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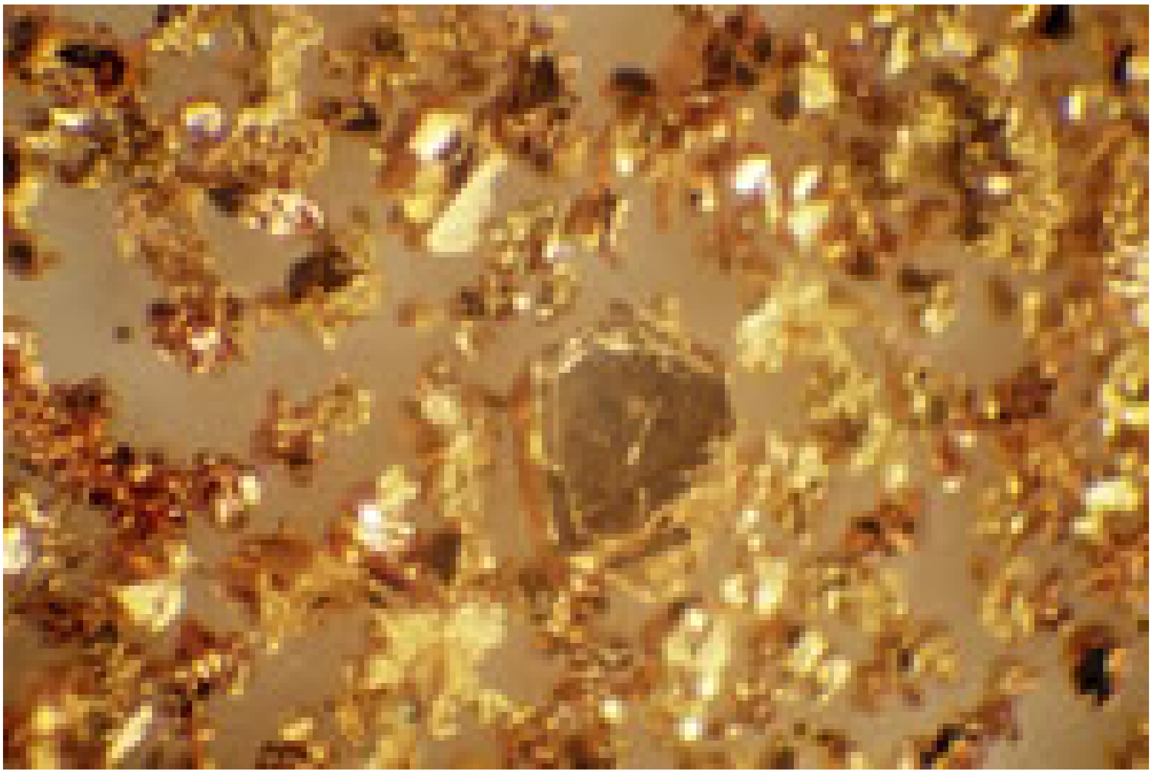

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Abstract:

Well-exposed, fine-grained to pebbly coarse-grained fluvial sandstone of Late Miocene to Pliocene age crop out in the Eastern Province (Hofuf and Haradh) of Saudi Arabia.. These sandstones belong to the Hofuf Formation, and were deposited largely in stream channels along Wadi As-Sahba over a distance of 450 kms. The graben structure of Wadi As-Sahba reflects a strike-slip motion that took place in the Plio-Quaternary. The evolution of the Hofuf formation is related to the tectonic evolution of the East Arabian Block in the Neogene's time. These sediments are immature as indicated by poor sorting and other mechanical parameters. They are derived from Precambrian basement and Phanerozoic rocks, which are mostly represented by granitic rocks in addition to lesser amounts of volcanics, metamorphic and sedimentary rocks. The sandstones comprise three distinct facies: clast-supported gravel and conglomerate, coarse-grained sandstone, and fine-grained sandstone. Sandstone compositions show a uniform framework composition dominated by monocrystalline quartz and feldspar with less abundant polycrystalline quartz, calcite, micas and igneous, metamorphic and sedimentary rock fragments. Quartz was derived mostly from plutonic source rocks. The heavy-mineral assemblage is characterized by abundant unstable minerals , particularly hornblende and pyroxene. The pebbles are granitic, metamorphic and sedimentary rocks derived from the Arabian platform. Modal compositions of the sandstones indicate a transional provenance that ranges from continental to a craton interior and recycled orogen.

