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Sedimentological Features of the Bathan Formation (Miocene?) North of Sharm Ubhur, Jeddah Region, Saudi Arabia

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ABSTRACT. Two vertical sections were made in the Tertiary coastal hills near Jeddah. Their lithology was studied and sediment samples were taken concurrently for grain size and mineralogical analyses. Their depositional environments, paleogeography and source rocks, deduced from their sedimentological, mineralogical and petrological characteristics are discussed herein.

The sequences represent alluvial terraces and fan deposits typical of debris flows. They are comprised of poorly sorted, subrounded to rounded pebbles and cobbles embedded in a coarse-grained sand and clay matrix with generally inclined planar bedding. They were probably laid down in a braided-stream environment and may represent alluvial deposits of a proto-Wadi Fatima. The alluvial recorded is characterized by drainage lines generally active enough to cut the basement rocks as indicated by high epidote content. These hills document the uplift of a Red Sea Escarpment considerably after deposition of the Jizan group.

Repeated cyclic variation with a dominant regressive phase and a period of non-deposition interrupted by volcanism probably indicates a post Oligocene drainage system.

Along the eastern Red Sea coastal plain, near Sharm Ubhur, north Jeddah area, a bedded sequence consists of bedded siltstone with mottled shale at the base, grading upward to conglomeratic sandstone with basalt as a cap rock. This sequence forms small topographically low exposures known as Bathan Formation.

An attempt has been herein to identify the sedimentological and mineralogical

characteristics of the Bathan Formation that crop out on the coastal plain as low hills with nearly 20 m of relief near Sharm Ubhur, Jeddah region (Fig. 1). The relationship between Red Sea tectonics and sedimentary rock exposures of the coastal area are discussed herein.

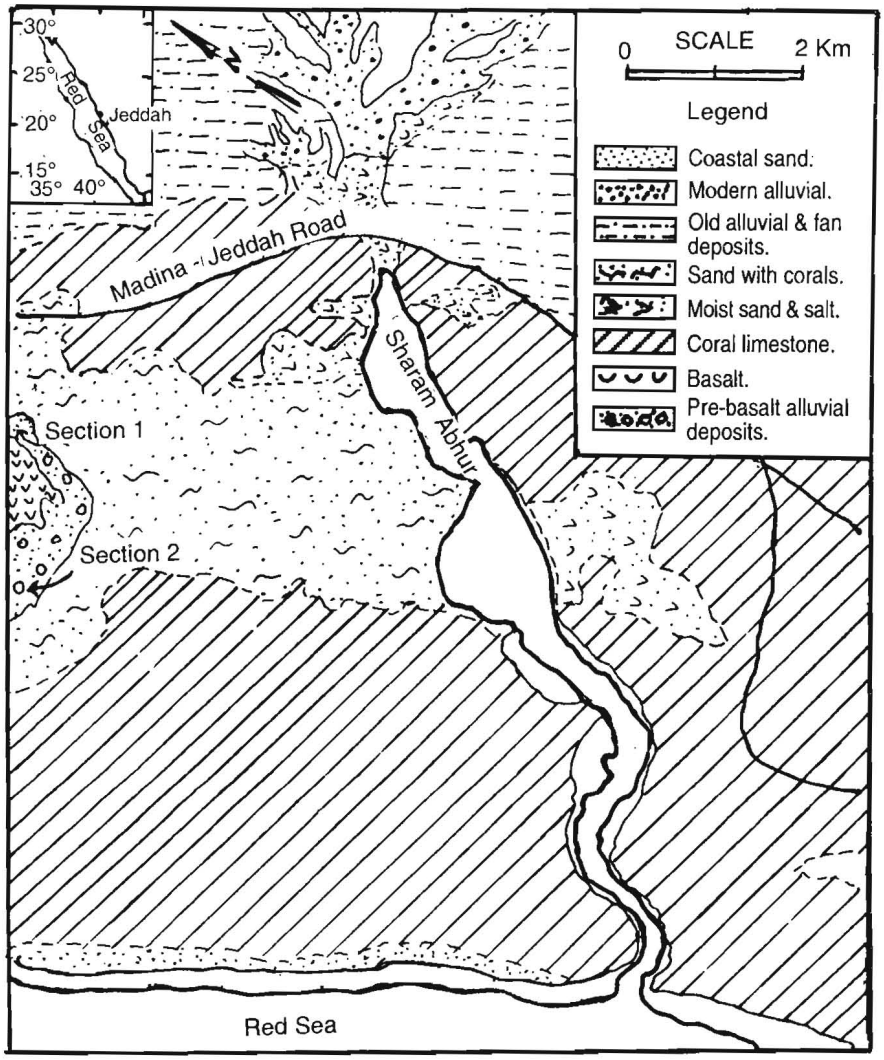

Fig. 1. Geology of the study area and location of the measured sections.

