J. King Saud Univ., Vol. 10, *Science* (1), pp.61-77, Riyadh (A.H. 1418/1998)

Storm-Generated Channels in the Middle Dubaydib Sandstone Formation, South Jordan

Issa M. Makhlouf

Department of Earth and Environmental Sciences,
Hashemite University, Zarqa P.O. Box 150459, Jordan

(Received on 21/10/1995; accepted for publication on 12/10/1997)

Abstract. The Late Ordovician Dubaydib Sandstone Formation in south Jordan consists of a 155m sequence of clastic sediments made up of three lithofacies: channeled sandstone (CS), hummocky cross-stratified sandstone (HCS) and silty shale (SS). The formation has been divided into three members: lower, middle and upper. This paper focuses on the middle member.

The channeled sandstone facies is confined to the middle member of the Dubaydib Sandstone Formation, and is partly overlain by the hummocky cross-stratified facies. Both facies are either surrounded by or interfinger with the silty shale facies, and are arranged in three distinct fining-upward sequences. In each sequence the channeled trough cross-bedded (or structureless) sandstone abruptly overlies a scoured channel floor, occasionally covered by intraformational clasts. It passes upwards into hummocky cross-bedded and rippled sediments usually associated with a marine fauna. Individual channels are superimposed on each other forming more complex, compound channel forms. The channel formation is attributed to storm generated offshore rip currents in the subtidal zone, and idividual beds within each channel body is thought to record successive storm surge events, during the prevailing tempestite conditions.

Introduction

The Dubaydib Sandstone Formation, previously known as the Sabellarifex Sandstone [1] in the southern desert of Jordan comprises about 155m of siliciclastic sediments. It has been divided into three members: lower, middle and upper [2]. These sediments conformably overly the Hiswah Sandstone Formation and are conformably overlain by the Mudawwara Sandstone Formation [2-8]. A Llandeilo to Caradoc age has been suggested for the Dubaydib Sandstone Formation based on its stratigraphic position [5] since samples analyzed for their palynological content were totally barren (H. Dwaikat, written comm., 1990). During the present work, two litholgical sections were measured and described in Sahl el Suwwan (Figs. 1-3).

In the middle member of the Dubaydib Sandstone Formation an interesting palaeomorphological phenomenon (channels) evidently occur in the shallow water, nearshore environment of the southern Tethys sea. Channels are absent from the lower and upper members. A detailed sedimentological study was carried out in order to describe and interpret the sedimentary structures, facies and depositional environments of these subaqueous sandy channels.

Description of facies

The middle member comprises 54.5m of fine- grained trough cross-bedded and hummocky cross-stratified sandstones, with subordinate silty shales, overlying channeled bases. It can be divided into three facies: channeled sandstone, hummocky cross-stratified and silty shale facies (Plate 1 A to C). The channeled sandstone facies is either localized within or interfingers with the silty sand facies. These lensoid shale bodies vary in size when traced laterally and vertically along the outcrop (Plate 1 B and C). Sandstones and silty-shales are generally arranged in three distinct fining-upward sequences, in which the sandstone abruptly overlies a scoured channel floor, occasionally covered by intraformational clasts (Plate 1 C) [8]. Nevertheless, it is not uncommon to find the sandstones amalgamated and locally concentrated into the basal third of the member (Plate 1).

The channeled sandstone facies (CS)

This facies attains a total thickness of about 20m, and consists of fine-grained, micaceous, massive, light-brown quartzarenite, which passes upward into cross-bedded sandstone. Individual sandbodies possess an elongate channel geometry with erosive bases and gradational tops, and are either localized within or interfingering with silty shales (Plate 1 B, Figs. 2-4).

The most striking feature of this facies is the presence of several superimposed channel sandbodies from 2.2-12m thick and 9-80m wide, cutting into silty shales [8]. The channels, which are gentle to steep-sided, decrease in slope with increasing channel width, and cross-cut the face of the outcrop at three distinct stratigraphic levels. They form part of three prominent fining-upward sequences (Plate 1 B and D).