The Lower gravely unit of the Hofuf Formation in the Eastern Province is ~20 m thick and consists of at least 8 sedimentary cycles. Each cycle is composed of sandy gravel and conglomerate followed by coarse-grained-, and fine-grained arkosic sandstone. The gravels and conglomerates are rich in pebbles of various igneous and metamorphic rocks (granite, basalts, gneiss, schist, quartzite and amphibolites) derived from the gold-bearing Arabian shield as well as limestone, dolomite and marl derived from the Phanerozoic. Sixty representative samples were collected and sieved. The stream sediments of Al-Hofuf and Haradh areas, Eastern Province of Saudi Arabia, were studied for their content of gold A geochemical signature of gold (placer) deposits was detected in the lower unit of the Hofuf Formation. Total sample from the Haradh fan were analyzed for gold. In the type section area, total samples as well as three fractions (400-250 Φ, 250-125 Φ, and <125 Φ) of each sample were selected for gold analysis. The results show that the very fine-grained fraction (<125 Φ) of the samples from the two upper cycles (TS-17 to TS-23, and TS-28 to TS-30) of the sand unit in the type-section area contains the highest amounts of gold (0.16-1.87 ppm). The coarse- and medium-grained fractions contain low amounts of gold (<0.1 ppm). Samples representing the lower cycles (TS-1 to TS-16) in the type section area contain only few amounts of gold (<0.1 ppm). Gold contents are highest in the first two upper cycles (TS-17 to TS-23, and TS-28 to TS-30) and decreases downward (TS-16 to TS-1).

Samples from Haradh area were collected from the surface the sample WS-a long a horizontal traverse. The samples represent only the uppermost cycle. The gold dispersion anomaly at the Haradh area, which occurs along the Wadi As Sahba, is of a high extent in three samples, representing three locations; The sample WS-19 contains the highest amount of gold (24.22 ppm), whereas the samples WS-1 and WS-3 contains 12.58 ppm and 4.83 ppm respectively. The rest of the samples contain only low amount of gold

(<0.1 ppm). Samples representing the calcarenite and argillaceous sandstones from the second and third unit of the Hofuf Formation were collected from Jabal Qarah area. None of these samples contain gold. On mineralogical basis, the present work suggests that Al-Hofuf and the Haradh stream sediments represent a promising target for further geochemical exploration for precious metals, especially gold. Fire assay data indicate that placer gold in the studied sediments sometimes reaches 24 *g/t*. Background concentration of gold and variation in lithology suggest multiple source of the metal.

The primary gold source of the Hofuf Formation is probably related to weathering of paleo-placers, and/or to weathering and transport of gold-bearing igneous rocks from the Arabian Shield. Placer gold is concentrated in the fine fraction (< 125 um).

It is recommended that exploration of gold in arid region must be directed essentially to the fine sized fraction.

1-Introduction:

Transported (allochthonous) sediments of economic interest are usually referred to by geologist as placer deposits . Fluvial process (River transport) is effective in liberating and transporting gold as well as many heavy minerals and may concentrate them to economic grade (e.g., Bussey et al., 1993; Seeley and Senden, 1994; Tingly and Caster, 1999; Hsu et al., 1995). The mechanisms of Au dispersion in sediments are primarily controlled by environmental and paleo-environmental factors such as relief, weathering, erosion processes and the nature of the Au source (e.g., Butt, 1992; He'rail et al., 1999; Colin et al., 1993; Bowell et al., 1993; Fletcher and Loh, 1996). The Precambrian rocks of Saudi Arabia are highly dissected by dry valleys that are filled by a wide variety of stream sediments (Fig. 1) . The Arabic term "Wadi" is always dedicated to dry streams and hence the expression

"Wadi deposits" is sometimes used instead of "stream sediments". In this study, the mechanism of gold dispersion in arid environments is studied in order to characterize their placer gold and associated heavy minerals. Regardless the type of environment, the mechanism of gold dispersion is controlled by environmental and pale environmental factors in addition to nature of source rocks from which gold is derived. Very little information on placer gold of arid environment is known, but some useful contributions were made by Bogoch et al. (1993) and Herail et al. (1999) who studied the effect of geomorphological factors on the concentration of gold in placers. The present study sheds more light on the effect of source rocks on the dispersion of gold in the arid environments in terms of grain size, background values and source multiplication. Understanding of the behavior of gold dispersion in arid regions has its emphasis on the style of geochemical exploration because such regions are characterized by low-geochemical activity and dominancy of mechanical weathering.

