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Textural Characteristics and Environmental Interpretation of the Lower Miocene Siliciclastic Succession, Dafin Formation, Rabigh Area, Saudi Arabia

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Abstract. The main textural characteristics such as grain-size parameters, roundness and sphericity of the exposed Lower Miocene siliciclastic succession in Rabigh area indicate their deposition in a river system. The succession is composed of several cycles, each of which consists of fining-upward channel conglomerates, sandstones, and flood plain mudstones that confirm their formation in a river system.

Grain size analysis of 54 selected samples representing the lower sandstone member of Dafin Formation showed that the grain size distribution is varying from gravel to mud. These are classified into slightly gravelly sand, gravelly sand, sand (specify sorting), muddy sandy gravel, and less frequent muddy sand, gravelly muddy sand or slightly gravelly muddy sand categories.

The sand showed mostly bimodal distribution in addition to unimodal class, with a mean size ranges from very coarse to very fine. The degree of sorting ranges from moderately well sorted to very poorly sorted. The skewness of the sand, on the other hand, ranges from strongly coarse skewed to slightly fine skewed and kurtosis ranges from platy kurtic to very leptokurtic. The Dafin sandstones are texturally immature.

Roundness and sphericity of 100 to 150 sand grains of 24 samples indicate that the roundness ranges from subangular to very angular, and the sphericity is low.

The results of the textural parameters, lithology, cyclicity and sedimentary structures of the Dafin siliciclastics support the fining-upward character and the predominance of bimodal class which reflect their deposition in a river system.

Keywords: Textural analyses, River system, Dafin Formation,Rabigh area, Saudi Arabia.

Introduction

Grain size parameters are potentially useful tool for recognizing sedimentary environments, as beach, dune and river and several sectors of the continental shelf through graphical or calculated methods used along with other textural properties (Blott and Pye, 2001; and Martins, 2003). Grain size is the most fundamental property of sediment particles, affecting their entrainment, transport and deposition. Therefore, grain size analysis provides important clues to the sediment provenance, transport history and depositional conditions (*e.g.* Folk and Ward, 1957; Friedman, 1979; Bui *et al.*, 1990; and Blott and Pye, 2001).

From the 1960's to the 1980's, a large number of papers on statistical parameters of grain size distributions of recent sedimentary environments, and the distinction between beach, dune and river sands were published using graphic calculation method (Folk and Ward, 1957), or calculated moment measures (Friedman, 1961). More than one hundred sedimentological papers support the relation between grain size parameters and sedimentary environment (*e.g.* Inman, 1952; Friedman, 1961; Warren, 1974; Moussa, 1977; Omara *et al.*, 1974, Martins, 2003; and references their in). The importance of the grain size as a fundamental property of sedimentary materials, regarding their origin and history, was emphasized by McCave and Syvitski (1991). Martin (2003) agreed that a large part of information related to sedimentary particles transport and deposition can be obtained from grain-size. Cheetham *et. al.* (2008) carried out a comparison of grain-size analysis methods for sand-dominated fluvial sediments, he concluded that, the data for sand-dominated fluvial sediments gained from the long-established sieve/ hydrometer method can be compared with confidence to those obtained by modern studies using laser diffraction techniques

On the other hand some authors disagree with the use of grain-size parameters as a helpful tool to distinguish some modern sedimentary environments (Shepard and Young, 1961; Moiola and Weiser, 1968; and

Solohub and Klovan, 1970). However, during the last decade new contributions were published on the question of the validity of grain size parameters in environmental interpretation (Tanner, 1991; Medina *et al.*, 1994; and Martins *et al.*, 1997). Martins (2003) based on his study of more than 15,000 samples from several transitional and marine environments, was able to distinguish and characterize modern sedimentary environments, mainly beach, dune, river and continental shelf.

This work is based on grain size analysis of 54 samples taken from eight stratigraphic sections measured in wadi Al Haqqaq and wadi Al Hajar, Rabigh area. Other textural parameters such as roundness and sphericity, besides mineraological composition and sedimentary structures are helpful in distinguishing the paleosedimentary environment of the studied samples.

Geologic Setting

Rabigh area on the Red Sea coast of Saudi Arabia extends from Tihamat al-Hijaz and the Hijaz Mountains to Harat Rahat, between latitudes 22° 36′ to 22° 55′ N. and longitudes 39° 00″ to 39° 13″ E. Geologic map of the study area revealed the presence of four rock units (Fig. 1), the lower two units are of Precambrian age and related to the Arabian Shield rocks and the upper two are of Tertiary age (Ramsay, 1986).

Precambrian Rocks

These are represented by two main units, the Birak Group and Rabigh suite. The Birak group (Camp, 1986) crops out in the southern part of the Hijaz terrain, and consists of metamorphosed volcanic and sedimentary rocks. It is divided into the Suri, Qahah, and Labunah formations (Camp, 1986; and Ramsay, 1986). Rock types include greenschist-facies basaltic, andesitic, dacitic, and rhyolitic flows and pyroclastic rocks (agglomerate, lapilli tuff, and ash tuff), graywacke, marble, quartzite, and chert. Chert is thinly bedded to finely laminated. White to banded pale gray and white marble is conspicuous at Jabal Farasan. The formation may represent oceanic-floor to continental-slope deposits (Ramsay, 1986; and Johnson *et al.*, 2003).

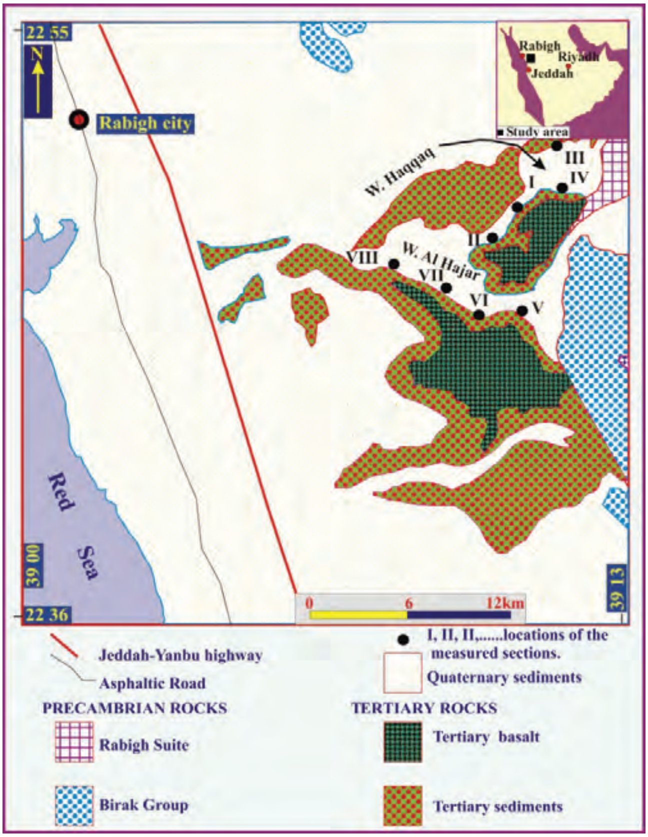

Fig. 1. Geologic map of Rabigh area showing the locations of the measured sections of Fig. 2 and 3 (Modified after Ramsay, 1986).

