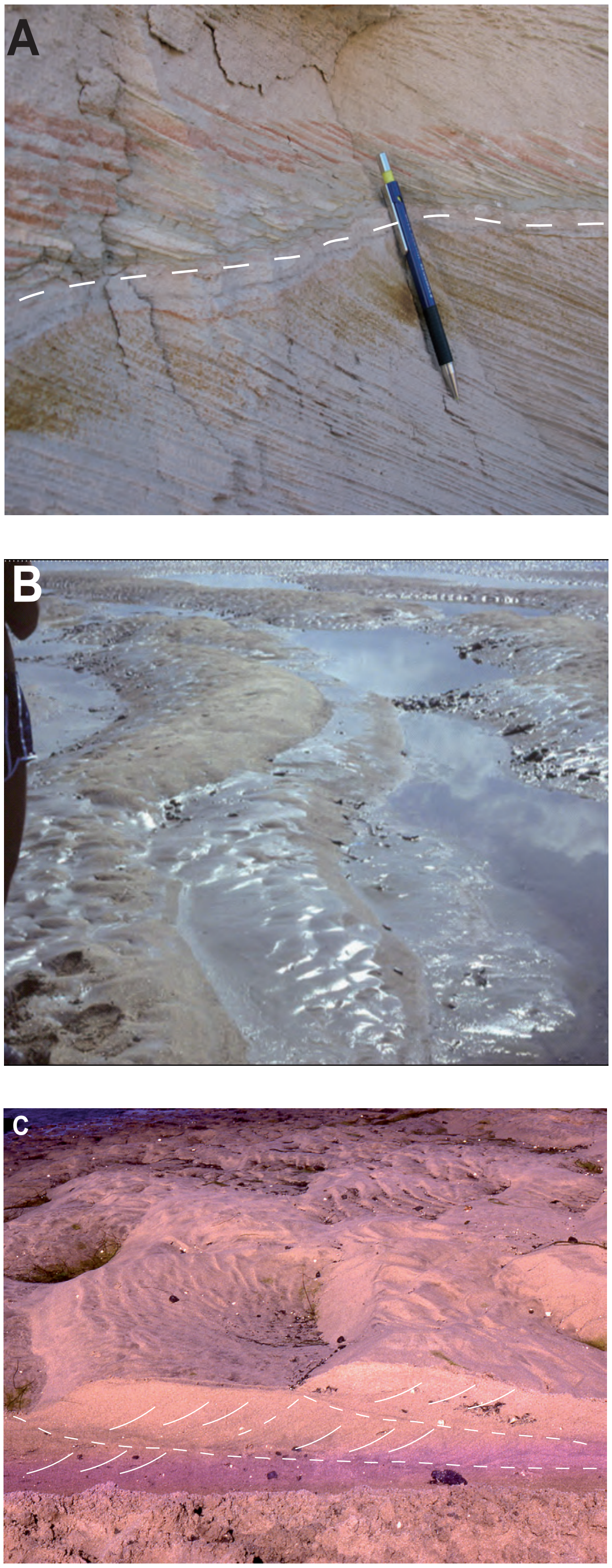

Fig. 13. photos A to C, show (A; Dur At Talah) mud drapes which appear in green, coating the cross bedded sandstone forests. In (B) Mont Saint Michael) the mud is draping the sandstone's current megaripple. In (C, Mont Sainte Michael)) mud drapes occurrences are very similar to that in (A), the white inclined lines represent foresets, the drapes appears as a greenish shade on the foreset. Dashed line in A indicates the reactivation surface between two sets of cross bedding.

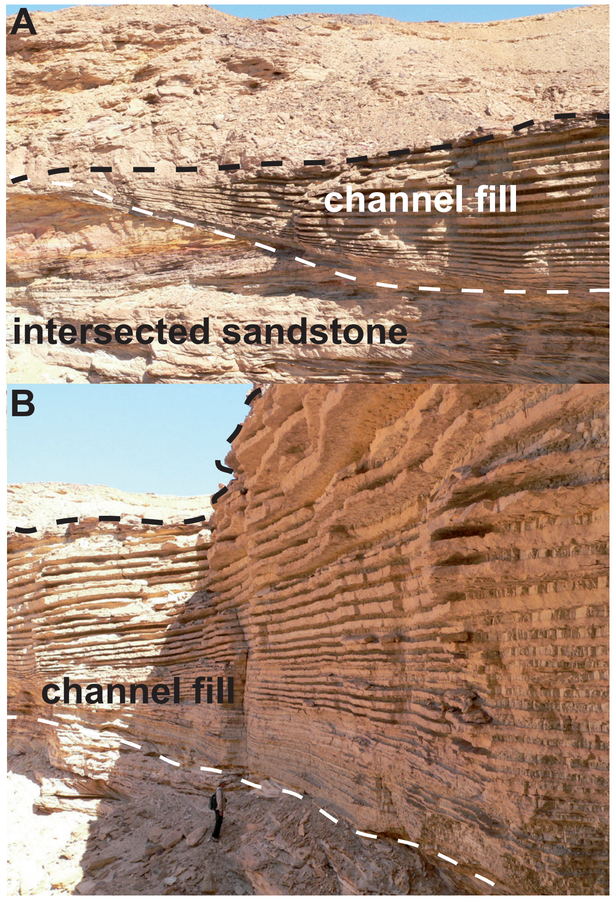

Fig. 14. photos (A and B) from Dur At Talah Formation show locally existed channel infilling morphology. Photo A shows general view indicating the channel base and top and the alternating sand and mud beds occupying the channel (width of the photo about 50 m). B is another view of the same package to the right of photo A (the center of the channel), regular thickening up of the bed is observed.