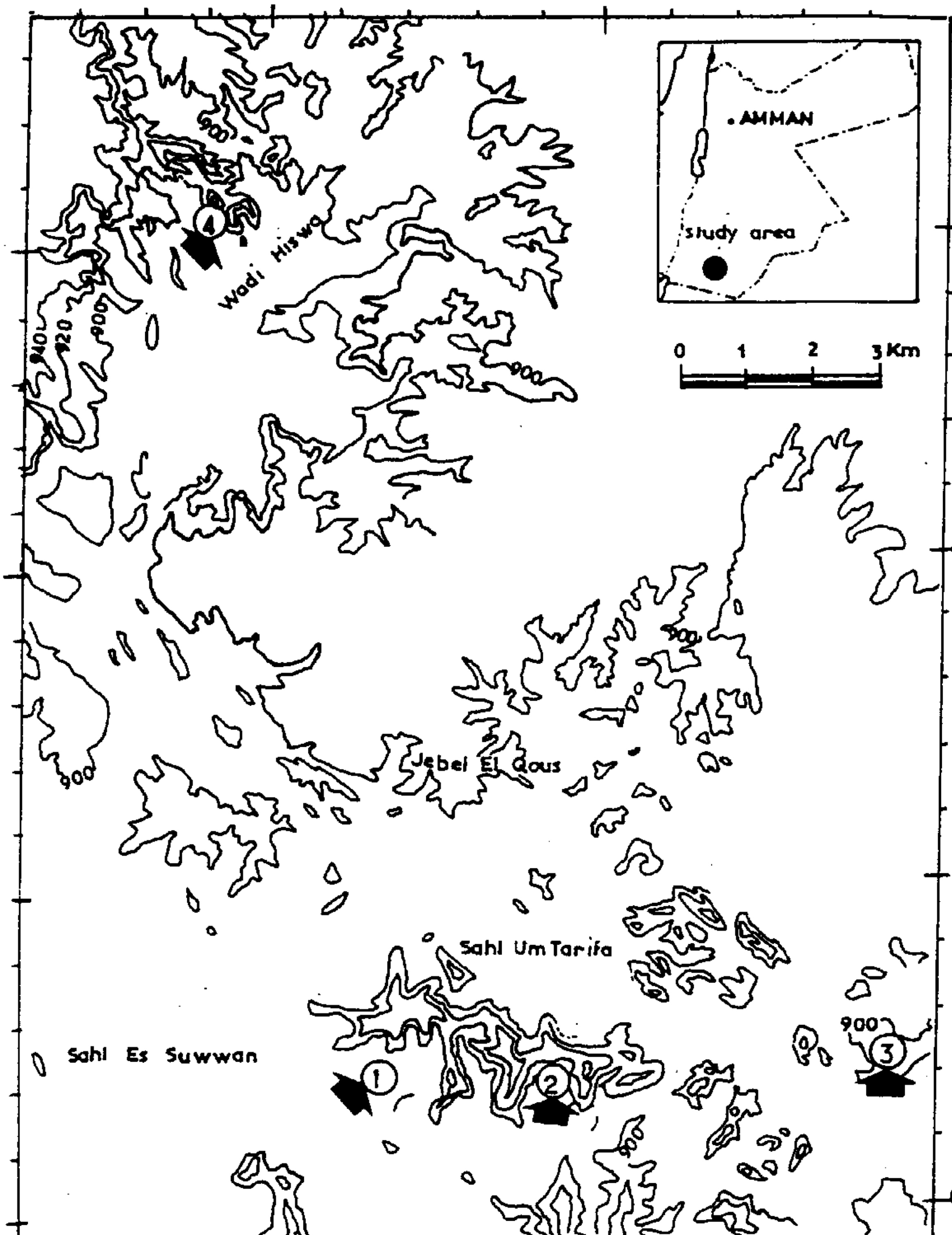

Fig. 1. Location map of study area in the southern desert of Jordan, showing position of section localities referred to the text.

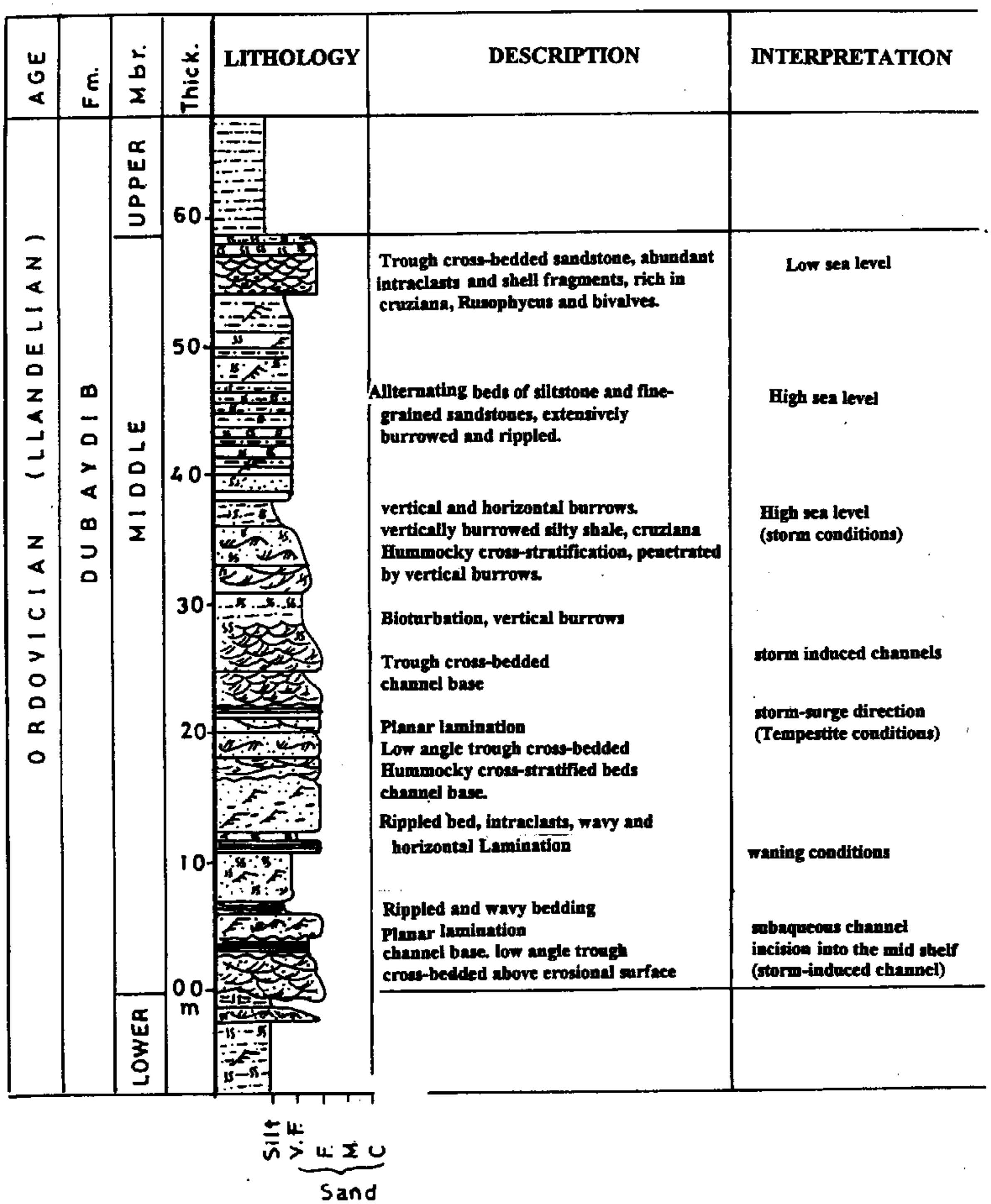

Fig. 2. Graphic log of the middle dubaydib sandstone formation at Sahl es Suwwan area, locality No. 1, south Jordan.

