Arab Gulf J. scient. Res. 1(1), pp. 143-156 (1983)

Primary Sedimentary Structures and Depositional Environments of the Haddat Ash Sham Sedimentary Sequence, Northeast of Jeddah, Saudi Arabia

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ABSTRACT. The depositional environments of the Haddat Ash Sham and Usfan Formations, exposed at Haddat Ash Sham area NE of Jeddah have been identified on the basis of the vertical variation in primary sedimentary structures.

The base of the Haddat Ash Sham Formation (Kheslef Member) is characterized by bioturbation, Cross-bedding of Planar, herringbone and longitudinal types, ripple marks, cross-lamination and rare mud-cracks, which might reflect deposition on shallow intertidal-subtidal subenvironment with numerous channels and sand bars. On the other hand, the top of the same formation (Borma Member) shows planar and channel cross-bedding, graded bedding, scour and fill structures. Also within this member few horizons with poor bioturbation and cross-lamination are also encountered. These features might indicate alluvial fan (water laid and debris flow sediments) depositional environment under arid and semi-arid climates.

The Usfan Formation exhibits moderate to poor bioturbation, ripple marks, cross-lamination, lenticular and flaser-bedding, planar cross-bedding, and rare trough-cross-bedding, mud-cracks and rain drop prints. Consequently, the lower and upper members of the formation were probably deposited on shallow intertidal-subtidal zones. The middle member, however, was probably accumulated as a pelecypod bank in shallow water, under moderate to high agitation, with good current circulation.

The studied area lies to the northeast of Jeddah, to the east of Medina-El Gommoum Road. It lies between longitudes 39° 35′ and 39° 50′ east, and latitudes 21° 28′ and 21° 41′ north (Fig. 1). Geological mapping (Bahafzalla *et al.* in press) has shown that the area is covered by Cretaceous (or even older)-Paleocene succession, which has already been traced and mapped as two formations, namely, the Haddat Ash Sham Formation at the base (Cretaceous or even older) and the Usfan Formation at the top (Upper Cretaceous-Paleocene). The Haddat Ash Sham Formation has been further subdivided into the Kheslef Member at the base (at the north and its counterpart El Hegre Member at the south) and the Borma Member at the top, whereas the Usfan Formation has been subdivided into the informal lower, middle and upper members (Bahafzalla *et al.* in press).

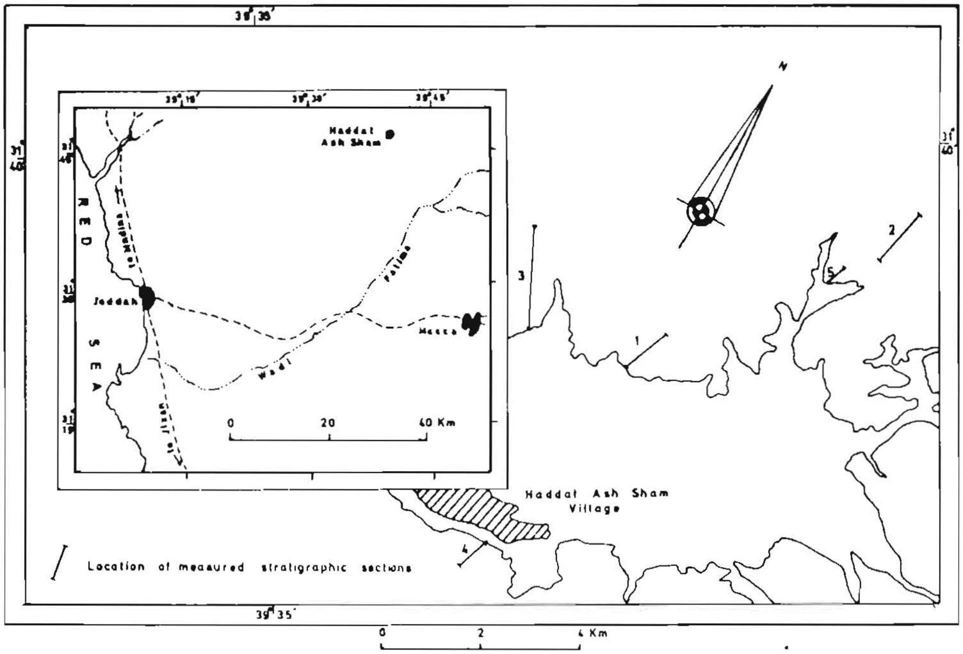


Fig. 1. Index map showing location of concerned area with the studied columnar sections.