Tertiary Sedimentary Rocks

These are represented along the Red Sea coast by thick clastic and evaporite rocks. The clastic rocks are friable, barely exposed in most places and are generally covered by a thin veneer of Quaternary alluvium or corals. Where tongues of Tertiary lava have flowed down onto the coastal plain they have formed resistant caps. Therefore, most exposures of Tertiary sedimentary rocks are studied along their margins. The rocks are generally horizontal but have been faulted and consequently attain flexure dips, in places, as much as 40°. They are nonconformably enclosed between Tertiary lava flows and and/ or are faulted against the Precambrian rocks. They are the Usfan, Shumaysi and Dafin formations (Ramsay, 1986). They attain a total thickness of 3000 meters between Yanbu Al-Bahr and Jeddah (Agocs, 1962).

Tertiary, mainly clastic sedimentary rocks have been mapped in the Rabigh quadrangle as Dafin Formation after the Dafin Harrat by Ramsay (1986). It crops out on the Tihamat Al Hijaz around the margin of Harat Dafin lava fields and underlying the low exposures of the Quaternary cover in the Rabigh area. These rocks were mapped as unnamed Miocene and Pliocene formations by Brown *et al.* (1963), whereas they were included in the Raghamah Formation by Schmidt *et al.* (1982), as there is no firm correlation between the rocks in the northwest corner of the Rabigh quadrangle and those at Jabal ar-Raghamah. Gilboy and Skiba (1978) described Dafin Formation as mostly immature brown sedimentary rocks (in many places gypsiferous) arkosic sandstone interceded with shale, conglomerate, fossiliferous limestone and some massive gypsum.

The age of the Dafin Formation is unknown except by correlation (Ramsay, 1986). It was considered Miocene by both Brown *et al.* (1963) and Schmidt *et al.* (1982), an age consistent with the younger formations of the Raghamah Group in the area around Jabal ar-Raghamah, Gulf of Aqaba. Taj *et al.* (2001) investigated the economic potentiality of the Tertiary argillaceous sediments in Makkah and Rabigh quadrangles including the Dafin Formation.

Taj and Hegab (2005) found that the siliciclastic rocks are exposed in all the measured sections in a cyclic fining upward pattern in Rabigh area. Each cycle is made up of basal conglomerate unit followed by sandstone unit and then a shale unit at the top. The modal composition of the Dafin sandstone tectonically suggests derivation from continental source area.

Tertiary Basalt

Basalt lava flows form discontinuous cap overlying the upper levels of both the basement complex and the sedimentary rocks; the lavas rest either on peneplain or infilled ancient wadis.

Stratigraphy of the Dafin Formation

The exposed succession of the Dafin Formation in Rabigh area has been subdivided into three members by Taj and Hegab (2005). These members are: a) Lower siliciclastic member, b) Middle carbonate member, and c) Upper evaporite member. The siliciclastic member is widely exposed in most of the eastern part of Rabigh area at Wadi Al Haqqaq, Wadi Al Hajar and Wadi Al Jerba. The carbonate member outcrops at the southeastern part of the sedimentary cover at Wadi Al Jerba. The evaporite member outcrops at the most northwestern part of the sedimentary cover at Miqat Al-Gehfa, and increases in thickness towards north and northwest.

Hughes and Johnson (2005) found that the Lower Miocene siliciclastic rocks of Al Wajh Formation have regional distribution from Al Wajh and Yanbu basins at north to Jeddah at south. In turn, the siliciclastic Member of Dafin Formation is equivalent to the siliciclastic of Al-Wajh Formation, *i.e.* Early Miocene in age. The present study dealt mainly with the lower siliciclastic member of the Dafin Formation.

Wadi Al Haqqaq Sections

Section I (Fig. 2A)

This section attains up to 30 m thick and is composed of four fining-upward cycles (Pl. 1A, B). The first cycle (7m thick) begins with cross-bedded medium grained sandstone grading upward into cross-laminated fine-grained sandstone and terminated by thinly laminated siltstone. The second cycle (3m thick) begins by trough cross-bedded pebbly sandstone with thin mudstone intercalations (Pl. 1C). The upper part of this cycle is composed of interbedded shale and fine-grained cross-bedded sandstone. The third and fourth cycles are composed of basal trough cross-bedded pebbly coarse-grained sandstone (Pl. 1D) and terminated by thinly bedded fine grained sandstone and thinly laminated mudstone.

Section II (Fig. 2B)

This section attains up to 15m thick and it is composed of two fining-upward cycles (Pl. 1E). The lower cycle (cycle 1; 8m thick) begins with 6m thick trough and tabular coarse-grained pebbly sandstone and terminated with cross-laminated siltstone and thin laminated mudstone. The second cycle (7m thick) begins by cross-bedded sandstone and terminated by cross laminated fine-grained sandstone/siltstone.

Section III (Fig. 2C)

This section attains up to 24m thick. It consists of four fining-upward cycles (Pl. 1F). The first cycle begins with cross-bedded coarse-grained sandstone and terminated by thinly laminated mudstone. The second cycle begins by tabular and trough cross-bedded pebbly sandstone and terminated with thinly laminated mudstone. The third cycle begins with cross-bedded coarse-grained sandstone and terminated by mudstone. The sandstone contains secondary satin spar gypsum veins parallel to the bedding planes. The fourth cycle begins with cross-bedded medium-grained sandstone and terminated with thinly laminated mudstone.