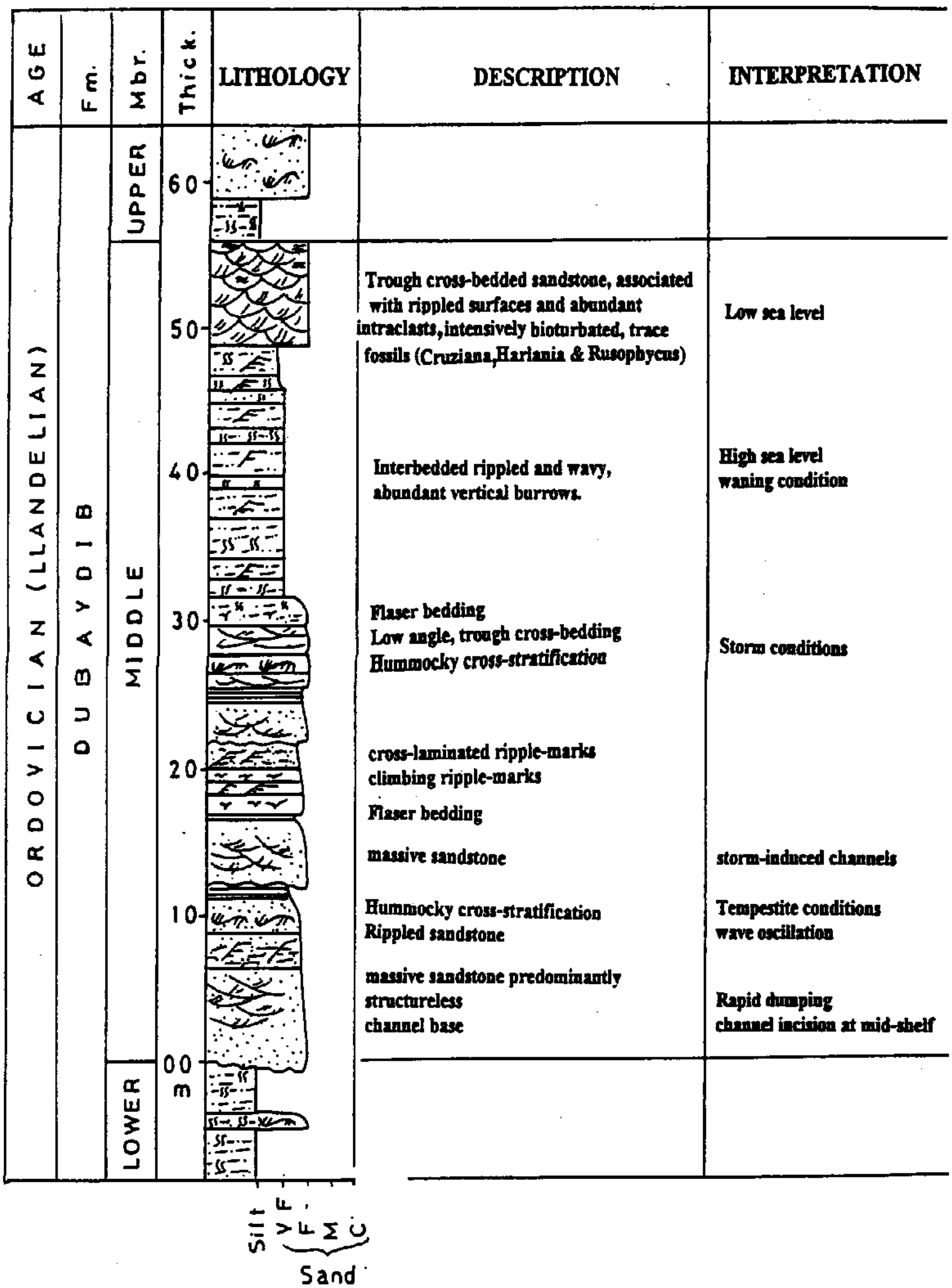

Fig. 3. Graphic log of the middle Dubaydib sandstone formation at Sahl es Suwwan area, locality No. 2, south Jordan.