The present contribution deals with the primary sedimentary structures and the depositional sedimentary environemtns of the succession exposed along the northern scarp of the concerned area. Consequently four stratigraphic columnar sections representing the aforementioned formations have been measured in detail, whereas the vertical variation of lithology and primary sedimentary structures have been described and hence the depositional environments have been interpreted.

Primary Sedimentary Structures

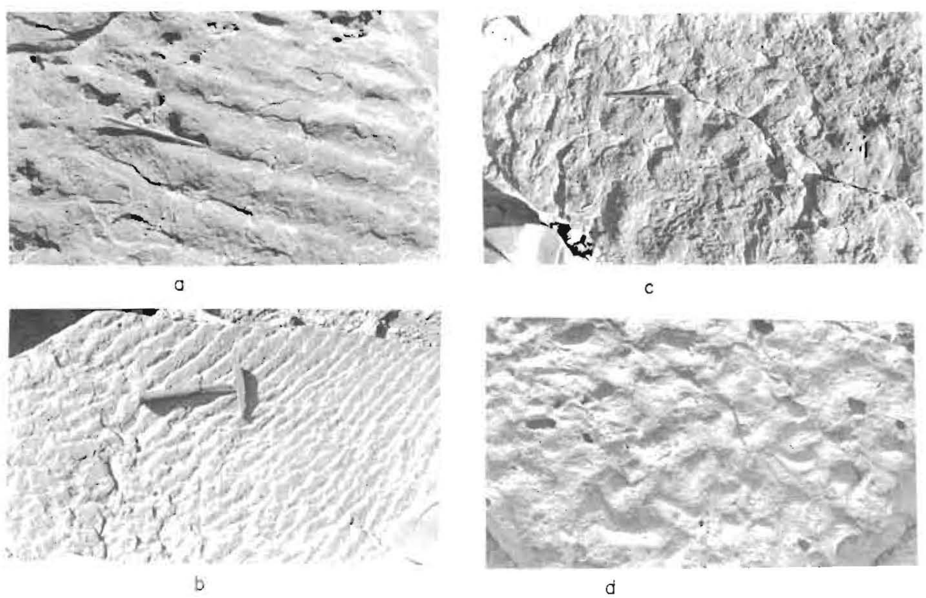
A. Inorganic Primary Sedimentary Structures

1. Ripple Marks

Both symmetrical and asymmetrical wave and current ripples have been encountered. Their crests are mostly rounded to flattened in symmetrical types and sharp in the asymmetrical ones. In case of the asymmetrical wave ripples, the crests are slightly undulated (Pl.1) and they are mostly bifurcated. The lengths of wave ripples range between 6 and 15 cm, their ripple heights range between 3 and 5 cm, and their ripple index (L/H) ranges between 2 and 3. In vertical section, the asymmetrical wave ripples are built upward on an overlapping manner developing climbing-in-drift ripples (Pl.2a).

The current ripples are of small scale type. Their height ranges between 5 and 8 cm, and their ripple index ranges between 3 and 4. On the basis of the nature of their crests strongly undulatory, and lingoidal types (Pl.1) have been encountered (*cf.* Reineck and Singh 1973).

Both wave and current ripple marks are represented in many horizons in the Kheslef Member as well as in the lower and upper members of the Usfan Formation.