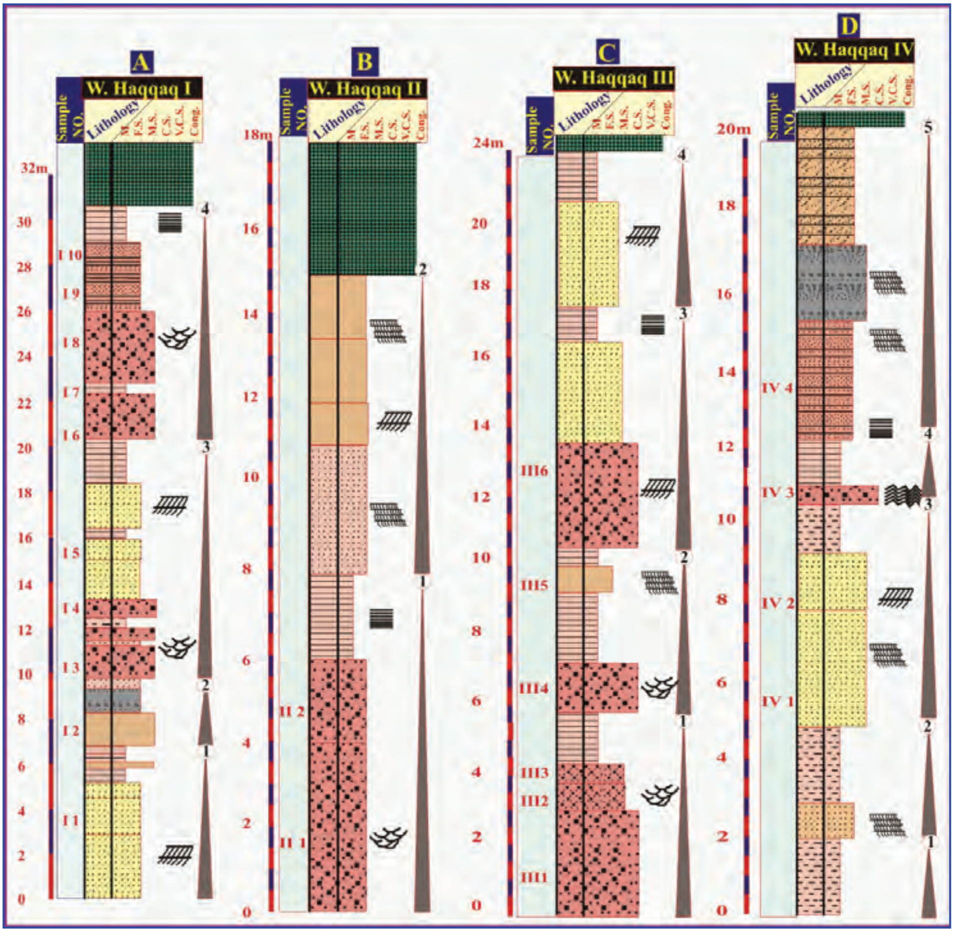

Fig. 2. Stratigraphic sections of Dafin Formation in wadi Al Haqqaq (For legend see Fig. 2 continue).

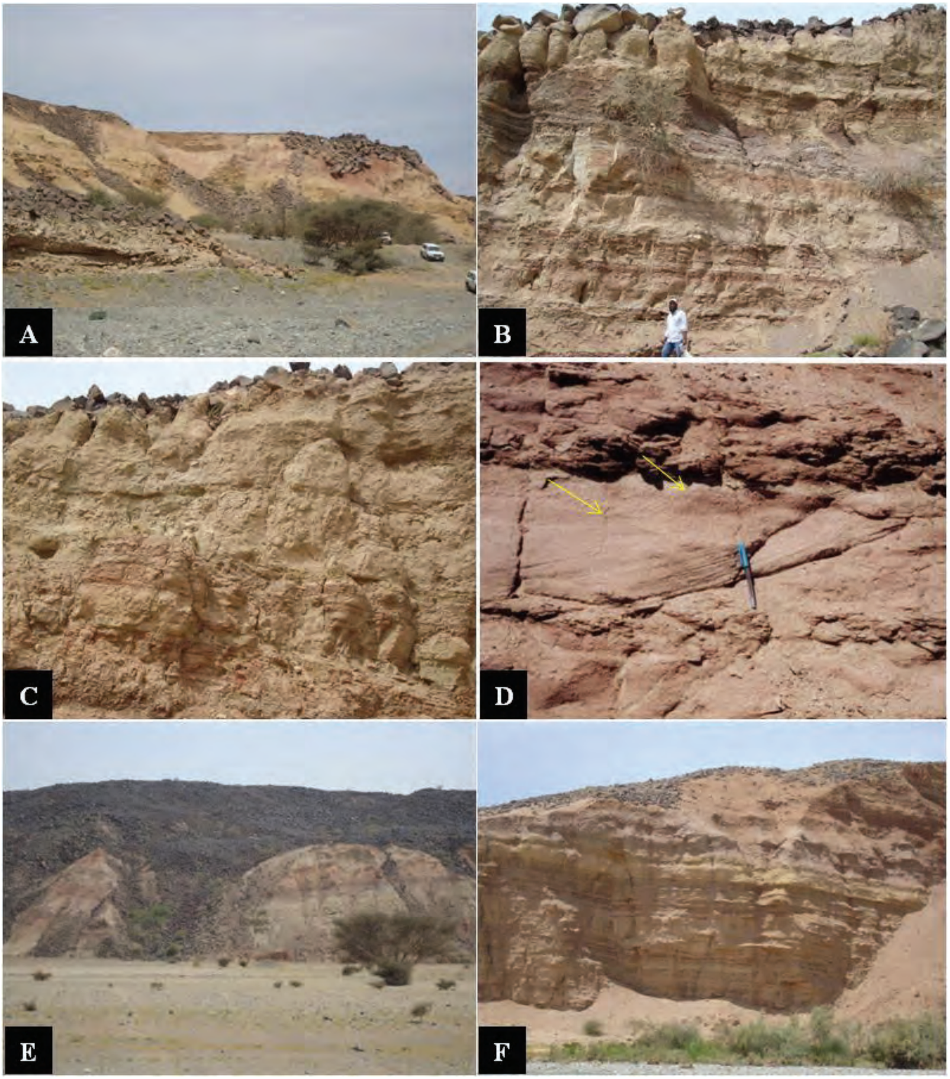

Plate 1. A, B = Interbedded siliciclastic units of Dafin Formation (section I, W. Al Haqqaq); C = Interbedded conglomerates, sandstone and mudstone (Section I, W. Al Haqqaq); D= Medium-grained sandstone with simple planar cross-bedding (arrows; W. Al Haqqaq, section I); E = Section II of W. Al Haqqaq, capped by basalt (black); F= Section III of wadi Al Haqqaq.

Section IV (Fig. 2D)

This section attains up to 20m thick and it begins with relatively thick unit of intercalated mudstone and siltstone representing the upper part of fining-upward cycle of unexposed base (Cycle 1; Fig. 2D; Pl. 2A). This unit is followed upward by four fining-upward cycles. The second cycle attains up to 5.5m thick and consists of cross-bedded medium-grained sandstone followed upward by thinly laminated mudstone (Pl. 2B). The third cycle is relatively thin (11.5m thick) and consists of basal coarse-grained sandstone (Pl. 2C) and terminated by mudstone. The fourth cycle began by conglomerate (1m thick) and terminated by mudstone. The fifth cycle begins with thinly bedded sandstone which grades upward into cross-bedded and cross-laminated fine-grained sandstone/siltstone, respectively. The uppermost part of this cycle is chocolate brown in color and is composed of thinly laminated ferruginous mudstone contains white kaolinitic mudstone bands (Pl. 2D).

Wadi Al Hajar Sections

Section V (Fig. 2E)

This section attains up to 30m thickness. It consists of six successive fining -upward cycles. These cycles are composed of tabular and trough cross-bedded pebbly coarse-grained sandstone alternating with cross-bedded and cross-laminated fine-grained sandstone/siltstone, respectively. The latter is terminated by parallel laminated mudstone/shale.

Section VI (Fig. 2F)

This section (12m thick) comprises four fining-upward cycles (Pl. 2E, F). Cycle No. 1 begins with cross-bedded coarse-grained sandstone. Cycles Nos. 2, 3 and 4 begin by pebbly coarse-grained sandstone grade upward into cross-laminated fine grained sandstone/siltstone. The coarse sandstone contains ball and pillow bodies of brown ferruginous sandstone. All these four cycles are terminated by thinly laminated mudstone.

Section VII (Fig. 2G)

This section attains up to 24m thick and it consists of three cycles. Each of these cycles begins with trough cross-bedded pebbly coarse-grained- sandstone which grades upward into cross-laminated to cross-bedded fine-grained sandstone/siltstone and terminated by parallel laminated mudstone. Friable fine sandstone with wavy gypsum layers extended parallel to bedding planes. Reddish, highly indurated shale had underlies coarse-grained highly indurated yellowish white sandstone at the middle parts of these cycles.