aggrading phase involves equilibrium between sedimentation rate and accommodation space availability.

Tide-influence: The deposition of transitional or tidal influenced (cross bedded medium to coarse sandstone) facies has occurred after a remarkable rapid and strong erosion of the underlying tide-dominated sediments, this is proven by the presence of erosional relics (Fig. 17) from the tidal unit floating in the transitional facies above the prominent erosional surface. Those relics are in form of pebbles and cobbles of intrabasinal mud clasts and, occasionally, in form of erosional remnants (with depositional sedimentary structures preserved) embedded within the cross bedded sandstone. Similar erosional remnants are observed also in Mont Saint Michael Bay. The presence of such remnants indicate two facts: (i) stronger energy acted on that unit, than that acted in the tide-dominated unit below,

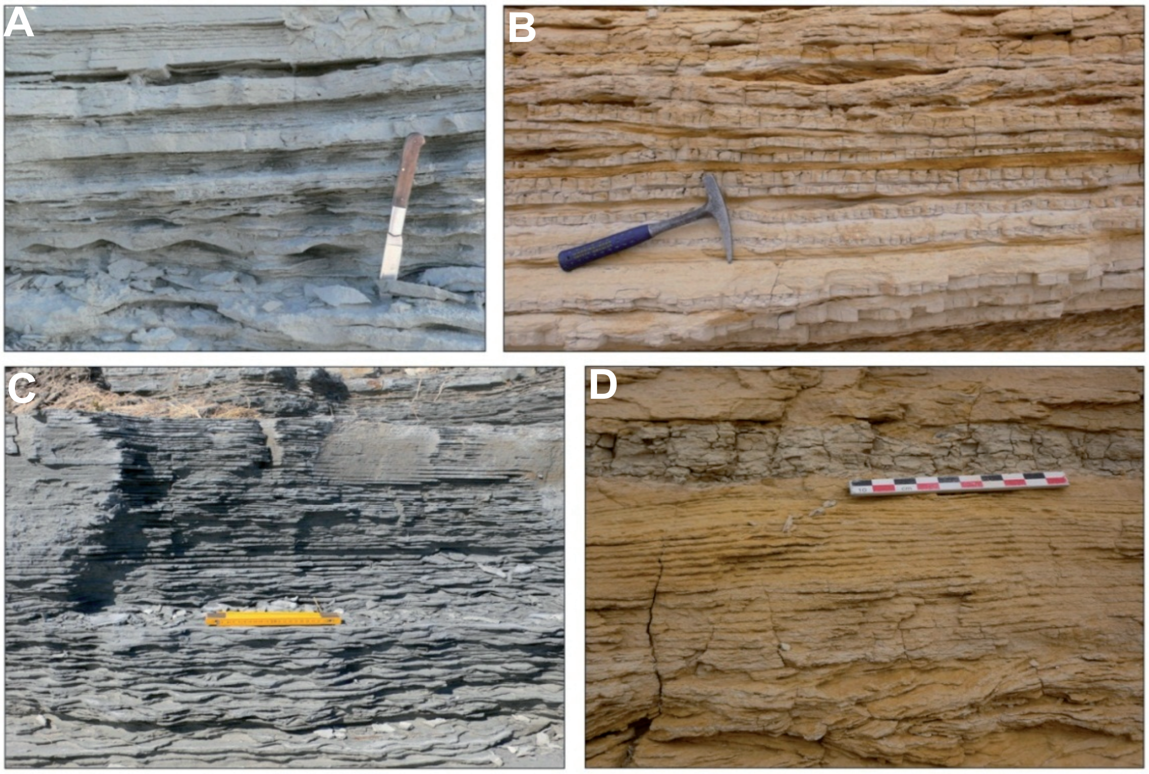

Fig. 15. Photos A to D illustrate mud-sand alternation which is common in the bioturbated (mud-dominated) facies succession, Dur At Talah formation (B and D, Eocene). Structures in B and D are closely comparable with those in A and C from the intertidal zone of Mont Saint Michael. The photos above shows neap spring tide variations, the photos below shows ebb aggradation.

Fig. 16. photos (A to D) show examples of vertebrate fossils from Dur At Talah Formation: (A) well preserved crocodilian skull, (B) well preserved fish, (C) vertebra of fish, and (D) large bone probably from whale body. These fossils are known for nearshore environments.