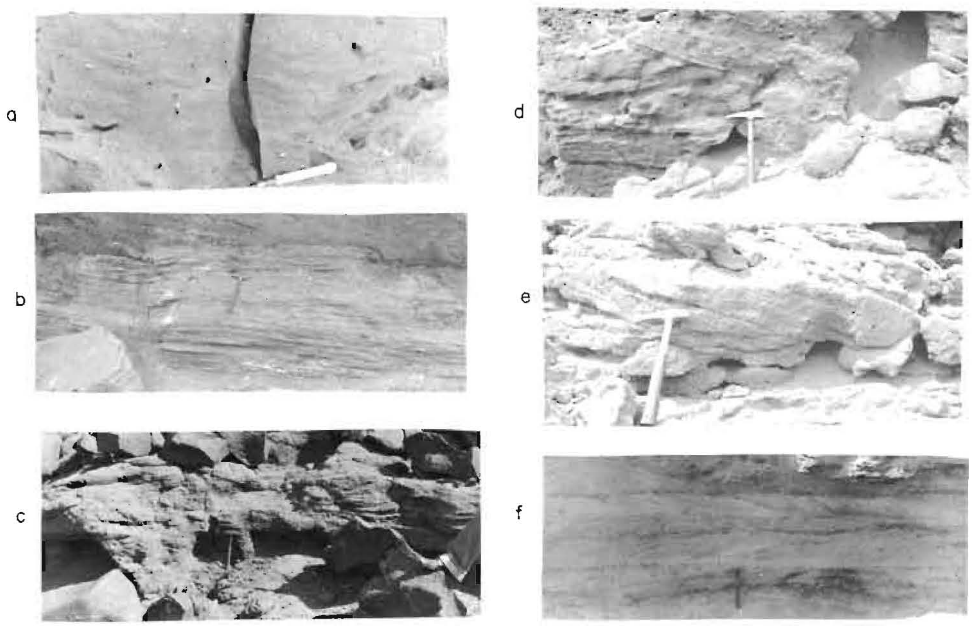
Pl.1 a. Symmetrical wave ripples, Kheslef Member.
b. Asymmetrical wave ripples, Usfan Formation.
c. Strongly undulatory small current ripples, almost tending to the lingoid type, Usfan Formation.
d. Lingoid shape, small scale current ripples, Kheslef Member.

2. Cross-Bedding

Planar cross-bedding (P1.2d) are most abundant. Both small and large-scale types (Reineck and Singh 1973) have been met with. The thickness of the sets ranges from 8 cm to 100 cm or even more. The foreset laminae are either planar or slightly wave. Their thicknesses range from few mm to 2 cm. The dip of foresets is mostly less than 25°. Planar cross-bedding has been encountered in beds at the lower and upper parts of the Kheslef Member, in many beds of the Borma Member and several beds of the Usfan Formation.

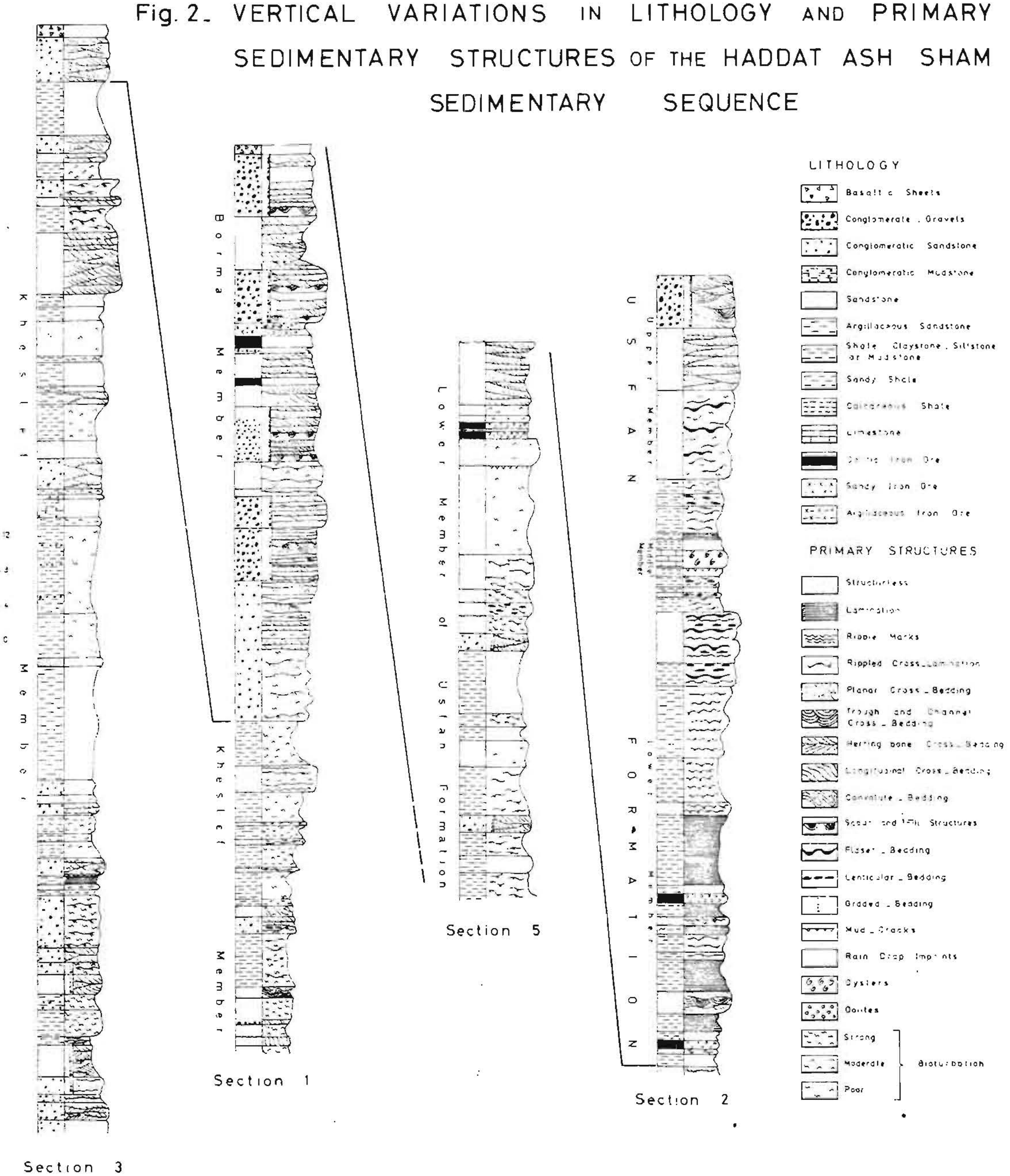
Trough cross-bedding (P1.3b) of major-scale type is only restricted to one bed at the lower member of the Usfan Formation.