Section VIII (Fig. 2H)

This section attains 56m thick and is composed of two fining-upward cycles. The first cycle begins with pebbly coarse-grained sandstone and is terminated by thinly laminated mudstone. The second cycle is composed of cross-laminated to cross-bedded fine to medium-grained sandstone and terminated with sandstone and highly weathered brown shale.

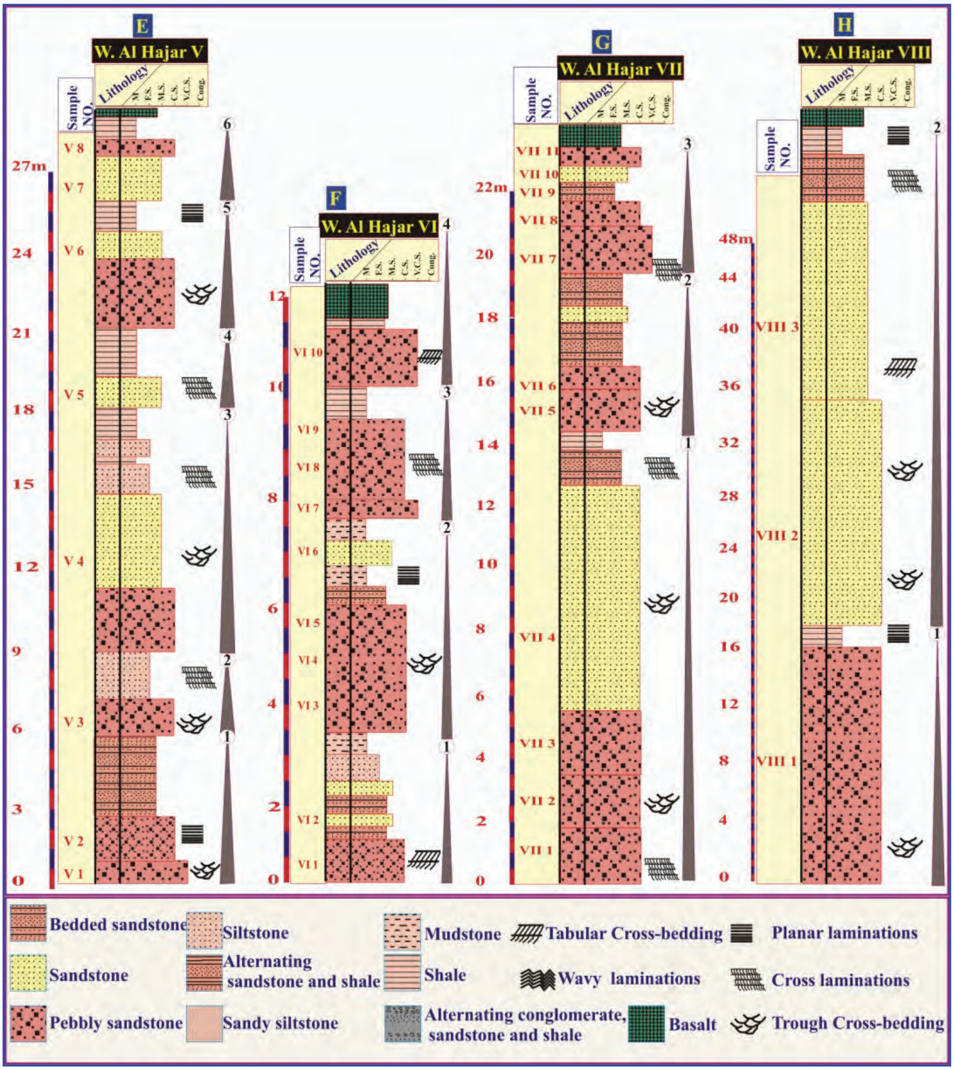

Fig. 2 continue. Stratigraphic sections of Dafin Formation in wadi Al Hajar.

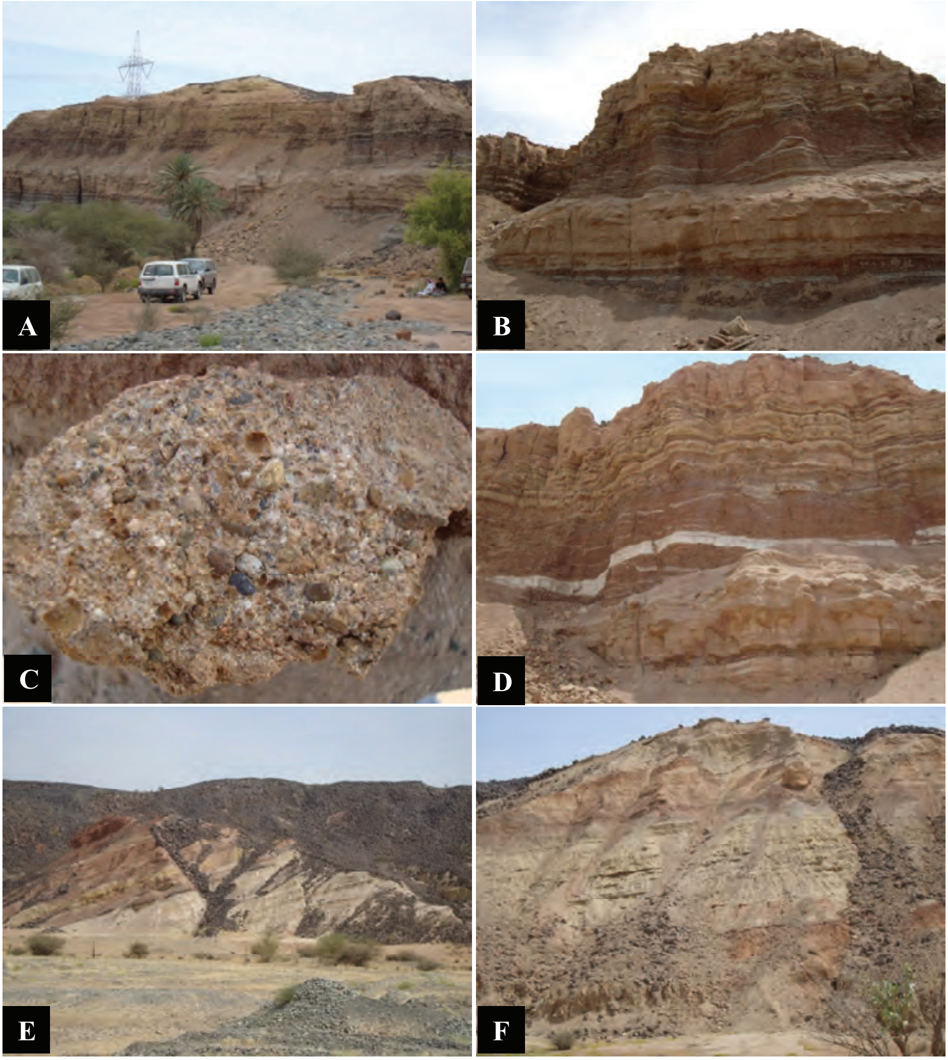

Plate 2. A = General view of section IV, W. Al Hajar); B= The cyclic nature of the interbedded sandstone, siltstone and mudstone of section IV, W. Al Hajar; C= Friable disorganized conglomerates in the base of the fining-upward cycles of section IV, W. Al Hajar; D= The thickly bedded sandstones overlained by flood plain mudstone containing a characteristic white kaolinitc mudstone bed (section IV, W. AL Hajar); E= The complete succession of Dafin Formation of section VI, W. Al Hajar; F= Reddish interbedded sandstones and mudstones of Dafin Formation of section VI, W. Al Hajar.