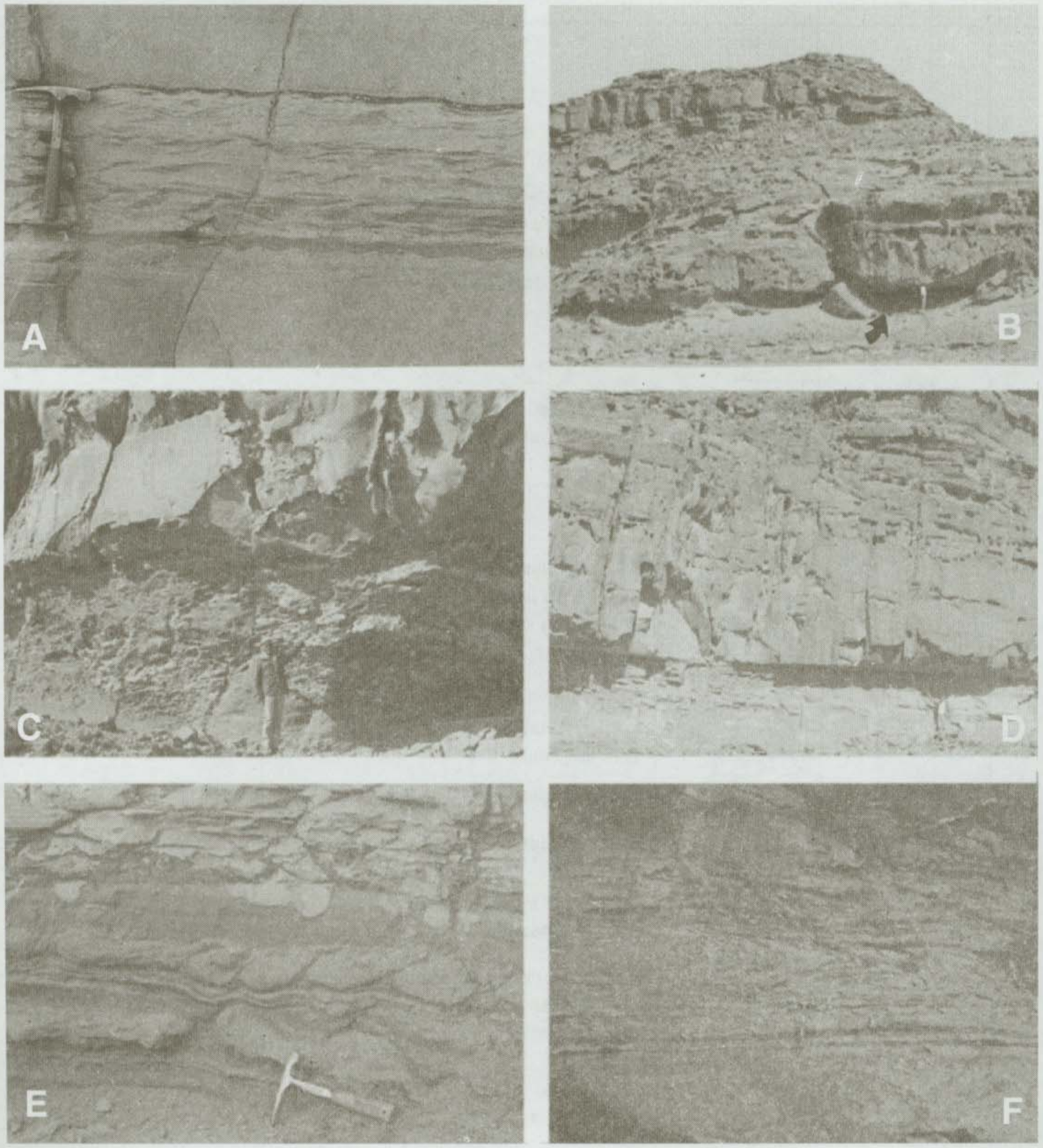

Plate 1 (A-F).

List of plate captions

A. Silty-sandy rippled horizon incised between two massive sand bodies, with a sharp upper and lower contacts. Middle member, Dubaydib Sandstone Formation, Section 4. (Hammer is 30cm long).

B. General view showing a well defined channel, with steep slope margins (arrow). Note the superimposed channel pattern to the right. Middle member, Dubaydib Sandstone Formation, Section 4.

C. Vertical section showing channel cut into silty shale material under high energy conditions, responsible for breaking and deposition of huge intraformational silty and sandy blocks up to 2m long. The massive and structureless nature of the overlying 12m-thick sandstones indicates rapid dumping. Middle member, Dubaydib Sandstone Formation, Section 2.

D. Vertical section showing sharp contact between the lower and middle members of the Dubaydib Sandstone Formation. The channeled facies appear to be concentrated in the basal part of the member.

E. Water escape structures (ball and pillow) in an interbedded sequence of siltstone and sandstone, possibly due to differential compaction (thixotropy). Middle member, Dubaydib Sandstone Formation, Section 2 (Hammer is 28cm long).

F. Overturned cross-beds forming simple recumbent fold with completely overturned limbs. The fold nose is near to the upper surface. Middle member, Dubaydib Sandstone Formation, Section 2. (Scale is 15cm long).

The channels are filled by fine-grained sandstone which is generally structureless, except towards the channel margins where a concentric pattern of infill, concordant with the margins, can be seen. These marginal laminations grade into massive sandstone fill.

The channel fill facies is unrelated to the silty shale facies which they cut, except in one channel (Plate 1 C) which has large intraformational clasts up to two metres long. These angular to subrounded clasts and boulders appear to have been eroded and redeposited from the underlying siltstone. The top of the channels is flat and gradationally overlain by a particular association of sedimentary structures occurring above channels: trough cross-bedding, low-angle cross-stratification, hummocky cross-stratification, horizontal lamination, cross-lamination and ripple marks (Figs. 2-4).

At each channeled level the sandy facies appears as individual lensoid bodies which wedge out laterally (Plate 1 B). The concave-up channel scour surface can be defined in each channel, occurring on different scales ranging in width from a few metres to tens of metres in cross-section. Individual channels are superimposed on each other forming more complex, compound multistorey fills, with each storey bounded by an erosional base (Plate 1 B).

Sets of large-scale low-angle cross-bedding up to 13m wide and up to one metre thick are present in which foreset azimuths show an offshore unidirectional orientation towards the northeast, with a vector mean of 52° (Fig. 4). The foreset laminae are smooth and pass upwards into rippled foreset laminae. The bounding surfaces have sharp to planar undulating erosive bases and non-erosive tops. The base of the bed may possess sole marks including balling-up structures, load casts, pot and gutter casts and water escape structures (Plate 1 E), occasionally lined with intraformational clasts. The upper bounding surface of bed sets and foresets may be sharp, planar or wave rippled, gradational or bioturbated, especially in the upper half of the member where trace fossils *(Cruziana, Sabellarifex, Rusophycus)* are abundant.

Sandstones with low-angle cross-stratification infill broad shallow erosional scours several metres broad but only a few tens of centimetres deep. This is commonly associated with planar lamination, which may display primary current lineation trending NE-SW, the dominant internal structure.

Overturned cross-bedding was also observed in this facies to form single or double (S-shaped) recumbents, the bottom set being tangential to the lower bedding plane; the overturned cross-set reaches thicknesses up to 95cm . Both recumbents are overturned towards N30°E-S210°W (Plate 1 F). A water escape structure can also be seen with rounded lower surfaces and angular penetrating crests at the top (Plate 1 E).

The hummocky cross-sratified facies (HCS)

Hummocky Cross-Stratified beds dominate the upper member of the Dubaydib succession. However, they are not uncommon in the middle member. Some hummocky cross-stratified beds occur above the channeled sandstone facies. They are composed of fine-grained quartzarenites, well sorted, micaceous, light grey to yellowish in colour. In some cases, hummocky cross-stratified layers occur as interbeds within the silty-shale facies, with laminations parallel to the undulating surface of the swales and hummocks, but lacking any preferred orientation to the cross-stratification. These structures are characterised by the following features: (1) The lower surface of individual sets is erosional and undulate to broad troughs, (2) the laminae within the sets are nearly parallel to the lower erosional surface, and (3) the dip directions of the erosional surfaces and overlying laminae are not systematic.