Little information is to be gained from the published papers dealing with the Tertiary rock exposures of the coastal plain of the Jeddah area. Karpoff (1957) visited the area briefly and published two descriptions of the Cenozoic. Al Shanti (1966) studied the oolitic iron ore deposits in and around Wadi Fatima. Moltzer and Binda (1981) dealing with the palynology of the Shumaysi Formation. Spencer (1982) distinguished four groups of rocks that characterize the Jeddah region, these include from the oldest; the Precambrian crystalline basement, the Tertiary sequence, the alkali-olivine Harrat basalt and finally a surficial cover of Quaternary age, consisting predominantly of sands and gravels along the coast coral reefs, raised reefs and sabkhat deposits. Recently, Abou Auf and Gheith (1995) carried out field, sedimentological and paleontological investigations on the clastic Shumaysi Formation exposed east of Jeddah region and suggested that the Shumaysi Formation preserves an early rifting history while the late Oligocene - early Miocene sedimentary rocks are the earliest record of Red Sea rifting.

Geological setting:

Thick deposits of titled conglomeratic sandstones covered with basaltic blocks northeast of Jeddah were assigned to the Bathan Formation by Schmidt *et al.* (1982). Sharief (1971) considered the thick layers of very coarse-grained clastic sediments northeast of Jeddah as a Neogene. They were derived from the surrounding Precambrian basement. The Fatima Formation north of Wadi Fatima (30 km east of Jeddah) consists mainly of Precambrian rocks separated unconformably from the underlying Pre-Fatima basement which is composed of metamorphic and volcanic rocks intruded by plutonic rocks (Fig. 2). More detailed information can be found in the works of Karpof (1957a, b), Brown and Jackson (1960) and Nebert *et al.* (1972). Near the coast these deposits are covered by reefal limestone. The age of the Bathan Formation is between 15 and 12 ma according to Schmidt and Hadley (1984) and is overlain by the Harrat basalt of the Hammar Formation of Late Miocene age (Schmidt *et al.* 1982). A strong oxidation of the upper layer can be seen and must be due to the intense heat of the basalt that flowed over it.

The Bathan Formation records the first erosion of a high-relief Precambrian terrain to the east of the continental rift. Spencer (1987) dealing with the Tertiary rocks in the Jeddah region, assumed that the Bathan Formation consists of alluvial cones against the rising escarpment and is composed of boulder conglomerates. It is probably of Middle to late Miocene age, corresponding to the rejuvenated second stage scarp uplift of Schmidt *et al.* (1982). The geologic history of the Bathan Formation is summarized in Table (1). However, no detailed study of these sediments has yet been made. The outcrops of clastic sediments indicate that the basement rocks are broken into tilted blocks: horsts and grabens.