Textural Analyses

Grain-Size Analysis

Fifty four samples (Tables 1 and 2) covering the eight stratigraphic sections (Fig. 2) were selected for grain-size analysis. The Dafin siliciclastics are semi-friable and easily disaggregated by finger *i.e.* insignificant compaction and cementation. The samples were quartered and certain weight of 100 gm of each sample was screened on one phi set of standard sieves with the openings 2.0, 1.0, 0.5, 0.25, 0.125 and 0.063 mm by using an electrical shaker for about 20 minutes. The fraction retained in each sieve was weighed and the percentages (wt % and cum. wt %) were calculated.

Roundness and Sphericity

Roundness and sphericity of 100 to 150 sand grains (1/8-1/16 mm) of 24 samples (Tables 3 and 4) covering the studied eight stratigraphic sections were measured according to the visual estimation method proposed by Pettijohn (1975). Pettijohn (1975) constructed a grain silhouette comparator illustrating six classes of roundness in combination with two classes of sphericity, modified from Powers (1953). This type of comparative measurement is completely sufficient for many purposes of study (Muller, 1967), and perhaps represent the most widely used method (Carver, 1971). Recently, Al Shibli and Al Saleh (2004) introduced two new indices for particle roundness and sphericity, compared with Powers (1953) classification by using digital microscopy.

Results and Discussions

Gravel, Sand and Mud Ratio

The results show that the grain size distribution is varying from gravel to mud. Variability in grain size is attributed to different transport mechanisms (Holz *et al.,* 2004). These are classified into five categories:

1) 20 samples slightly gravelly sand.
2) 20 samples gravelly sand.
3) 9 samples sand (specify sorting).
4) 2 samples muddy sandy gravel.
5) One sample for muddy sand, slightly gravelly muddy sand and gravelly muddy sand.

Grain Size Distribution (Modal Classes)

Frequency curves were constructed for the studied samples (Fig. 3). The grain size distribution of the different stratigraphic sections are bimodal, a mixture of uni-bimodal and unimodal in decreasing order of abundance (Fig. 2). The bimodality in the Dafin samples may be due to the incomplete mixing of two sizes of materials by natural agencies as fluvial sediment is composed of isolated saltation and suspension components (Donghuai Sun *et al*., 2002), or the continuity of the influx of clastic material in the fluviatile deposits may have been interrupted by intermittent supply from different sources (Pettijohn, 1975).

Grain Size Parameters

Cumulative frequency curves have been constructed for the studied samples and statistical parameters according to Folk and Ward (1957) were calculated (Tables 1 and 2); these include graphic mean size (Mz), inclusive graphic standard deviation (σ_I), inclusive graphic skewness (SK_I,) and graphic kurtosis (K_G) and described according to the verbal limits suggested by Folk (1961).

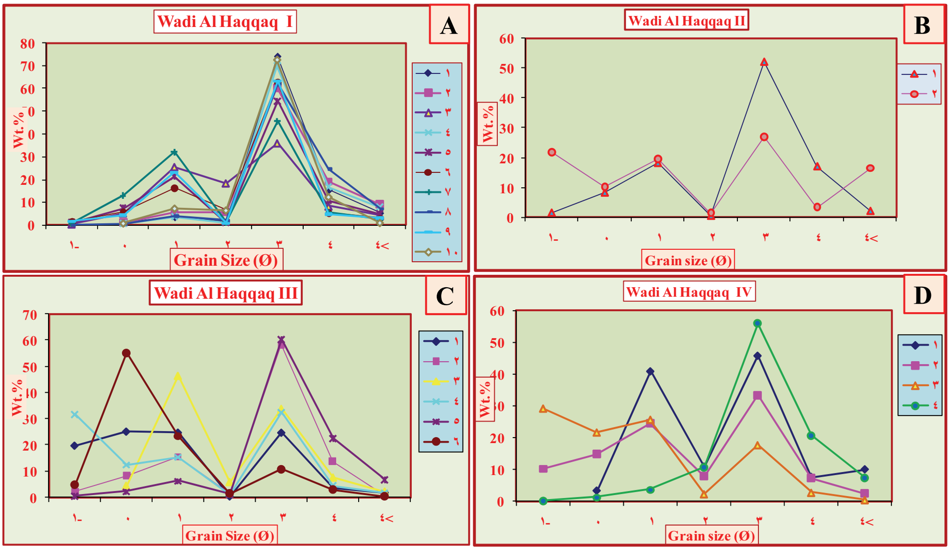

Fig. 3 (A, B, C & D). Frequency curves showing the modal classes of the studied stratigraphic sections in Wadi Al Haqqaq. A) section I, B) section II, C) section III and D) section IV.

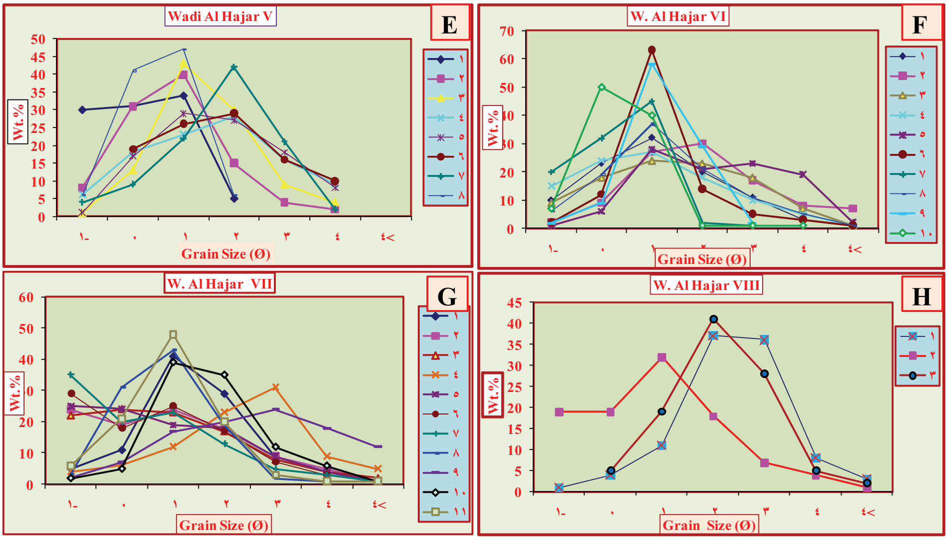

Fig. 3 (E, F, G & H). **Frequency curves showing the modal classes of the studied stratigraphic sections in Wadi Al Hajar: (E) section V, (F) section VI, (G) section VII and (H) section VIII.**

Table 1. Statistical grain size parameters of the analyzed sand samples of the studied Dafin sections.