Herringbone cross-bedding (P1.2f) has been seen in one bed at the base of the Kheslef Member (Fig. 2). The top and base of the structure are erosional ripple marks. The foreset laminae are planar to wavy and exhibit micrograded bedding.



Pl.2 a. Climbing-in-drift ripples, Borma Member.
b. Interlamination of fine terrigenous sediments with evaporites (gypsum and or anhydrite). Lower Member of the Usfan Formation.
c. Small-scale planar cross-bedding, Borma Member.
d.e. Major-Scale planar cross-bedding, Borma Member.
f. Herringbone cross-bedding, base of Kheslef Member.

Fig. 2. VERTICAL VARIATIONS IN LITHOLOGY AND PRIMARY SEDIMENTARY STRUCTURES OF THE HADDAT ASH SHAM SEDIMENTARY SEQUENCE

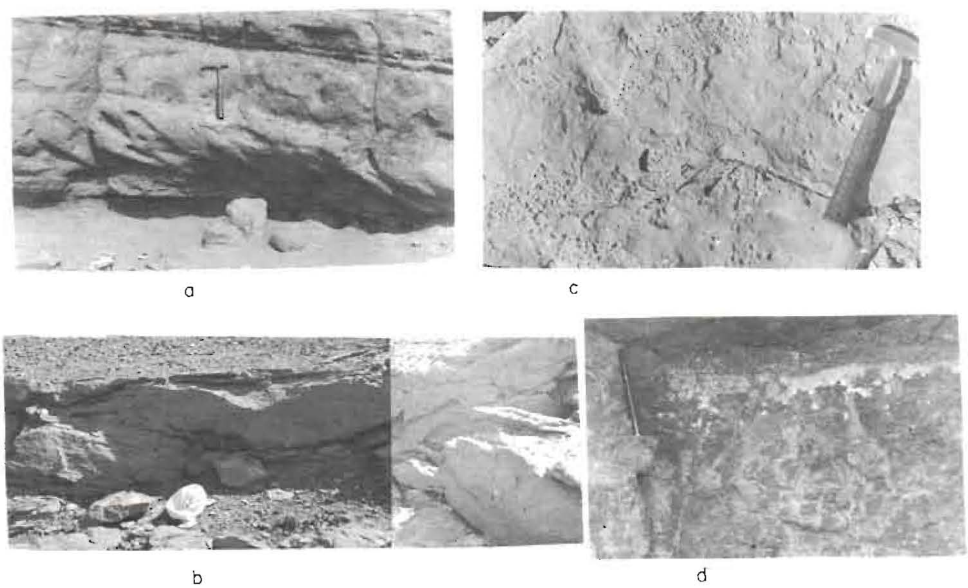


Longitudinal cross-bedding (Pl·3a) is only represented at the upper part of the Kheslef Member (base of section No.1). It has probably resulted by lateral shifting of tidal channels (Reineck and Singh 1973). The recorded type is characterised by curved slip planes.