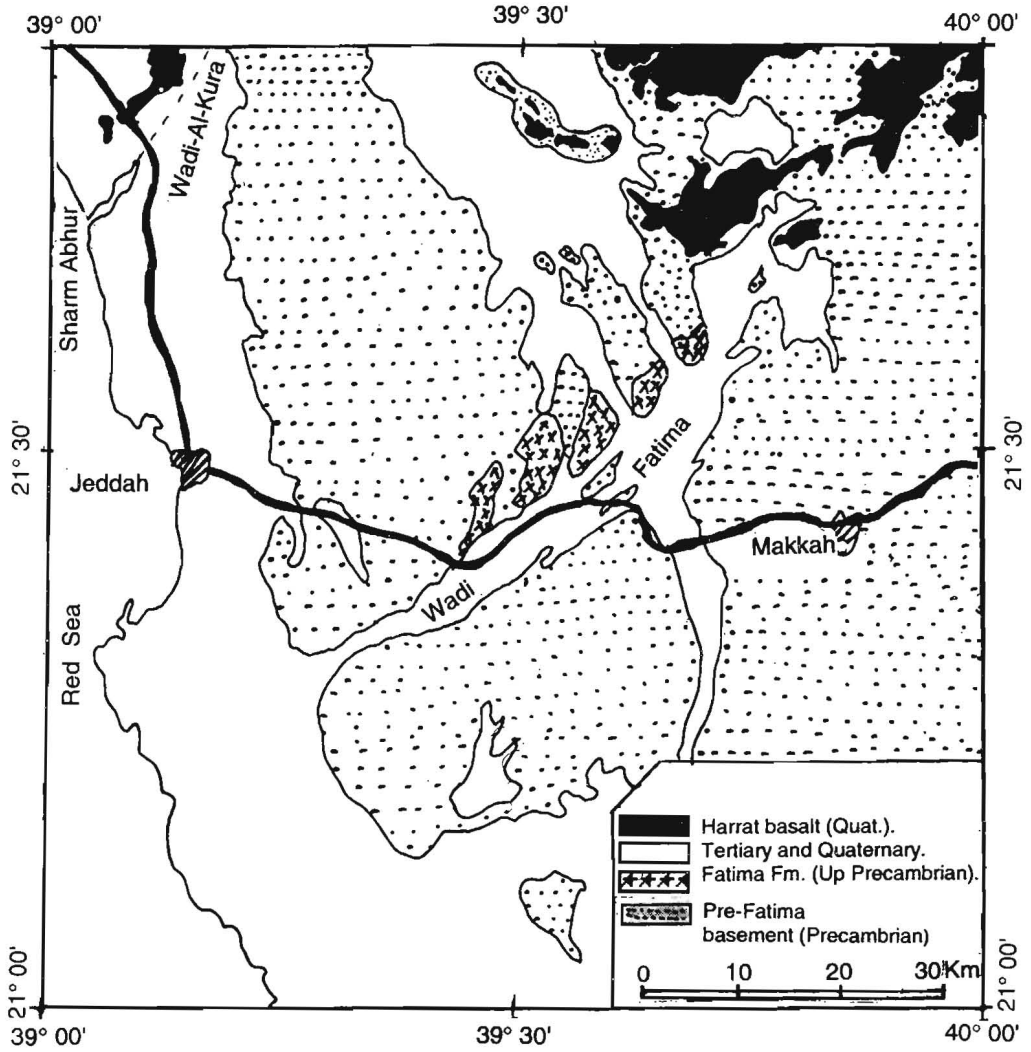

Fig. 2. Geology of the surrounding area of Jeddah.

Table 1. Summary of the Geologic History

Units	Age	Structural Events	Process and Environment
Quaternary deposits Rahat Group	Late Miocene	Isostatic uplift	
Bathan Formation	Middle to Late Miocene	Faulting and tilting	Rapid erosion and deposition by fluvial process
Ubhur Formation	Early Miocene	Extension and fracturing 1st stage opening of Red Sea	Sedimentation and evaporation
Suqar Group	Eocene to Paleocene	Red Sea rift system initiated	Deposition in a newly developed intercontinental trough. Minor marine incursions and emergence
Fatima Group	~ 688 Ma	Folding	

The predominant structure underlying this area is that of a step - faulted rifted edge down thrown toward the west (Skipwith 1973). The Bathan Formation lies unconformably over the Khylays Formation and is thought to have formed as alluvial cones against the rising escarpment (Spencer 1987).

Aim and Method of Study:

Two vertical sections in two of the small topographic hills along the coastal area of Jeddah near Sharm Ubhur were examined. Field work involved description of the sections and sedimentary structures and collecting rock samples. Fourteen samples were chosen and subjected to grain size analysis and petrographic and mineralogic investigations.

All samples were first analysed for carbonate, gravel, sand and mud content. (Füchtbauer and Müller 1970). Grain size analysis was carried out by dry sieving (Folk 1968). The graphic grain size parameters of Folk and Ward (1957) were statistically calculated and interpreted.

Mineralogical investigation was carried out by separating the heavy mineral grains from the light ones (0.125 - 0.063 mm size fraction) using tetrabromoethane

(sp.gr. 2.85). Identification was made with the polarizing microscope. The sedimentological features and field data were used in interpretation paleogeography and provenance.

Results and Discussion

Lithostratigraphy:

The two sections of the Bathan Formation (Fig. 3) consist of thick layers of very coarse-grained clastic sediments alternating with thin layers of poorly bedded, fine-grained calcareous or argillaceous sand and shale. They are mostly conglomeratic, strongly indurated and moderately tilted. The conglomerates vary from boulders, cobbles, pebbles to small granules embedded in a greenish yellow fine-grained matrix. The gravels appear subrounded to rounded and of different composition being mostly igneous and metamorphic composition. The sandstone of variable grain size and whitish, yellowish or greenish in colour. Primary structures observed were massive and graded bedding, flaser and ripple bedding and scour and fill structures.

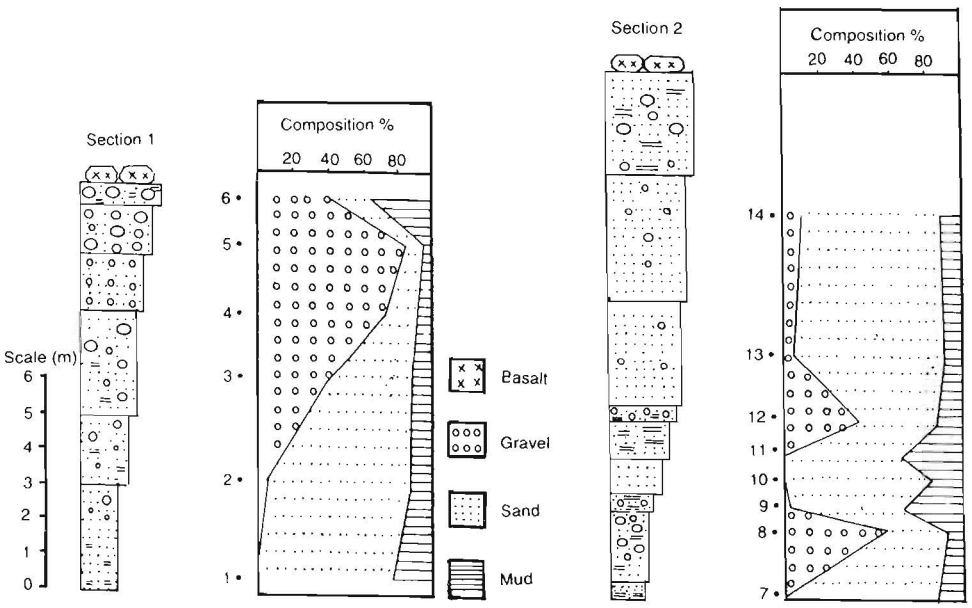

Fig. 3. Stratigraphic variation of gravel, sand and mud contents of the studied two sections.