S.N.	Mz (Mean Size)		σ_I (Std. Dev.)		SK_I (Skewness)		K_G (Kurtosis)	
I-1	2.73	F. S.	0.58	M. W. S.	0.42	S. F. S.	1.80	V. Lept.
I-2	2.86	F. S.	0.91	M. S.	0.22	F. S.	1.54	V. Lept.
I-3	1.86	M. S.	1.25	P. S.	0.063	N. S.	0.91	Meso.
I-4	1.66	M. S.	1.28	P. S.	-0.36	S. C. S.	0.74	Plat.
I-5	2.90	F. S.	0.70	M. W. S.	0.52	S. F. S.	2.04	V. Lept.
I-6	2.00	M. S.	1.23	P. S.	-0.027	F. S.	1.43	Lept.
I-7	2.00	M. S.	1.09	P. S.	-0.44	S. C. S.	1.33	Lept.
I-8	1.86	M. S.	1.05	P. S.	-0.49	S. C. S.	0.81	Plat.
I-9	2.83	F. S.	0.72	M. S.	0.20	F. S.	1.13	Lept.
I-10	2.46	F. S.	0.65	M. W. S.	0.008	N. S.	1.75	V. Lept.
II-1	1.96	M. S.	1.46	P. S.	0.21	F. S.	1.01	Meso.
II-2	1.16	M. S.	2.31	V. P. S.	0.063	F. S.	0.85	Plat.
III-1	0.53	C. S.	1.65	P. S.	0.22	F. S.	0.74	Plat.
III-2	1.90	M. S.	1.26	P. S.	-0.61	S. C. S.	0.88	Plat.
III-3	1.36	M. S.	1.2	P. S.	0.45	S. F. S.	0.77	Plat.
III-4	0.46	C. S.	2.05	V. P. S.	0.04	N. S.	0.69	Plat.
III-5	2.80	F. S.	0.91	M. S.	-0.15	C. S.	1.68	V. Lept.
III-6	0.36	C. S.	1.19	P. S.	0.63	S. F. S.	1.41	Lept.
IV-1	1.70	M. S.	1.07	P. S.	-0.29	C. S.	0.75	Plat.
IV-2	1.06	M. S.	1.58	P. S.	0.03	N. S.	0.92	Meso.
IV-3	0.23	C. S.	1.76	P. S.	0.18	F. S.	1.10	Meso.
IV-4	2.76	F. S.	0.84	M. S.	0.14	F. S.	0.78	Plat.

Table 1. Continue.

S.N.	Mz (Mean Size)		σ_I (Std. Dev.)		SK_I (Skewness)		K_G (Kurtosis)	
V-1	-0.32	V. C. S.	0.77	M. S.	0.09	N. S.	0.752	Plat.
V-2	0.29	C. S.	0.97	M. S.	0.11	F. S.	1.09	Meso.
V-3	0.93	C. S.	0.95	M. S.	0.16	F. S.	1.12	Lept.
V-4	1.17	M. S.	1.18	P. S.	0.09	N. S.	0.85	Plat.
V-5	1.08	M. S.	1.34	P. S.	-0.02	N. S.	0.88	Plat.
V-6	1.22	M. S.	1.17	P. S.	0.12	F. S.	0.79	Plat.
V-7	1.24	M. S.	1.04	P. S.	-0.19	C. S.	1.08	Meso.
V-8	0.03	C. S.	0.63	M. W. S.	-0.04	N. S.	0.99	Meso.
VI-1	0.60	C. S.	1.25	P. S.	0.12	F. S.	0.95	Meso.
VI-2	1.52	M. S.	1.36	P. S.	0.16	F. S.	1.06	Meso.
VI-3	0.97	C. S.	1.41	P. S.	0.03	N. S.	0.85	Plat.
VI-4	0.49	C. S.	1.39	P. S.	0.17	F. S.	0.9	Meso.
VI-5	0.69	C. S.	0.85	M. S.	0.25	F. S.	1.84	V. Lept.
VI-6	1.77	M. S.	1.26	P. S.	0.03	N. S.	0.77	Plat.
VI-7	-0.20	V. C. S.	0.72	M. S.	-0.20	C. S.	0.76	Plat.
VI-8	0.80	C. S.	1.24	P. S.	0.15	F. S.	1.09	Meso.
VI-9	0.72	C. S.	0.64	M. W. S.	-0.03	N. S.	1.16	Lept.
VI-10	-0.11	V. C. S.	0.59	M. W. S.	-0.01	N. S.	0.98	Meso.
VII-1	0.92	C. S.	1.08	P. S.	0.09	N. S.	1.28	Lept.
VII-2	0.37	C. S.	1.43	P. S.	0.18	F. S.	0.78	Plat.
VII-3	0.32	C. S.	1.41	P. S.	0.25	F. S.	0.85	Plat.
VII-4	1.80	M. S.	1.38	P. S.	-0.20	C. S.	1.23	Lept.
VII-5	0.27	C. S.	1.40	P. S.	0.29	F. S.	0.76	Plat.
VII-6	0.20	C. S.	1.32	P. S.	0.20	F. S.	0.78	Plat.
VII-7	-0.01	V. C. S.	1.27	P. S.	0.36	F. S.	0.87	Plat.
VII-8	0.40	C. S.	0.83	M. S.	0.10	F. S.	1.00	Meso.
VII-9	2.13	F. S.	1.51	P. S.	-0.08	N. S.	0.83	Plat.
VII-10	1.22	M. S.	0.99	M. S.	0.19	F. S.	1.18	Lept.
VII-11	0.49	C. S.	0.90	M. S.	-0.02	N. S.	1.11	Meso.
VIII-1	0.35	C. S.	1.34	P. S.	0.11	F. S.	0.93	Meso.
VIII-2	1.91	M. S.	1.00	P. S.	-0.05	N. S.	1.22	Lept.
VIII-3	1.63	M. S.	0.97	M. S.	-0.01	N. S.	1.09	Meso.

The (Mz) values (in Ø units) are variable in the studied stratigraphic sections. The Mz values range from –0.01 (very coarse sand) to 2.9 (fine sand). The sorting values (σ_I) for the analyzed samples range from 0.58 (moderately well sorted) to 2.31 (very poorly sorted). The skewness (SK_I) values are variable in the studied stratigraphic sections. The (SK_I) values range from –0.49 (strongly coarse skewed) to 0.63 (strongly fine skewed). The kurtosis values (K_G) for the analyzed samples range from 0.69 (platy-kurtic) to 2.04 (very lepto-kurtic). The distribution of the grain size parameters; and their minimum, maximum and average values in the studied stratigraphic sections are shown in Table 2.

Table 2. Average, Maximum and Minimum grain size parameters of the siliciclastic samples of the different Dafin sections.