Channel cross-bedding (McKee 1957) may be produced in the filling-up of small alluvial or erosional channels. In the concerned area, it has been recorded in numerous, coarse grained terrigenous beds of the Borma Member, where it is characterised by eroded trough-shaped floor (Pl·4a).

3. Convolute Bedding

Convolute bedding is a structure showing marked crumpling or complicated folding of laminae of a rather well defined sedimentation unit (Potter and Pettijohn 1963). In the studied sequence, convolute bedding (Pl.5a) has been encountered in one sandstone horizon intercalating the upper part of the Kheslef Member (Section No.1).



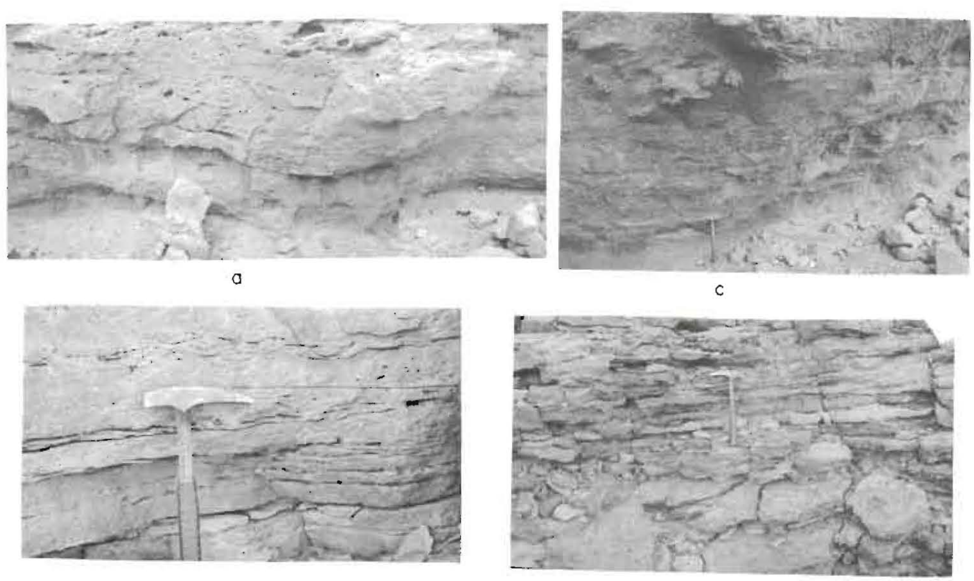
Pl.3
a. Longitudinal cross-bedding, top of Kheslef Member.
b. Major scale trough cross-bedding, lower member of the Usfan Formation.
c. Rain drop prints associated with mud cracks, base of the middle member of the Usfan Formation.
d. Strong bioturbation characterises the top of Kheslef Member.

4. Flaser Bedding

Flaser beddings (P1.4b) in the area under consideration have been shown in some mudstone and fine sandstone beds in the lower and upper members of the Usfan Formation. The structure is mostly associated with rippled cross-lamination, and lenticular bedding. It is probably a ripple-bedding in which mud streaks are completely preserved in troughs and partly on crests (Reineck and Wunderlich 1968). Plate 4b shows that both simple, wavy welling, and bifurcated wavy vergabelte (terminologies of Reineck and Wunderlich 1968 and Reineck and Singh 1973) are represented.