Gravel, sand and mud proportions (Fig. 4) indicated that the samples have four main compositional classes:

i) Slightly gravelly muddy sand.
ii) Gravelly muddy sand.
iii) Muddy sandy gravel.
iv) Muddy gravel.

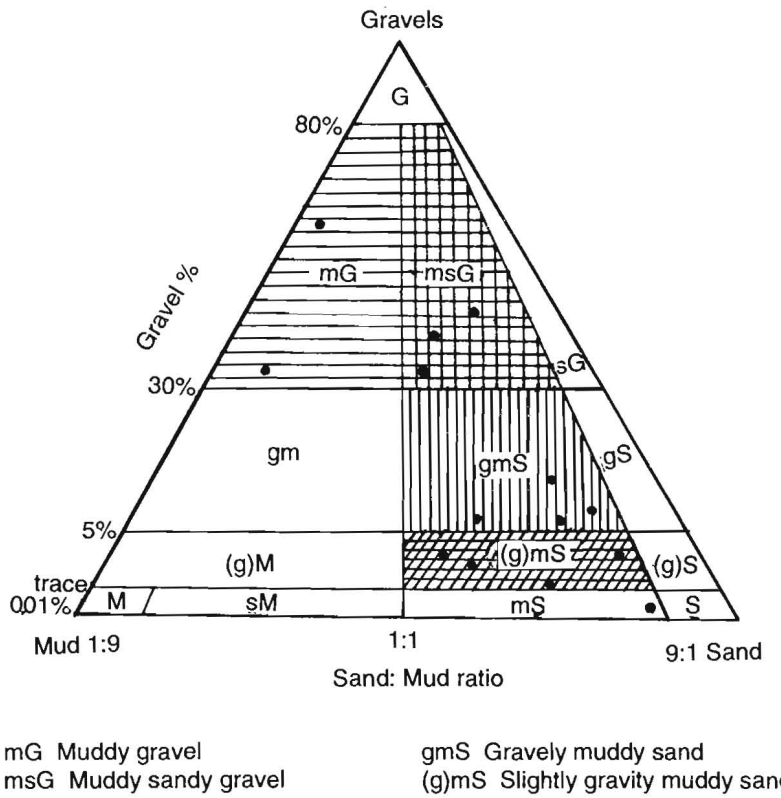

Fig. 4. Gravel - sand - mud triangular diagram (after Folk 1968) for the studied sediments.

The gravel content seems to increase upward while sand decreases (Fig. 3). Section 1 shows mainly a coarsening upward sequence. The high percentage of gravel suggests a high current velocity at time of deposition. Mud content shows no specific trend. However, in section 2, gravel shows no systematic variation with depth (Fig. 3). Mud content is appreciable only in the lower part of section 2. Carbonate, sand and mud content data are represented graphically in the traingular

diagram (Fig. 5). It was shows that most of the samples are composed of muddy sand and sand. A few samples from section 1 are composed of calcareous sands.

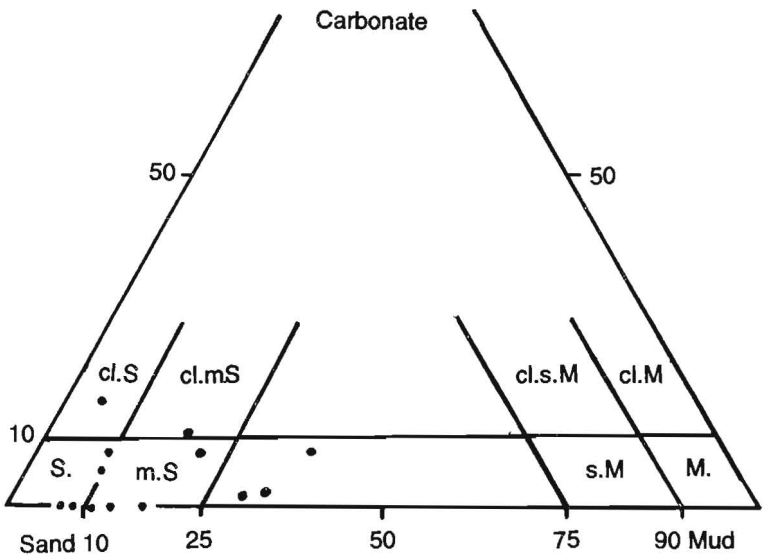

Fig. 5. Carbonat - sand - mud triangular diagram (after Füchtbauer and Müller 1970) for the studied sediments.

Distribution and significance of grain size parameters:

Fourteen sand samples were texturally analyzed after disaggregation and removal of the carbonate and mud components. The data obtained are represented graphically as cumulative grain size distribution curves shown in Fig. (6). Graphic textural parameters of Folk and Ward (1957) for grain size distributions; mean size (Mz), standard deviation (σ_I), skewness (SK_I) and kurtosis (K_G), have been calculated and interpreted (Table 2).