This facies is identified by the presence of "antiforms" with low-angle laminae, a lack of orderly spacing and orientation sharp erosional bases. This facies is commonly interstratified with shale or siltstone, with abundant marine fauna (*Sabellarifex*). Bedding surface and foreset surfaces are either smooth or display ripples of diverse forms and orientations.

The silty shale facies (SS)

In the middle Dubaydib Sandstone Formation, this facies occurs as a unit about 30m thick. It is composed of siltstones and subordinate claystones and rare fine-grained sandstones that are light brown, pinkish, yellowish, greyish and cream-coloured, and contain several types of ripple marks including symmetrical, current modified, linguoid, climbing and interference ripples ranging in wavelength from 8-20cm and 1.5-2cm in amplitude . Brownish siltstone usually drapes the ripple marks and is commonly preserved along the ripple troughs. Wave ripple cross-lamination has been observed in the silty shale facies, including linsen and flaser bedding. The cross-lamination is mainly bi-directional. Based on measurements of ripple mark trends in the middle member, rose diagrams indicate a ENE-WSW palaeocurrent direction (Fig. 4).

Parallel laminations are also common and usually overlie the ripple cross-lamination with gradational contacts. These are present as alternations within the silty lithology. This facies is also characterised by the presence of horizontal (*Cruziana* and *Rusophycus*) and vertical (*Sabellarifex*) burrows.

Discussion

In southern Jordan and during the Ordovician time clastic detritus was supplied from the south where the Arabo-Nubian Shield was situated. These clastics were reworked by shoreline processes of the Tethys sea which lay to the north, giving rise to a series of major and minor transgressive -regressive events. The terrigenous influx would have been derived from the reworking of the Cambro-Ordovician substratum under wave and tide conditions.

In the middle member, channeled sandstone and silty-shale facies are arranged in various sequences, most of which fine upwards. Fining-upward trends reflect the gradual change from an upper flow regime (storm surge) to a lower flow regime (waning stage) [5]. The presence of numerous V-shape profiles of channel sandbodies with sharply defined margins, cross-cutting the face of the exposure at three vertical levels, suggests that various superimposed channels were formed. The channeled sandbodies are elongated in a NE-SW direction, with a consistent NE unidirectional palaeocurrent direction indicating that the sandbodies represent channels whose long axes were oriented normal to the NW-SE shoreline and directed offshore [8].

These sediments are considered to be shallow marine by virtue of their locally intense bioturbation (*Cruziana* and *Rusophycus* traces), and concentrations of vertical burrows (*Sabellarifex).* Furthermore, the absence of late stage emergence run-off (ladder-back ripples, mudcracks, rain drop imprints etc.) suggests a subtidal environment of deposition.