5. Lenticular Bedding

Lenticular bedding (P1·4d) has been encountered associated with flaser bedding in the upper member of the Usfan Formation (Fig. 2). Plate 4d shows that the sand lenses forming the lenticular bedding are either discontinuous and isolated or are connected and arranged in certain parallel horizons. Transition forms between flaser bedding and lenticular bedding are rather frequent.



a c b d

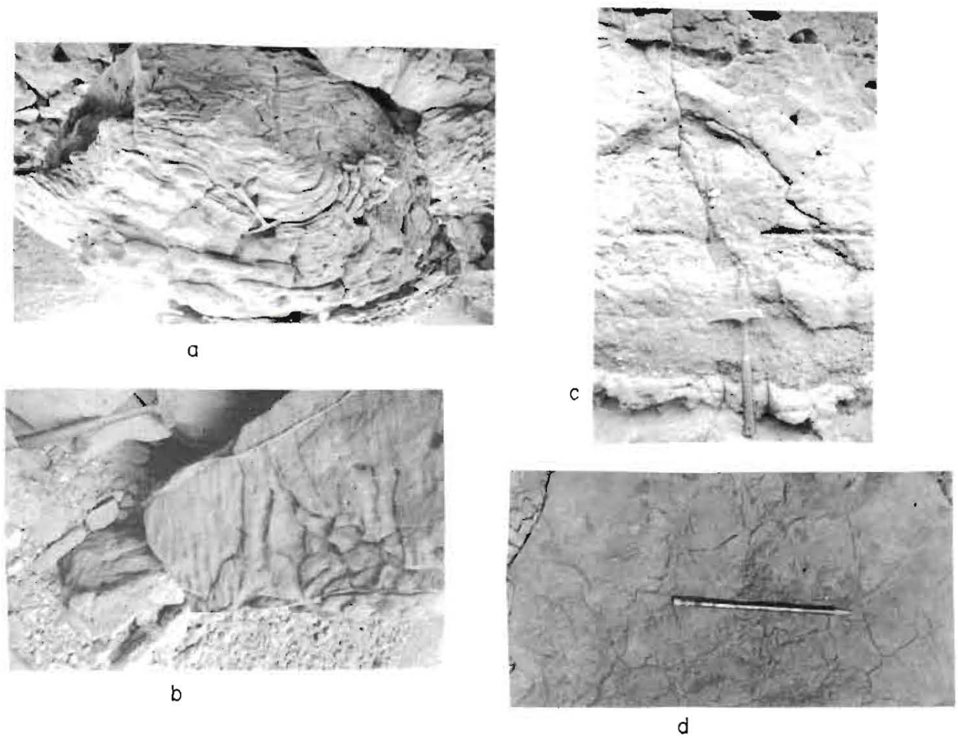
P1.4 a. Channel cross-bedding, Borma Member.
b. Flaser bedding, Upper Member of the Usfan Formation.
c. Vertical view of scour and fill structure. Borma Member.
d. Lenticular bedding, upper member of the Usfan Formation.

6. Graded Bedding

In general, graded beds are sedimentation units characterised by a gradation in grain size; coarse at the base fining upward. In the concerned sequence, graded beds (Pl.5c) are distinctive in the Borma Member where complete grading from gravel size at the base to siltstone or clay sizes at the top is easily visible. However, noncomplete micrograded units are encountered in the cross-bedded units of the Kheslef Member and Usfan Formation. The lower boundary of the graded bedded unit is mostly erosional. The graded units range in thickness between few cm and one meter thick, and they are related to the second type of Pettijohn (1957).

7. Scour and Fill Structures

Small-scale scour and fill structures (small channels) are well developed in



Pl.5 a. Convolute bedding, upper part of the Kheslef Member.
b. Horizontal view of scour and fill structure, Borma Member.
c. Graded-bedding, Borma Member.
d. Mud-cracks, Lower member of the Usfan Formation.

numerous horizons of the Borma Member (P1.4c and P1.5b). Mostly the channels are encountered in coarse grained sediments and are filled up by sandy or muddy sediments. The channels are asymmetrical in form, and they are probably developed with a steep up current slope and a gentle down-current slope (Reineck and Singh 1973). However, in some cases they are filled by laminae conforming roughly to the channel shape. Moulds of scour on the lower surface of sandstone beds have been depicted in some horizons of the Borma Member. The moulds are elongate, continuous and discontinuous and they are arranged in parallel manner most probably in the same direction of the Paleocurrent (Reineck and Singh 1973).

8. Mud Cracks and Rain Drop Imprints

Mud cracks (P1.5d) have been observed on the upper surface of a fine sandstone bed in the middle part of the Kheslef Member and on another horizon in the lower member of the Usfan Formation. Poorly developed mud cracks are encountered together with rain drop prints on the upper surface of a marl bed at the base of the middle member of the Usfan formation (P1.3c). The cracks are straight or slightly curved. They are either single or bifurcating. The polygons are generally small, less than 15 cm in diameter whereas the cracks are less than 2 cm in cross-section and few cm in depth.