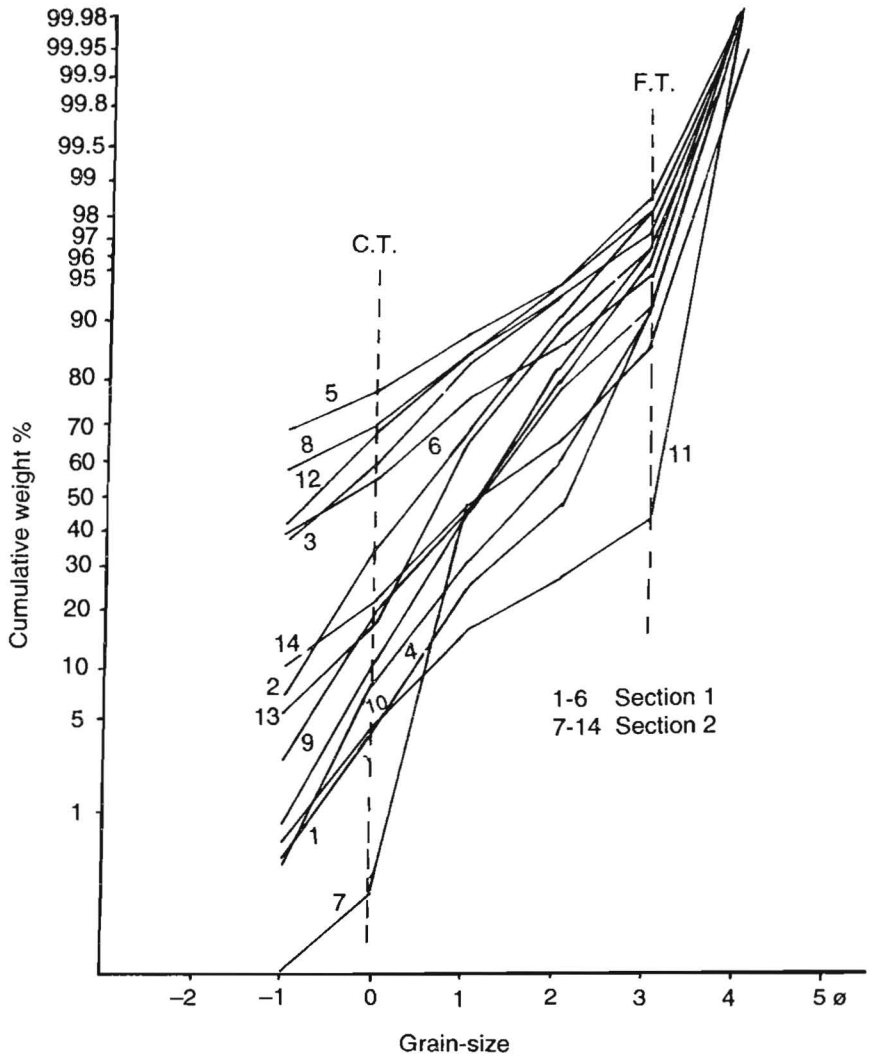

Fig. 6. Constructed cumulative curves for the studied sandstone samples.

Table 2. Results of Statistical Grain - Size Parameters of Folk and Ward (1957)

S. No.	Mz	Description	σ_I	Description	SK_I	Description	K_G	Description
Section 1								
1	1.84	Medium Sand	0.97	Moderately Sorted	0.31	Fine Skewed	2.52	Platykurtic
2	0.52	Coarse Sand	1.07	Poorly Sorted	0.10	Near - Symmetrical	0.96	Mesokurtic
3	–0.15	Very Coarse Sand	1.07	Poorly Sorted	0.40	Strongly Fine Skewed	0.90	Mesokurtic
4	1.18	Medium Sand	0.95	Moderately Sorted	0.04	Near - Symmetrical	1.03	Mesokurtic
5	–0.61	Very Coarse Sand	1.07	Poorly Sorted	0.78	Strongly Fine Skewed	1.60	Very Leptokurtic
6	0.12	Coarse Sand	1.42	Poorly Sorted	0.43	Strongly Fine Skewed	0.86	Platykurtic
Section 2								
7	1.69	Medium Sand	0.99	Moderately Sorted	0.22	Fine Skewed	0.71	Platykurtic
8	–0.55	Very Coarse Sand	0.96	Moderately Sorted	0.74	Strongly Fine Skewed	0.86	Platykurtic
9	1.18	Medium Sand	1.20	Poorly Sorted	0.00	Near - Symmetrical	0.96	Mesokurtic
10	1.64	Medium Sand	1.07	Poorly Sorted	–0.14	Coarse Skewed	0.85	Platykurtic
11	2.48	Fine Sand	1.06	Poorly Sorted	–0.76	Very Coarse Skewed	1.07	Mesokurtic
12	–0.37	Very Coarse Sand	1.11	Poorly Sorted	0.56	Strongly Fine Skewed	1.07	Mesokurtic
13	0.79	Coarse Sand	1.03	Poorly Sorted	0.12	Fine Skewed	1.36	Leptokurtic
14	0.99	Coarse Sand	1.29	Poorly Sorted	–0.18	Coarse Skewed	1.01	Platykurtic