Section No.	M_Z			б$_I$			SK_I			K_G		
	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
I	1.66	2.9	2.316	0.58	1.28	0.943	-0.49	0.52	0.012	0.74	2.04	1.355
II	1.16	1.96	1.56	1.46	2.31	1.885	0.063	0.21	0.136	0.85	1.01	0.93
III	0.36	2.8	1.321	0.91	2.05	1.402	-0.61	0.63	0.075	0.69	1.68	1.067
IV	0.23	2.76	1.456	0.84	1.76	1.308	-0.29	0.18	-0.008	0.75	1.1	0.9
V	-0.32	1.24	0.656	0.63	1.34	1.002	-0.19	0.16	0.029	0.72	1.12	0.936
VI	-0.20	1.77	0.735	0.59	1.41	1.059	-0.2	0.25	0.06	0.76	1.84	1.08
VII	-0.01	2.13	0.786	0.83	1.51	1.22	-0.2	0.36	0.116	0.76	1.28	0.977
VIII	0.35	1.91	1.23	0.97	1.34	1.124	-0.05	0.11	0.022	0.93	1.22	1.078

Bivariate Grain Size Parameters

Grain size analysis is an essential tool for classifying sedimentary environments (Blott and Pye, 2001). The significance of grain size parameters of detrital sediments has been well established by Inman (1952), Folk (1966), and Friedman (1961, 1967).

Many attempts have been carried out to differentiate the sediments from widely varying environments by using the statistical parameters and their relationships. Most of these attempts were based on bivariate plots of grain size parameters (Mason and Folk, 1958; Steward, 1958; Friedman 1961, 1967; Moiola and Weiser, 1968; and Buller and McManus, 1972), linear discriminant functions (Sahu, 1964), shape of size frequency curve (Sindowski, 1957; and Visher, 1969) and triangular diagrams (Asseez, 1972).

In contrast to this, very few attempts (Sevon, 1966; Greenwood, 1969; and Veerayya and Varadachari, 1975) have been made so far by utilizing the statistical method in diagnosing the finer differences that may exist within a particular environment of the same physiographic units as subtidal, intertidal and supratidal environments. Some works have been made in Saudi Arabia (Moshrif, 1980; and Taj, 2003) to evaluate the grain size parameters in distinguishing ancient sedimentary environments. Rea and Hovan (1995) indicated that grain size analyses of the mineral component of abyssal Pacific surface sediments showed distinctly different size distributions that can be associated with sediments that are dominantly aeolian and dominantly hemipelagic, respectively.

The differences in grain size parameters of the sediments generally reflect the transport, erosional and depositional processes that operate in the specific area (Veerayya and Varadachari, 1975). In addition, it may reflect change in energy or water depth in the depositional environments (Amaral and Pryor, 1977). This may explain the grain size variation in the different studied stratigraphic sections.

Most of the bivariate plots are designed to differentiate among beach, fluvial and various aeolian sediments. The applied type of bivariate plots depends on the size parameters suggested by Folk and Ward (1957). In the present work an attempt is devoted to evaluate the boundaries suggested by Stewart (1958), Friedman (1961) and Moiola and Weiser (1968) to recognize the depositional environment of the studied siliciclastic samples of the Dafin Formation (Fig. 4). The studied samples plot (excluding samples of <1Ø Mz values) indicate that using of such bivariate plot diagrams should be used as an additional tool to recognize the depositional environments. According to the different suggested boundaries, only the suggested boundary of Stewart (1958) pointed out that 48% of Dafin sandstones are formed by river processes.

Roundness and Sphericity

As shown in Table 3, the roundness of quartz grains is variable with common angular, subangular and very angular in decreasing order; moreover, few exceptions are present. According to Fuchtbauer and Elord (1971) the roundness is increased with increasing the distance from the parent rocks. Decreasing of roundness values in some samples may be due to the fracturing of sand grains during transport (Moss, 1966). Pettijohn (1975) believed that roundness and sphericity values decrease in the direction where the particles become finer. The percent of sand grains with low sphericity values of the Dafin sandstones are slightly higher than those with high sphericity values. This may be due to the little environmental sensitivity of the shape (Pettijohn *et al.*, 1973).

The distribution of roundness classes and their counterpart sphericity are variable between each section (Table 4). The difference in roundness between the quartz grains of the studied sections may be due to the effect of distance of transport (abrasion of grains), which is mostly short in the Dafin samples recognized as immature sandstones.

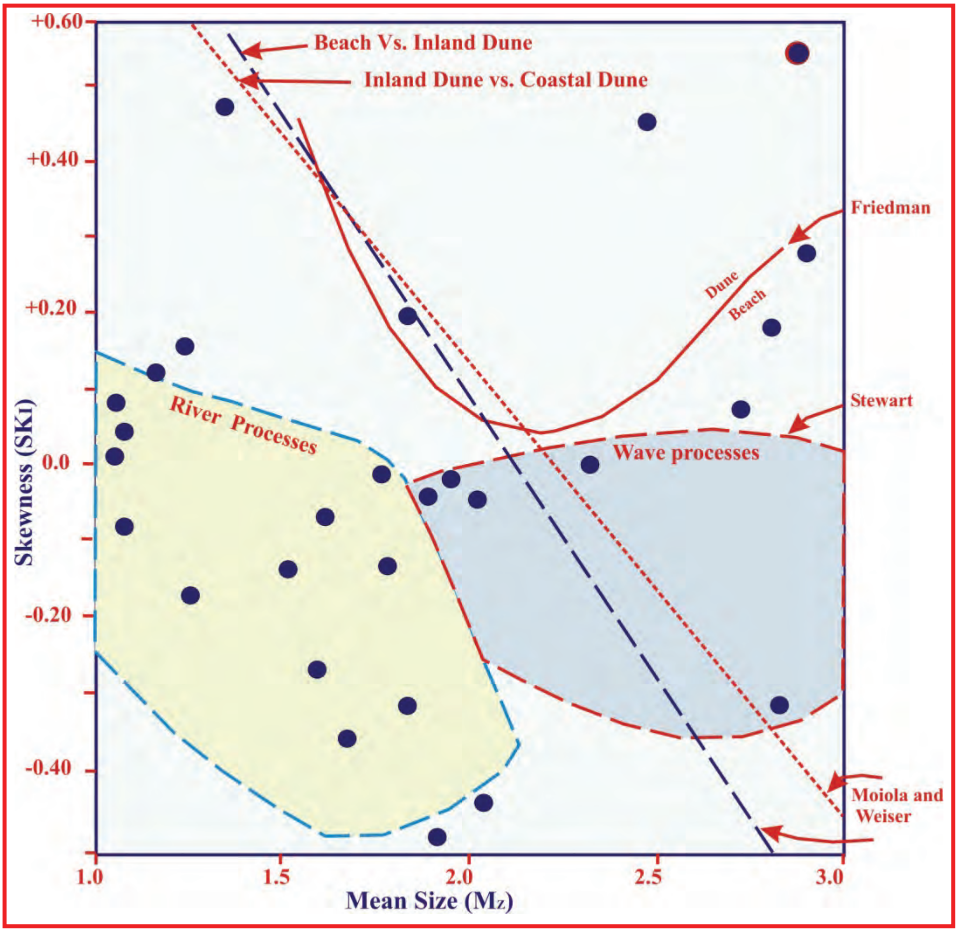

Fig. 4. Bivariate plots of Mz versus SKI, boundaries after Stewart (1958), Friedman (1961) and Moiola and Weiser (1968).

Table 3. Roundness of sand grains and their sphericity in the Dafin sandstones. WR= Well Rounded, R= Rounded, SR= Subrounded, SA= Subangular, A= Angular, VA= Very Angular.