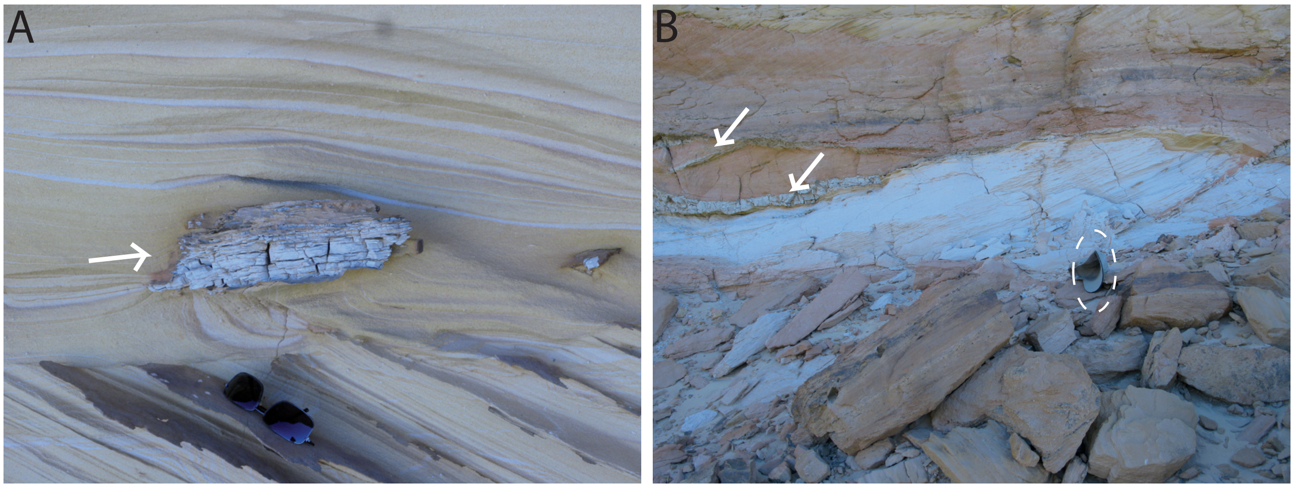

Fig. 17. photos A and B from cross bedded (tide-influenced) sandstone facies of Dur At Talah Formation: (A) shows small remnant (arrow) from the underlying tide-dominated facies, floating in the younger sandstone. Photo B is another example shows larger erosional remnant composed of muddy sediments (arrows; the hat inside the circle for scale). The presence of such erosional relics would indicate rapid sedimentation, and it also indicates that the deposition of the sandstone is shortly after the mud of the lower unit.

(ii) short or no time gap between the depositions of both facies. In spite of this increase in the energy spectrum, tidal processes are still acting as evidenced by sedimentary structures illustrated in Figs. (10-14 in the previous section) such as mud drapes on sandy foresets (Selly, 1992; Darymple and Choi, 2003), mud couplet (Dalrymple, 1992) and bidirectional cross bedding.

This unequivocal change in sedimentary features between the tide-dominated and the tide-influenced facies suggests three alternatives: (i) change of the environment from narrow embayment to less restricted more open marine (closely resemble to the Lower Cretaceous Woburn sand in Southern England; Yoshida *et al* 2002) side of the Sirt embayment; (ii) the second alternative suggested occurrences of a pulse of transgression (i.e., relative see level rise) which allowed change from more muddy intertidal zone to more sandy subtidal setting. The later situation is comparable with the modern macrotidal environments of Mont Saint Michael, and that of the Bay of Foundy in the Canadian coast (e.g. Dalrymple and Choi, 2003).

Fluvial setting: The contact of the transitional facies with the overlying fluvial facies is irregular and complex; it requires more field investigation to be well defined. Nevertheless, a zone of pebbly sandstone beds amalgamated with paleosoil appears to be located above the contact zone. In some places, there is an intensive silicified wood bearing sandstone bed lies above the tidal influenced sandstone facies. This sandstone bed with dominating, large size wood trunk marks the onset of completely terrestrial environment that certainly bears fluvial characteristics. This interval therefore, is probably represents a forced regression and northward shoreline retreat.

CONCLUSIONS

Sediments composing Dur At Talah escarpment are made up, from bottom to top, of three different packages of facies: (i) the clay-oyster bank interbedded facies, (ii) the bioturbated fine sand to mud facies, (iii) the medium to coarse sandstone facies, and (iv) the micro conglomeratic sandstone facies.

Facies (i) correspond to marine environment, facies (ii and iii) correspond to tidal environment, and facies (iv) is a typical fluvial environment.

Both the bioturbated facies and the cross bedded sandstone facies (ii and iii) bear sedimentary structures that are operating in modern tidal environment of Mont Saint Michael Bay.

Many described sedimentary structures suggested that the studied sequence has been deposited rapidly without indications of major interruption of sedimentation, and because the sequence display coarsening upward trend it might suggest an overall regressive trend, interrupted by transgressive pulses.

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