The cumulative curves (Fig. 6) generally have three populations, which are interpreted in terms of Visher's (1969) scheme. The traction and saltation subpopulations range widely in size and are very poorly sorted. The saltation load constitutes the major part of the samples, while the suspension population is very limited and mostly well sorted. In general the cumulative curves favour a fluvial environment of deposition (according to Visher 1969). Furthermore, the wide variation in curve shape probably reflects strong and variable transporting currents. Significance of the grain size parameters is summarized as follows:

1. Mean grain size data are mainly distributed in a cyclic pattern especially in Section 1. However, the Mz values are oscillatory and generally show a coarsening upward sequence. The oscillation is between very coarse and medium - grained sands.
2. The values of the inclusive graphic standard deviation range between 0.95 ϕ and 1.42 ϕ which according to Folk and Ward (1957), places these sediments in the categories of moderately sorted to poorly sorted sands. Mostly they are poorly sorted.
3. The inclusive graphic skewness varies widely from strongly fine skewed, near symmetrical to very coarse skewed.
4. The graphic kurtosis varies between platykurtic and mesokurtic.

Paleoenvironmental interpretation:

An attempt has been made to interpret the conditions of sedimentation and mechanism of transport using the C-M method of Passega (1957, 1964).

Most samples have values of C greater than 1000 μm which plot in Class I, indicating that the sediments were transported by rolling (Fig. 7). The hydraulics of transport and deposition are greatly different for the individual beds within a sequence of fan deposits. This result in a sequence of beds that vary greatly in particle size, sorting and thickness (Bull 1972). In general, the C - M pattern constructed displays a rectilinear type that is roughly parallel with the limit C = M and is typical of debris flows (Bull 1962). Debris-flow deposits are poorly sorted and show graded bedding.

Alluvial fan deposits are associated with braided river deposits of mountainous regions. The main condition for the formation of alluvial fans is a sudden change in slope, leading to deposition and intermittent stream action which may be result of heavy seasonal rainstorms in an arid climate according to Reineck and Singh (1975). Sediments of alluvial fans are deposited in a tectonically active area and preserved as marginal facies of the basin of deposition.

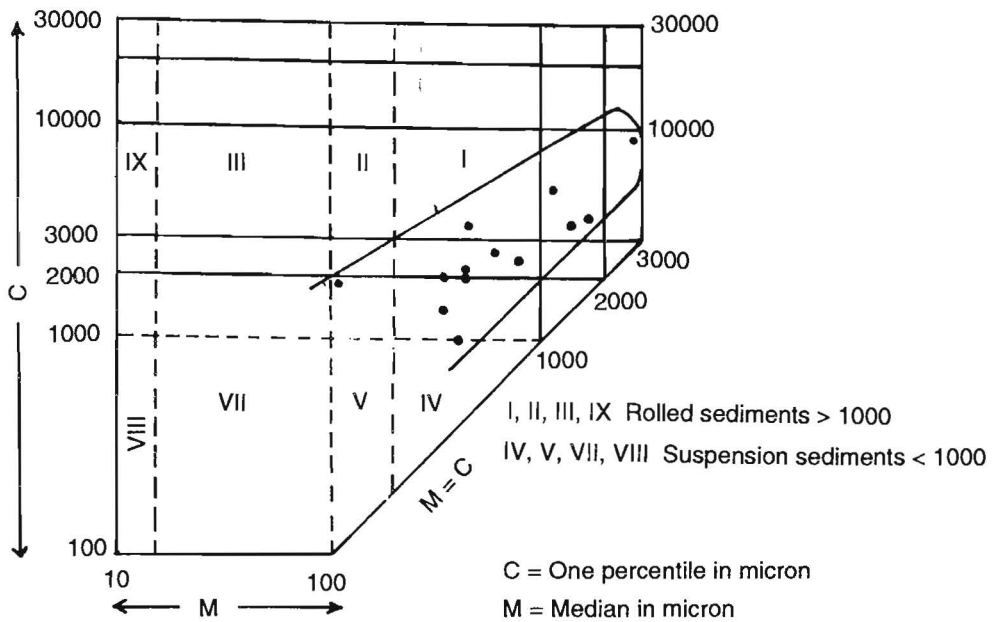

Fig. 7. Constructed C-M Pattern (after Passega 1964) for the studied sandstone samples.

Petrography and diagenesis:

Microscopic examination of four samples from the exposures revealed that the sandstones are essentially composed of quartz grains and many rock fragments. Besides these components, feldspar, collophane, heavy minerals and clay minerals are present.

The quartz grains are of different size fractions vary in size from gravel, very coarse, medium to fine-grained. They are single or composite grains, subangular to subrounded. Generally these deposits are poorly sorted and texturally immature.

Microscopic examination of thin sections showed that the pore spaces between the quartz grains are partially filled with clay minerals and carbonates. The quartz grains have corroded margins due to diagenesis.

The feldspar present is mainly plagioclase of labradorite composition based on thickness of the lamellar twinning. In addition, microcline grains with cross- hatched

twinning are also present. The presence of feldspar in considerable amounts indicates a relatively short distance of transportation from a region of high relief and tectonically active neighbouring the basin of deposition.