Sample No.	Roundness												Total
	Low Sphericity						High Sphericity						
	WR	R	SR	SA	A	VA	WR	R	SR	SA	A	VA	
I-1	0	0	8	7	32	12	0	0	6	8	30	5	108
I-7	0	0	2	11	44	10	0	0	4	4	32	5	112
I-8	0	0	8	17	27	8	0	1	9	7	28	3	108
II-1	0	0	3	5	46	13	0	0	5	1	32	7	112
II-2	0	0	3	11	38	3	0	0	4	9	28	12	108
III-1	0	1	7	10	41	4	0	2	7	14	16	3	105
III-2	0	0	5	16	34	13	0	0	2	12	26	5	113
III-3	0	0	5	9	50	7	0	0	2	3	21	5	102
III-4	0	0	4	13	50	9	0	1	2	3	20	5	107
III-5	0	0	4	10	23	14	0	0	1	4	32	16	104
III-6	0	0	4	11	36	14	0	0	0	8	20	11	104
IV-1	0	0	5	15	36	16	0	0	1	7	21	11	112
IV-2	0	0	4	14	46	9	0	0	4	6	20	8	111
IV-3	0	0	5	9	47	7	0	1	3	7	21	5	105
V-1	0	0	4	14	49	12	0	0	1	6	21	4	111
V-2	0	0	8	11	27	17	0	1	3	8	23	9	107
V-3	0	0	8	11	43	5	0	0	1	12	25	5	110
V-5	0	0	4	9	29	16	0	0	3	13	25	10	109
VI-3	0	0	4	16	35	9	0	0	2	15	27	9	117
VI-5	0	1	3	15	32	9	0	0	5	13	20	8	106
VII-2	0	1	3	9	48	9	0	0	3	8	17	9	107
VII-9	0	0	6	8	39	8	0	1	4	7	20	8	101
VIII-1	0	1	10	20	25	9	0	6	13	18	27	11	140
VIII-3	0	0	6	14	34	16	0	0	8	7	20	9	114

Table 4. Roundness and sphericity of sand grains of Dafin sandstone in the different studied sections.

Sample No.	Roundness %						Sphericity %	
	WR	R	SR	SA	A	VA	Low	High
I-1	0	0	12.9	13.9	57.4	15.7	54.6	45.3
I-7	0	0	5.2	13.3	67.7	13.3	59.6	39.9
I-8	0	0.9	15.7	22.1	50.9	10.1	55.5	44.2
II-1	0	0	7	5.2	69.5	17.8	59.6	39.9
II-2	0	0	6.4	18.4	61	13.8	50.6	49
III-1	0	2.8	13.2	22.8	54.2	6.6	59.8	39.8
III-2	0	0	6.1	24.7	53	15.9	60	39.7
III-3	0	0	6.8	11.7	69.5	11.7	69.5	30.2
III-4	0	0.9	5.5	14.9	65.3	13	70.9	28.7
III-5	0	0	4.7	13.4	52.8	28.7	48.9	50.7
III-6	0	0	3.8	18.1	53.8	23.9	62.3	37.3
IV-1	0	0	5.2	19.5	50.8	24	64	35.5
IV-2	0	0	7.2	18	59.4	15.3	65.7	34.2
IV-3	0	0.9	7.5	15.1	64.7	11.3	64.5	35
V-1	0	0	4.5	18	63	14.4	71.1	28.8
V-2	0	0.9	10.2	17.6	46.6	24.2	58.6	40.9
V-3	0	0	8.1	20.9	61.7	9	60.7	39
V-5	0	0	6.3	21.1	49.5	23.7	53	46.6
VI-3	0	0	5.1	26.4	52.9	15.2	54.5	45.1
VI-5	0	0.9	7.5	26.3	48.9	15.9	56.3	43.2
VII-2	0	0.9	5.6	15.8	60.6	16.8	65.3	34.4
VII-9	0	0.9	9.8	14.8	58.4	15.8	60.3	39.4
VIII-1	0	4.9	16.4	26.8	37.2	14.2	46.3	53.2
VIII-3	0	0	12.2	18.3	47.3	21.8	61.2	38.4

Conclusion

The mean grain size of the studied siliciclastics of each cycle ranges from sand to gravelly sand to sandy gravel. The sand shows nearly bimodal distribution with subordinate mixture of unimodal and bimodal, and with an overall mean size ranges from very coarse to very fine. It shows a relatively broad spectrum of sorting which ranges from moderately well sorted to very poorly sorted. The skewness of the sand, on the other hand, ranges from strongly coarse skewed to slightly fine skewed and kurtosis ranges from platy to very leptokurtic.

The sphericity and roundness measurements which are generally indicative of textural maturity of sandstone (distance of transport) proved that the Dafin sandstones are texturally immature and composed mainly of low sphericity and angular grains.

The textural characteristics of the Dafin siliciclastic as well as its exposure in the fining upward cyclic fashion indicate deposition in a river system. Also the abundance of coarse fractions in these sediments suggests their deposition as a result of short and rapid transportation *i.e.* near the source area.

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الخواص النسيجية والتفسير البيئي للمنكشف السليكاتي الفتاتي للميوسين الأسفل، متكون دافن، منطقة رابغ، المملكة العربية السعودية

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المستخلص. تشير التحليلات النسيجية لقطاعات طباقية للمنكشفات السليكاتية الفتاتية لوادي الحكاك والهجر بمنطقة رابغ إلى إنها تكونت في بيئة نهرية اعتمادًا على كثرة الدورات الرسوبية والتي تتميز بخاصية تدقق الحبيبات في الإتجاه الأعلى مع وفرة الكونجلوميرات والأحجار الرملية لرواسب القناة النهرية، والأحجار الطينية لرواسب سهل الفيضان.

وقد أظهرت تحليلات النسيج الصخري لعينات مختارة ممثلة لطبقات الحجر الرملي لمتكون دافن السفلي تغيراً في توزيع أحجام الحبيبات من الحصى إلى الطين. وصنفت إلى رمل قليل الحصى، رمل حصوي، رمل (متميز الفرز)، حصى رملي طيني، وقليل من رمل طيني، رمل حصوي طيني، ورمل قليل الحصى طيني.

وأظهر الرمل انتشارًا يغلب عليه أن يكون ثنائي النمط وبعضًا لخليط لرتب من أحادي وثنائي النمط مع متوسط حجمي من عالي الخشونة إلى الناعم. وأظهر عامل الفرز تنوعًا نسبيًا لمدى فرز من جيد متوسط إلى فرز رديء جدًا. ومن ناحية أخرى أظهر معامل

التماثل للرمل مدى من انحراف عالي الخشونة إلى منخفض النعومة، ومعامل تفلطح متغير لمدى هضابي إلى قائم عالي التفلطح. وتعتبر أحجار رمل دافن غير ناضجة نسيجيًا نتيجة لدرجة التكور المنخفضة، أما درجة الاستدارة للحبيبات فهى من المزواة جدًا إلى تحت مزواة والتي تعتبر أقل انتشارًا. وقد أكدت نتائج الدراسة لمعاملات النسيج الصخري أنها تدعم دورات تدفق الحبيبات إلى الأعلى ونمط التوزيع الثنائي الغالب لأحجار الرمل التي تعكس ظروف الترسيب النهرية.