B. Organic Sedimentary Structures

Most of the horizons forming the Kheslef Member and relatively few horizons of the Usfan Formation are bioturbated. However, the intensity of bioturbation differs widely from horizon to horizon. Intensive bioturbation (Pl. 3d) is associated with fine grained terrigenous sediments (siltstone and claystone) whereas poorly developed ones are related to the sandstones. The holes formed by organisms through their bioturbation activity are filled by different materials which are mostly stained, probably due to addition of the fecal matter of the burrows (Reineck and Singh 1973) or to biochemical reaction in sediments (Frey 1971). The observed burrows are either nearly vertical or inclined, whereas horizontal burrows are relatively rare. The burrows which are simple, bifurcated, trifucated or much more complicated have no definite zonal distribution.

Depositional Environments

1. Tidal Flat Environment of the Kheslef Member

The Kheslef Member in the investigated area shows lithofacies and primary sedimentary structure associations which resemble those described in ancient and recent tidal flat environments.

This member is composed mainly of sandstones (coarse to fine), which are, in some horizons, conglomeratic or interbedded with siltstones, claystones and their derivatives. Calcareous mudstone variety forms two horizons. The sandstone horizons show either low-angle, small-scale or major-scale cross-bedding. Herringbone cross-bedding has been observed in a conglomeratic sandstone bed at the base of the member (section No. 3), whereas longitudinal cross-bedding has been met with in a sandstone bed at the upper part of the member (section No. 1). Most of fine grained terrigenous sediments are cross-laminated, bioturbated and in some cases ripple-marked. The bioturbation is either strong, moderate or weak. Convolute bedding is restricted to one bed (section No. 1) and mud-cracks is encountered below a thin band of basal intraformational conglomerate at the middle part of the member. Rare lenticular bedding and small-scale graded bedding are found in certain horizons.

It is believed that the sandstone beds which show low angle, small-major-scale cross-bedding and herringbone cross bedding were deposited on the tidal channels (Reineck and Singh 1973) or on sand bars and shoals (Klein 1970). Longitudinal cross-bedding might suggest deposition on point bar of gullies (Reineck and Wunderlich 1968). Micro-graded bedding is described from recent tidal flat sediments by Reineck (1972). The types of ripple marks in the present investigation characterise sand-flats and mixed-flat sediments (Reineck and Singh 1973, Reading 1978). On the other hand, bioturbated horizons suggest deposition on mud-flat and to some extent in the mixed-flat subzone of the intertidal flat (Reineck and Singh 1973). Wunderlich (1967) shows that convolute bedding is rather a common feature on the steeper sloper of sand bars in tidal flat environment. Sub-aerial exposure indicated by mud-cracks of the included surface is confirmed by the occurrence of basal intraformational conglomerate bed directly overlying the mud-cracked surface (disconformity surface). Evaporite (gypsum or anhydrite) deposits below the erosional surface at the boundary between the Kheslef and the Borma members (P1.3d) might suggest deposition on shallow intertidal or most probably supratidal zone.

It is concluded, therefore, that the aforementioned member exhibits features suggesting depostion on an environment ranging between shallow mud-flat (or probably supratidal zone) and subtidal zone. The latter was probably characterised with numerous channels and sand bars.

2. Alluvial Fan Environment of the Borma Member

The facies of the Borma Member show characters of alluvial fan facies. The sequence of the member is mainly composed of unfossiliferous, friable, highly oxidized, moderately to poorly sorted gravels and sandstone of different size-grades. Gravel components range in size between fractions of mm and 10 cm or even more, and most of them are of igneous and metamorphic origin. Fine-grained terrigenous sediments are relatively rare. Three oolitic iron ore beds (one of them is arenaceous) are encountered at the upper part of the concerned member. The rocks forming the member alternate with each other in a cyclic manner, with gradational or erosional contacts.

In the meantime, the succession exhibits low angle, small to major-scale planar and channel cross-bedding. Graded-bedding and scour and fill structures are dominant. Poor bioturbation, cross-laminated horizons are rather common.