Rock fragments are common including trachyte, basalt and rhyolite and some gabbro with porphyritic texture. The metamorphic rock fragments present are mainly slate and phyllite. All the fragments are embedded in kaolinite matrix.

As a conclusion, the abundant volcanic rock fragments indicate a constant supply from exposed igneous rock sources close to the basin of deposition. The metamorphic rocks exposed to erosion had been subjected to varying grade of metamorphism. Thus the recorded chlorite slate and phyllite rock fragments indicate low - grade metamorphic source rocks. However, the presence of kyanite among the heavy mineral components even in small quantities indicates that very high - grade metamorphic rocks were also supplied detritus to the basin of deposition and erosion must be deep to release kyanite.

Mineralogy of the heavy fractions:

Heavy minerals have been found to be exceptionally useful in determining the nature of the rocks from which the sediments were derived. The relative frequencies of the different minerals were calculated and the average percentages of the heavy mineral components are given below in Table (3). It was found that the heavy minerals are present in very small amounts. The most common non-opaque heavy

Table 3. Average relative frequency percentages of heavy minerals

	Section 1	Section 2
Opaque	27	35.8
Augite	41.7	35.6
Hornblende	1.8	0.9
Epidote	30.4	25.2
Zircon	7.2	20.5
Tourmaline	–	0.4
Rutile	3	6.2
Garnet	6.8	8.1
Kyanite	4.8	1.3
Staurolite	1.3	0.5
Biotite	1.8	–
Sphene	1.2	0.2

minerals identified are augite and epidote. They comprise over 70% of the total present. In addition zircon, garnet, rutile and kyanite are also observed in moderate amounts. The samples of section 2 are enriched in zircon, rutile and tourmaline.

Augite and epidote are the most abundant minerals in almost all the studied samples. The maximum average content of augite is about 42% recorded in section 1 (Fig. 8). While amphiboles occur only in traces and are represented mainly by brownish green hornblende. Zircon was recovered in all examined samples with maximum average content being 20% in section 2.

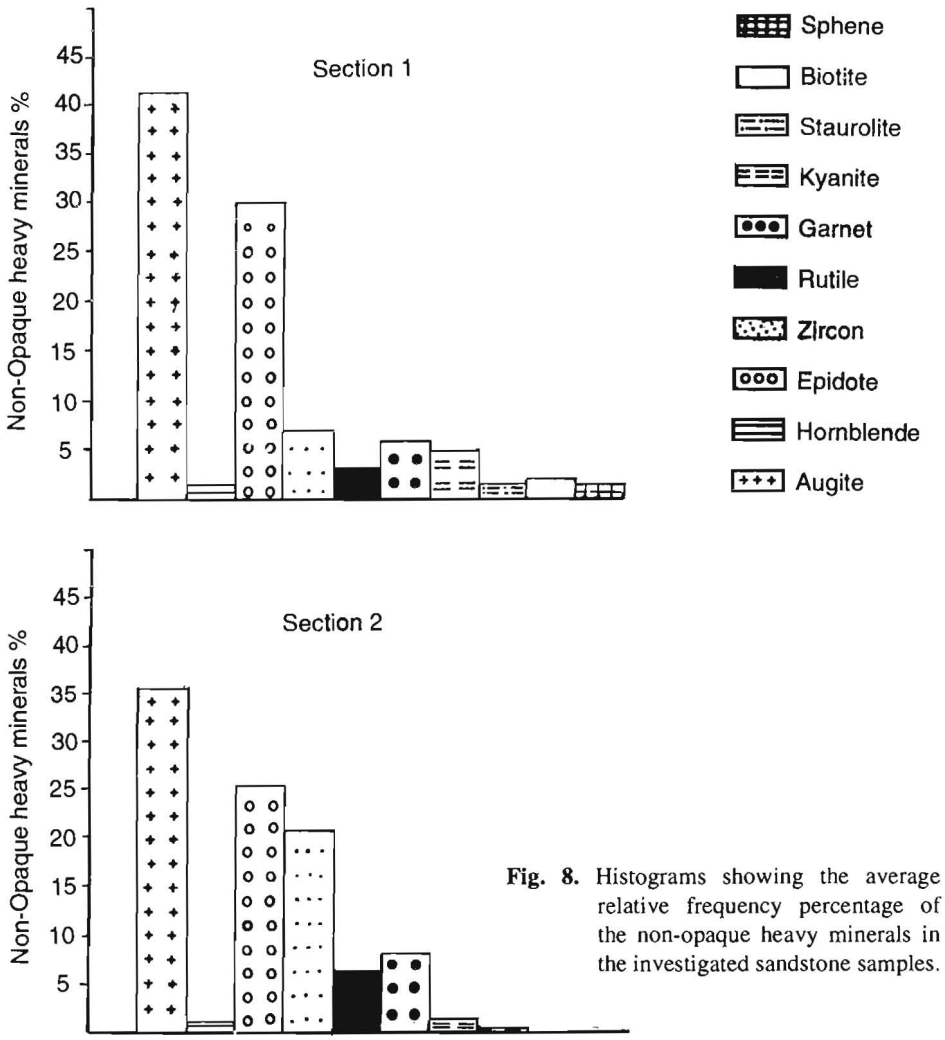

Fig. 8. Histograms showing the average relative frequency percentage of the non-opaque heavy minerals in the investigated sandstone samples.