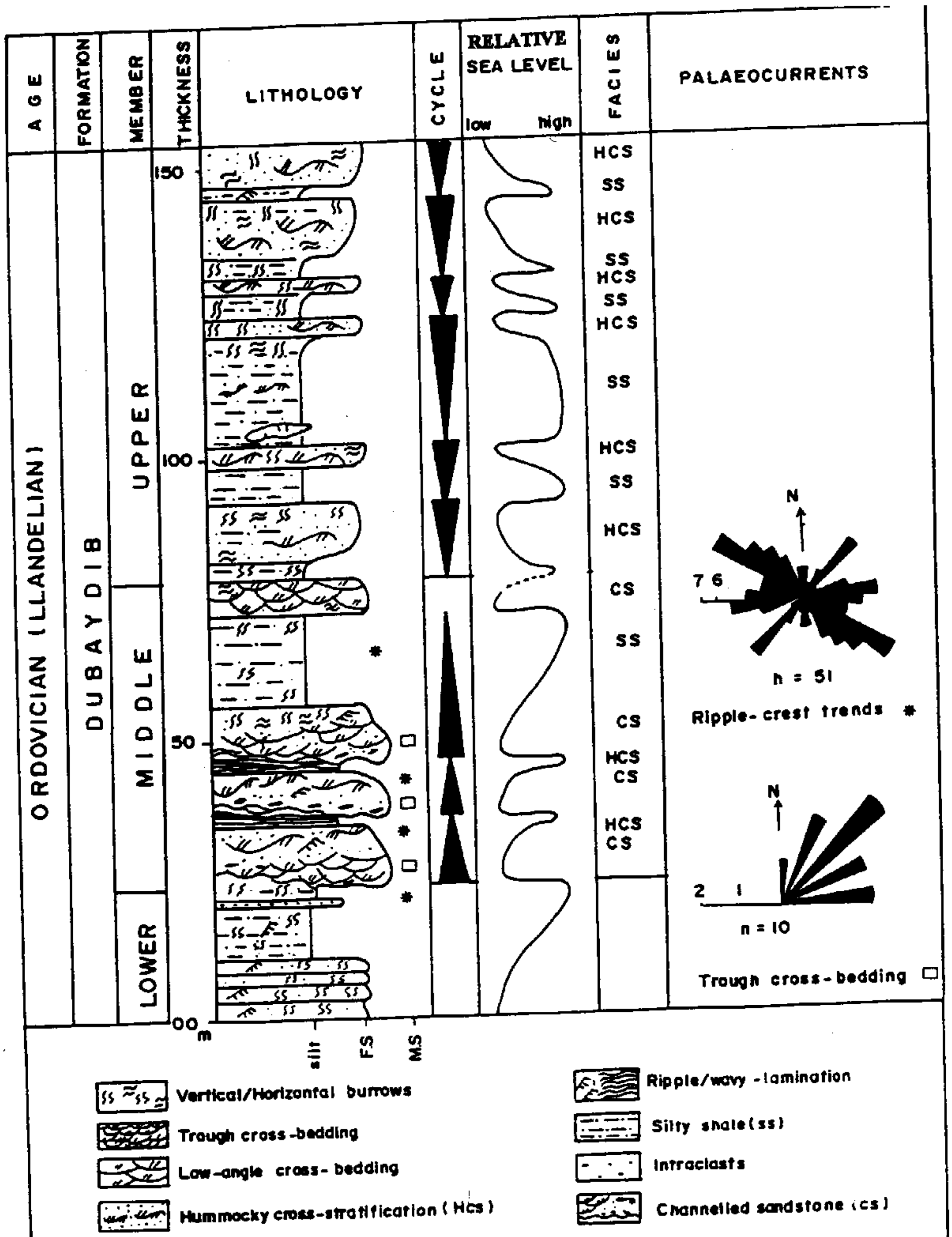

Fig.4. Generalised lithological section of the middle member and adjacent parts of the lower and upper Dubaydib Sandstone Formation at Sahl el Suwwan, illustrating depositional cycles, facies, relative sea level changes and palaeocurrent rose diagrams.

The wave-dominated conditions are marked by the oscillating ripple marks, types of lamination and bi-directional cross-lamination which are more typical of wave processes (Fig.4). The unidirectional palaeocurrent patterns (Fig.4), which, based on trough and low-angle cross-stratification directions, are directed offshore and are interpreted as representing the direction of the offshore rip currents resulting from storm surge, or possibly due to a gravity-driven high-energy transport as a consequence of an oversteepened slope in conjunction with sea-level changes.

The various types of sandstone lamination can therefore be interpreted in terms of fluctuating wave intensity and water depth. The highest energy sand layers in each facies can be equated with increased wave agitation accompanying storms, with several types of sedimentary structures including trough-cross bedding, low-angle cross-stratification and hummocky cross stratification (Fig. 4).

The channel formation is attributed to the storm generated offshore rip currents in the subtidal zone, as evidenced by the presence of trace fossils and dense vertical burrows in the silty shale facies in which the channels are incised. The locally structureless nature of the channel-fill sandstone indicates that the channel-fill formed by rapid deposition, where hydrodynamic sorting was inhibited. Mass flow conditions may contribute to the establishment of the structureless nature of the channel-fill sandstones, which could take place shortly after deposition. On reduction of storm flow in the channel area, dune deposition commenced and various types of cross-beds were established.

Although the abundance of such channels in the middle member of the marine Dubaydib section is impressive, they are noticeably absent in the underlying and overlying strata. However, the marine character of sedimentation is quite clear, since marine fossils such as *Brachiopod* coquina and *Skolithos* together with *Cruziana* and *Harlania* trace fossils occur throughout many beds.

Channeled sandy beds are interpreted as having been deposited rom a ni rg sediment-laden currents. Each bed is thought to record a single storm event comprising: (1) Initial storm erosion, (2) deposition and (3) post- storm reworking [9]. After storm-generated current erosion, deposition occurred as the storm decreased in intensity with the highest-energy deposits (channel lags) interpreted as storm channel-fills. These channels concentrate the strongest flows and therefore may preserve coarser sediment irrespective of the speed of filling [10]. The absence of laminations in the channeled sand body suggests that the channels were filled rapidly as the storm waned. Successive storm surge events and the resulting offshore rip currents were responsible for cutting channels up to 12m deep and then filling them with sand, after multiple occasions of partial filling and excavation relative to sea level fluctuations, which marks the base of each incised channel (Fig.4).

The models presented by Dalrymple et al (1992) [11] for incised-valley estuaries are not applicable for the Dubaydib channels, because they lack primary features distinguishing estuaries, such as tripartite zonation, barrier, tidal inlet, tidal delta deposits, elongate sand bars and broad sand flats of the tide-dominated estuaries.

Preservation of a very coarse lag concentration including intraformational pebbles, boulders and large blocks of siltstone and fine sandstone (Plate 1 C), is thought to result from the reworking of the sea floor over extensive areas by storm waves and associated currents, but may also form at the mouth of storm surge channels [9]. In addition, intense storms are capable of extensive coastal erosion, with storm surge rip currents particularly effective in transporting shoreline sands offshore. The different types of sedimentary sructures may reflect both particular stages of sand body development and vertical and lateral variations within a single channel [9].

Trough cross-bedding is attributed to high energy conditions, formed as a result of three dimensional dune migration down the channel following the storm surge. The unidirectional trend of the trough cross-bedded sets in the Dubaydib channels (Fig.5) indicates the strong offshore-directed unidirectional flow during the highly erosive tempestite conditions [12].

Deposition under decelerating flow conditions is indicated by the upward decrease in grain size and the scale of dune bedforms in the channel fill, prior to channel shifting and abandonment. The occurrence of cross-laminated, fine-grained sandstone with numerous mud-drapes, mudflakes and cross-bed sets with minor bioturbation indicates deposition in response to tidal currents, and currents of fluctuating strength with abundant fine-grained suspended sediment [9]. Cross-laminated sandstones include both wave and current formed varieties including climbing cosets, and the various laminations are frequently arranged in microsequences reflecting increasing and decreasing energy conditions. The occurrence of cross-bedded (cross-bed sets ca. 4-25cm thick) and flat bedded sandstones, numerous mudflakes and occasional mud-drapes indicate migration of dunes in response to tidal currents, possibly enhanced by storms [9]. Waning current conditions are demonstrated by graded beds and by the frequent occurrence of lower flow regime structures, including wave and current ripple cross-lamination immediately above the parallel laminated or cross-stratified beds. Post storm reworking is indicated by wave rippling or bioturbation above the channel top.

The most frequently recognised forms of wave action in the silty-shale facies of the middle member are symmetrical wave ripples, present as chevron structures, consisting of superimposed, oppositely-dipping laminations. These ripples were prodiced y qual or near-equal oscillatory wave velocities in which the ripples grew mainly through vertical accretion. In certain horizons, however, wave ripples migrated in one preferred directions thereby producing unidirectional cross-lamination. Water escape structures are formed as a result of differential loading and thixotropy. The presence of pot and gutter casts imply rapid filling during the same storm events that created depressions, particularly during the initial stages of the storm events, while during the latter stages oscillatory flow conditions prevail, as evidenced by wave-ripples and lamination in the sandy infills [12].