The gravel and sandstone with abundant planar, and channel cross-beddings, scour and fill structures might suggest deposition of the alluvial fan facies of the Borma Member by the action of a network of braided distributary channels and sheet floods (Bull 1972, Reading 1978). Horizons of relatively large, oriented and zoned pebbles within the gravels and sandstones might represent channel lag deposits (Reineck and Singh 1973). Horizons with upward finning might have resulted from migrating stream channels during floods or might represent flow deposits formed by decrease in velocity or depth of flow (Bull 1972, Reineck and Singh 1973). Oolitic iron beds might refer to moderate to high water energies.

Thus, it could be concluded that the alluvial fan sediments of the Borma Member were formed as water laid (stream and flood) debris flow sediments, interlayered in a complicated manner. The sequence may represent middle to lower fan segments as described by Reineck and Singh (1973). Lack of reduced deposits in the sequence is a typical characteristic of a fan accummulated in arid or semi-arid climates (Bull 1972).

Tidal Flat-Oyster Carbonate Bank Environment of the Usfan Formation

The lower and upper members of the Usfan Formation are mainly composed of an alternated coarse to fine sandstones, siltstones, claystones and their derivatives. Conglomeratic sandstone beds and three oolitic iron ore beds intercalate the lower member, and conglomerates of different size grades cap the upper member. The rocks of these two members show strong to poor bioturbation, siliceous stromatolites, ripple marks, cross-lamination, lenticular, flaser, small- to major-scale planar, and major-scale trough cross-bedding. Fig. 2 shows the vertical distribution of these structures. Mud cracks are encountered on the upper surface of sandstone horizon intercalating the lower member.

The features described suggest deposition of the lower and upper members of the Usfan Formation on an intertidal-subtidal environment. Interlamination of fine terrigeneous sediments with evaporites (gypsum or anhydrite) and the mud-cracked horizon in the lower member might reflect deposition on shallow intertidal or probably supratidal zone.

Towards the top of the upper member, an alluvial fan facies might have been developed, indicating the beginning of the second cycle of alluvial fan sedimentation.

The middle member of the Usfan Formation is composed of carbonate rich with pelecypods, and marls. The latter contains rare, fragmented and badly preserved planktonic and benthonic foraminifera (Bahafzalla *et al.* in press).

The high concentration of pelecypods refers to deposition in very shallow, turbid waters where many other organisms cannot live (Weller 1960). This type of organism built up possesses a potential capability for wave resistance (Teichert 1958). The facies of the member reflect bank deposition (Laporte 1967, Read 1974, Purser 1973, Wilson 1975). The sea water was essentially shallow, moderate to high agitated, and has a good current circulation (Neal 1969). However, mud cracks and rain-drop prints encountered in the upper surface of the marl bed at the base of the member indicate the emergence of the bank during the time of deposition (Purser 1973).

Conclusions

Analysis of primary sedimentary structures and lithofacies of the sedimentary sequences exposed in the Haddat Ash Sham area reflects cyclic tidal flat and alluvial fan sedimentation of the Haddat Ash Formation, and the lower and upper members of the Usfan Formation. However, the middle Member of the latter formation was deposited as pelecypods rich bank under shallow, agitated water with good current circulation.

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(Received 4/1/1983;
in revised form 8/3/1983)

البنيات الأولية وبيئات الترسيب للتتابع الرسوبي في منطقة هدى الشام شمال شرق جدة بالمملكة العربية السعودية

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درست الأنواع المختلفة من البنيات الأولية التي تتمثل في التتابع الرسوبي في منطقة هدى الشام شمال شرق جدة. وبناء على التغيير الرأسي في تلك البنيات الأولية، قُسّم التتابع الرأسي إلى سحن ترسيب مختلفة كل منها يُميِّز بيئة ترسيب معينة. وعليه، فإنه من المعتقد أن صخور العضو السفلي من مُتكون هدى الشام (عضو الخسلف) وأيضاً صخور العضوين السفلي والعلوي من مُتكون عسفان قد ترسبت من بيئة بحرية ضحلة شاطئية أَثَّرت عليها عمليات المد والجزر. أما صخور العضو العلوي (عضو البرما) من مُتكون هدى الشام فإنها قد ترسبت على هيئة مراوح نهرية في منطقة صحراوية أو شبه صحراوية. كما يعتقد أن العضو الأوسط في متكون عسفان قد ترسب على هيئة جسر من أصداف المحاريات في منطقة بحرية ضحلة ذات طاقة عالية.