Garnet and kyanite are also present in moderate amounts in all the studied samples with maximum average contents of 8.1% and 4.8% respectively.

The heavy mineral suite of the sediments seems to be derived from parent material of common origin. Most of these minerals are from the Arabian Shield with the ultimate source being common crystalline basic to intermediate volcanic igneous rocks and metamorphic rocks. The Jeddah Group occurs further inland and it is regionally metamorphosed to the green schist facies (Jackaman 1972). The higher content of epidote recorded is probably related to the weathering of plagioclase feldspar, the drainage channels were sufficiently active to erode the basement rocks. Therefore the Bathan Formation is thought to have been formed as alluvial cones along fairly rapidly developing faults.

Conclusion

The studied sequences of the Bathan Formation represent a local outcrop of clastic rocks, generally poorly sorted, coarse-grained gravels composed of rounded pebbles and cobbles in a coarse-grained sand matrix and local pockets of silt and clay and fine-grained sand. They are largely unconformably overlain by basaltic rocks. However they are covered by Quaternary reef carbonates along the seaward edge of the coastal plain and were uplifted during the second stage of uplift associated with Red Sea rifting. They have been moderately tilted and dip toward the Red Sea escarpment. This tilting records the intial uplift of the Red Sea escarpment.

Most samples analyzed varied texturally between gravelly muddy sand, muddy sandy gravel and muddy gravel. The gravel content seems to increase upwards forming a coarsening upward sequence and graded bedding structure. The amount of gravel reflects the high current velocity of a braided stream. Paleoenvironmental conditions as indicated by cumulative grain size distribution curves and the C - M diagram involved strong transporting currents capable of moving sediments by rolling (*i.e.* as bed load).

The petrographic investigation indicates derivation from a tectonically active area of volcanic and metamorphic source rocks. These source rocks were subjected to later alluvial processes with active drainage channels which cut into the basement rocks during the post Oligocene period. It may represent alluvial deposits of proto-Wadi Fatima. Deposition may have continued until interrupted by the volcanism or there may have been a period of non deposition prior to the influx of the lava.

The heavy mineral investigation indicated the presence of two associations; a less stable one generally dominant and composed mainly of augite and epidote and more stable association consisting of zircon, rutile and tourmaline. These mineral assemblages indicate erosion of different source rocks with common crystalline basic to intermediate igneous rocks and high grade metamorphic source rocks. They were derived from the surrounding Precambrian basement rocks of Jeddah series. It records the first erosion of high relief Precambrian terrain to the east of the continental rift.

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الظواهر الرسوبية لمتكون بطحان شمال شرم أبحر بمنطقة جدة ، المملكة العربية السعودية

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ص .ب (١٥٤٠) - جدة ١٢٤٤١ - المملكة العربية السعودية

قام الباحثان بقياس قطاعين رأسيين للتتابعات الفتاتية المكونة لبعض التلال الصغيرة التي تمثل تكوين بطحان والمنتشرة شمال شرم أبحر بمنطقة جده على الساحل الشرقي للبحر الأحمر .

وقد تم استنباط أصل هذه التتابعات الصخرية والتعرف على الظروف الجغرافية القديمة من الصفات الرسوبية والمميزات المعدنية والبتروجرافية .

وقد لاحظ الباحثان تغير متكرر في دورة الترسيب معظمها تشير إلى طور متراجع لفترة عدم ترسيب طويلة وتجويه شديدة للصخور الأم أدت إلى حفر أودية عميقة لصخور المصدر معظمها يشير إلى فترة ما بعد الأليجوسين كما حدثت ظواهر بركانية .

هذه الطبقات الفتاتية المكونة للتلال الصغيرة تمثل بيئة ترسيب مختلفة معظمها من الرواسب المروحية والشرفات النهرية . وهذه الرواسب تمثل تجمعات حطامية مجروفة من الوديان العميقة لصخور المصدر . وتتكون هذه الرواسب من الحصى والظلط المستدير وتحت المستدير متجمعة في وسط رملي خشن مع أرضية طينية . وتتبادل مع طبقات رملية متوسطة الحجم إلى ناعمة

تتخللها طبقات رفيعة من الحجر الطيني ذو لون بني إلى رمادي أسفل التتابع . كما لاحظ الباحثان أن معظم هذه التتابعات ومستويات تطبقها ذات ميل ناحية الشرق ومغطاه من أعلى بكتل ضخمة من البازلت .

ولقد أستنتج الباحثان أن هذه التتابعات تمثل طور نهري يتميز بمجاري تصريف عميقة تدل على تجويه شديده لصخور القاعدة المنتشره شرق المنطقة مما نتج عنه زياده كبيره في معدن الأبيدوت .

وتسجل هذه التلال الصغيرة عمليات الرفع لجروف البحر الأحمر التي حدثت بعد ترسيب متكون جيزان .