The formation of hummocky cross-stratification [13] is related to progressive shoaling of the sea floor, where the shelf bottom became increasingly affected by storm waves. As a result the bottom was scoured into an undulating surface of broad swales and hummocks, in which the suspended sediment quickly dropped into laminations parallel to the undulating surface [14].

Storm-dominated shallow seas have complex surface patterns and varied bottom surge directions, which explains the apparent lack of preferred orientation of any sole marks, cross-stratification or shells [13]. The waning stages of the storm are represented by upward progression of stratification types deposited under low energy conditions and by the local occurrence of slightly finer-grained sand or silt. Post-storm activity and the return to normal-weather conditions are indicated by (1) reworking of sediments by oscillatory waves, (2) horizontal burrowing along rippled surfaces, and (3) deposition of interbeds of finer-grained silt and mud [14].

In the channeled sandstone facies, sediment transport was consistently towards the northeast , parallel to sand body elongation (Fig.4), whereas wave ripple crests were mainly normal to this trend (Fig.4). A bi-directional trend may be indicative of tidal reversals but the unidirectional palaeocurrent pattern represents a storm enhanced current system. Indeed the relationship between current direction and wave ripple trend is suggestive of storm enhanced currents. The channels are oriented perpendicular to the regional palaeoshoreline directions and may represent deposits of sand material produced during floods and coastal storm attack and transported seaward as the storm surge waned.

Local stratal architecture of sequences and systems tracts can be highly variable as a function of local physiography, subsidence rate, eustacy, and sediment flux [15]. The basic premise of sequence stratigraphy is that cyclically varying rates of relative sea-level change result in varying rates of new space added to accomodate sediment influx; this in turn, results in cycles of deposition that are punctuated by sequence boundaries and maximum flooding surfaces [16, 17, 18]. Although a detailed sequence stratigraphic analysis is beyond the scope of this paper, a sequence stratigraphic framework is considered.

The Dubaydib storm-generated channels probably have no direct analogue, as they differ from the characteristic tidal channels which typically fine-upwards and are internally well structured, and lack several features, such as; the bidirectional herringbone cross-stratification, ebb and flood caps, reactivation surfaces, subaerial exposure features (desiccation cracks) and late stage emergence runoff (ladder-back ripples). Tidally influenced channels do not have a massive structureless fills with sheared marginal laminations.

It was stated by Reinson [19] that "the studies of Land (1974), Hubbard (1978), Carter (1978) and Hayes (1980) indicate that the channel-fill sequences resulting from barrier-inlet (or tidal channel) migration have the following characteristics: (1) an erosional base often marked by a coarse lag deposit; (2) a deep channel facies consisting of bidirectional large-scale planar and/or medium-scale trough cross-beds; (3) a shallow channel facies consisting of bidirectional small to medium-scale trough cross-beds and/or plane beds and 'wash out' ripple laminae; and (4) a fining-upward textural trend and a thinning upward of cross-bed set thickness. Shoreface and inshore tidal deposits usually form a series of coarsening- and fining-upward successions representing regressive and transgressive depositional events, which is not the case here [20]. The channel deposits under study associated with the two facies above (HCS and SS facies)only represent fining-upward sequences, which were laid down under storm-dominated mid-shelf conditions, whereas, the deposits of the upper member represents coarsening-upward sequences related to eustatic sea level changes (Fig. 4).

Palaeoenvironmental model

Depositional conditions were variable during Late Ordovician times. A major southerly transgression of the Tethys Ocean covered most of Jordan, and deposited predominantly clastic sediments at the margins of the Arabo-Nubian Shield, providing a good example of a linear clastic shoreline.

Facies and palaeocurrent analysis suggests that most of the Dubaydib sediments were deposited under shallow water marine conditions along the inner shelf and shoreface environments. Stacking of fining- and coarsening-upward cycles indicates fluctuation in the rate of advance and retreat of the shoreline, and the establishment of several minor transgressive and regressive events.

The extensive development of subaqueous channels in the middle member of the Dubaydib Sandstone Formation implies that deposition was largely a function of episodic phases of highly erosive tempestite conditions. After periodic storm-generated offshore rip current erosion, deposition occured in the incised-channels as the storm decreased in intensity, and several superimposed channel sandbodies were established.

Acknowledgment. Support for the present research was provided by the Natural Resources Authority to whom I am most grateful. Discussions with Mr. I.J.Andrews (British Geological Survey), and comments of Dr. B.R.Turner (University of Durham) greatly enhanced the original research on which this paper is based. Two anonymous reviewers are acknowledged for their valuable comments. I am also grateful to my colleagues in the Subsurface Geology Division for their assistance in the field; particularly Geol. Lutfi Abu Saad who also ably wordprocessed the manuscript.

References

[1] Bender, F. "Geology of Jordan. Contribution to the Regional Geology of the World." *Gebrueder, Borntraeger*, Berlin, 196 pp. (1974), [Originally published in German in 1968].

[2] Masri, A. "Al Mudawwara and Halat Amar Sheets, 3248 III and 3248 IV, Bulletin 13, 1:50,000 Geological Map Series." *NRA*, Amman, (1988).

[3] Sunna, B., El-Hiyari, M., Teimeh, M., Abdelhadi, M., Rabi, H. and Al-Harthi, T. "Nomenclature Unification Committee of the Jordanian Stratigraphical Column." Part 1: *Paleozoic Sequences. Internal Report, NRA*, Amman, (1988).

[4] Abu Lihie, O. "Dubaydib Sheet, 3148 I, 1:50,000 Geological Map Series." *NRA*, Amman (1989).

[5] Powell, J.H. "Stratigraphy and Sedimentation of the Phanerozoic Rocks in Central and South Jordan." Part A, *Ram and Khreim Groups, Bulletin 11, NRA*, Amman, (1989), 52-56.

[6] Teimeh, M., Abu Lihie, O., Taani, Y. and Abu Saad, L. "A Sudy of the Palaeozoic Formations of Jordan at Outcrop and in the Subsurface." (including measured sections and regional isopach maps). *Subsurface Geology Bulletin 1, Geology Directorate, NRA*, Amman, (1990), 54-58.

[7] Makhlouf, I.M. "Depositional Environments and Facies in the Dubaydib and Tubeiliyat Sandstones, Southern Desert, Jordan." *Subsurface Geology Bulletin 3, Geology Directorate, NRA*, Amman, (1992), 3-7.

[8] Makhlouf, I.M. "Tempestite Facies Displaying Hummocky Cross-stratification and Subaqueous Channels, Ordovician Shelf Deposits, South Jordan." *Africa Geoscience Review*, 2 (1995), 91-100.

[9] Johnson, H.D.and Baldwin, C.T. "Shallow Sliciclastic Seas." In Reading, H.G. (Ed.) *Sedimentary Environments and Facies* (2nd ed.). Oxford, *Blackwell Scientific Publications*, 229-282, (1986).

[10] Johnson, H.D. Shallow Marine Sand Bar Sequence: " An Example from the Late Precambrian of North Norway." *Sedimentology*, 24 (1977), 245-270.

[11] Dalrymple, R.W., Zaitlin, B.A. and Boyd, R. "Estuarine Facies Models: Conceptual Basis and Stratigraphic Implications." *J. Sediment. Petrol.*, 62/6 (1992), 1130-1146.

[12] Myrow, P.M. "Pot and Gutter Casts from the Chapel Island Formation, Southeast Newfoundland." *J. Sediment. Petrol.* 62/6 (1992), 992-1007.

[13] Harms, J.C., Southard, J., Spearing, D.R. and Walker, R.G. "Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences." *Lecture Notes: Soc. Econ. Palaeont. Miner., Short Course* 2, Dallas, pp. 161, (1975).

[14] Rice, D.D. "Widespread, Shallow Marine, Storm-generated Sandstone Units in the Upper Cretaceous Mosby Sandstone, Central Montana." In: Tillman, R.W. and Siemers, C.T (Eds) Siliciclastic Shelf Sediments. Spec. *Publs. Soc. Econ. Paleont. Miner.*, 34 Tulsa (1984), 143-161.

[15] Posamentier, H.W. and Allen, G.P. "Variability of the Seqence Stratigraphic Model: Effects of Local Basin Factors." *Sediment. Geol.*, 86 (1993), 91-109.

[16] Vail, P.R., Mitchum, R.M.Jr. and Thompson, S.III. "Seismic Stratigraphy and Global Changes of Sea Level, Part 3. Relative Changes of Sea Level from Coastal Onlap." In: *C.E. Payton (Ed.), Seismic Stratigraphy-Applications to Hydrocarbon Exploration. Am. Ass. Petrol. Geol. Mem.*, 26 (1977), 63-81.

[17] Posamentier, H.W., Jervey, M.T. and Vail, P.R. "Eustatic Controls on Clastic Deposition, (1) Conceptual Framework In: C.K. Wilgus, B.S. Hastings, C.G.St.C. Kendall, H.W.Posamentier, C.A. Ross and J.C. Van Wagoner (Eds.), Sea Level Change- An Integrated Approach. Spec. Publ. Soc. Econ. *Palaeont. Minr.*, 42, Tulsa, (1988), 110-124.

[18] Galloway, W.E. "Genetic Stratigraphic Sequences in Basin Analysis I): architecture and Genesis of Flooding-surface Bounded Depositional Units." *Bull. Am. Ass. Petrol. Geol.*, 73 (1989), 125-142.

[19] Reinson, G. E. "Barrier-island and Associated Strand-plain Systems." In: Walker, R.G. (Ed.) *Facies Models* (2nd ed.). Geoscience Canada Reprint Series 1. *Geological Association of Canada Publications*, 119-141 (1984).

[20] Trisgaard, H. "The Architecture of Precambrian High Energy Tidal Channel Deposits: An Example from the Lyell Land Group (Eleonore Bay Supergroup), Northeast Greenland. Sediment." *Geol.*, 88 (1993), 137-152.

القنوات الناشئة عن العواصف البحرية في صخور الديبدب بجنوب الأردن

عيسى محمد مخلوف

قسم علوم الأرض والبيئة، كلية العلوم، الجامعة الهاشمية،
ص. ب ١٥٠٤٥٩، الزرقاء، الأردن

(استلم في ٢٧/ ٥/ ١٤١٦هـ؛ وقبل للنشر في ١١/ ٦/ ١٤١٨هـ)

ملخص البحث. يتألف تكوين ديبدب الرملي الأردوفيشي المتكشف في جنوب الأردن من رواسب فتاتية، يصل سمكها إلى نحو ١٠٠ متراً. تقسم إلى ثلاث سحنات صخرية هي: (١) حجر رملي ترسب في القنوات البحرية، (٢) حجر رملي ذو تطابق متقاطع ربوي، و (٣) غضار غريني.

توجد الصخور الرملية التي توضعت في القنوات المحفورة في الأجزاء العميقة من الرصيف القارّي، إما محاطة بسحنة من الغضار الغريني أو تكون متداخلة معها لتشكيل ثلاث تتابعات واضحة في المقطع الجيولوجي، يتميز كل تتابع منها بزيادة في نسبة الأحجام الحبيبيّة الصغيرة نحو الأعلى. يلاحظ أن كل تتابع منها يرتكز على سطح يمثّل النحت والتعرية في قاع القناة، الذي تغطيه أحيانًا قطع صخرية مكانية النشأة، تكون متبوعة برواسب تحمل علامات تموّج وتطابق متقاطع من النوع الربوي، بالإضافة إلى احتوائها على مستحاثات بحرية.

وتظهر هذه القنوات على هيئة متراكبة، معطيةً أشكالا معقّدة من رواسب القنوات المتجمعة الناشئة عن تيارات العواصف البحرية، المؤثرة في نطاق تحت المد من الرصيف القارّي.