The Hofuf Formation has been generally dealt within a few geological studies of Eastern Province Peninsula, which are mostly concerned with its regional geologic setting (e.g., Covelier, 1970; Blondeau and Covelier, 1973; Standring and Sugden, 1978; Al-Sulaimi 1994; 1995).

The present study aims at elucidating the geologic history, depositional environments and provenance of the Hofuf Formation in Eastern Province (Fig. 2),in light of the geotectonic evolution of the Arabian

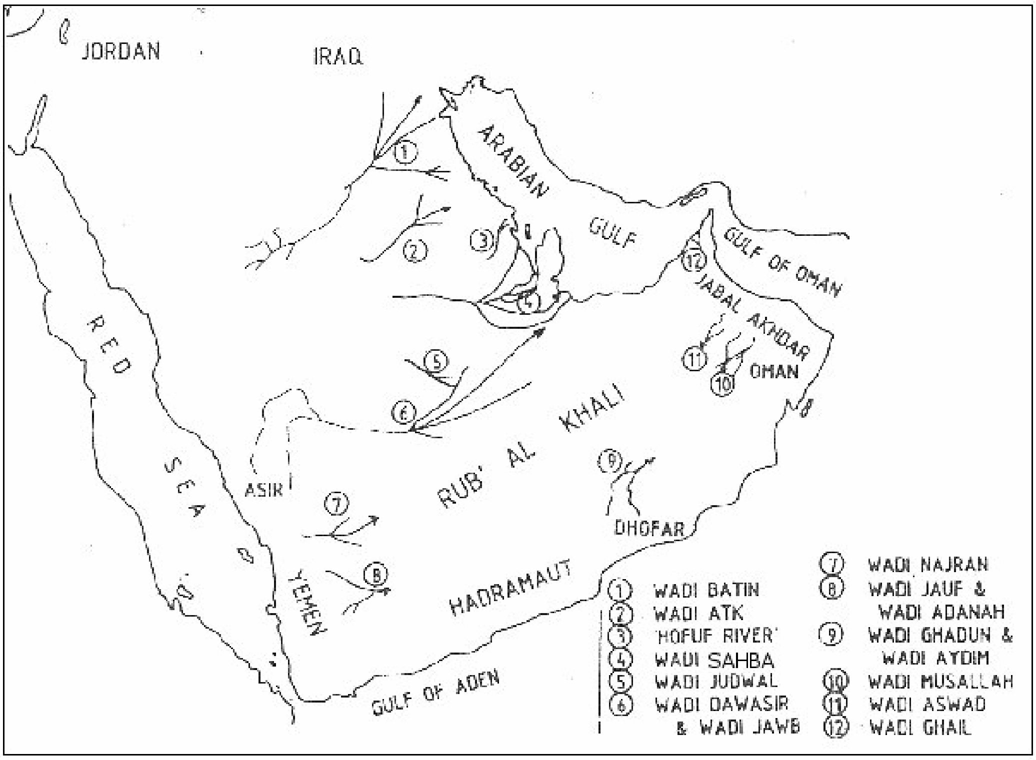

Fig.-1: Major wadies in Saudi Arabia (After Chapman 1978).

Plate and to study the possibility of gold dispersion in the alluvial sands and gravels of the gravel unit in the lower part of the Hofuf Formation, the Eastern Province of Saudi Arabia. One of the aims of the article is the correlation between composition of the stream sediments and their Precambrian source rocks in the hinterland.

Careful survey of relevant literature indicates that nothing has been published on the economics of stream deposits in Saudi Arabia except for construction materials.

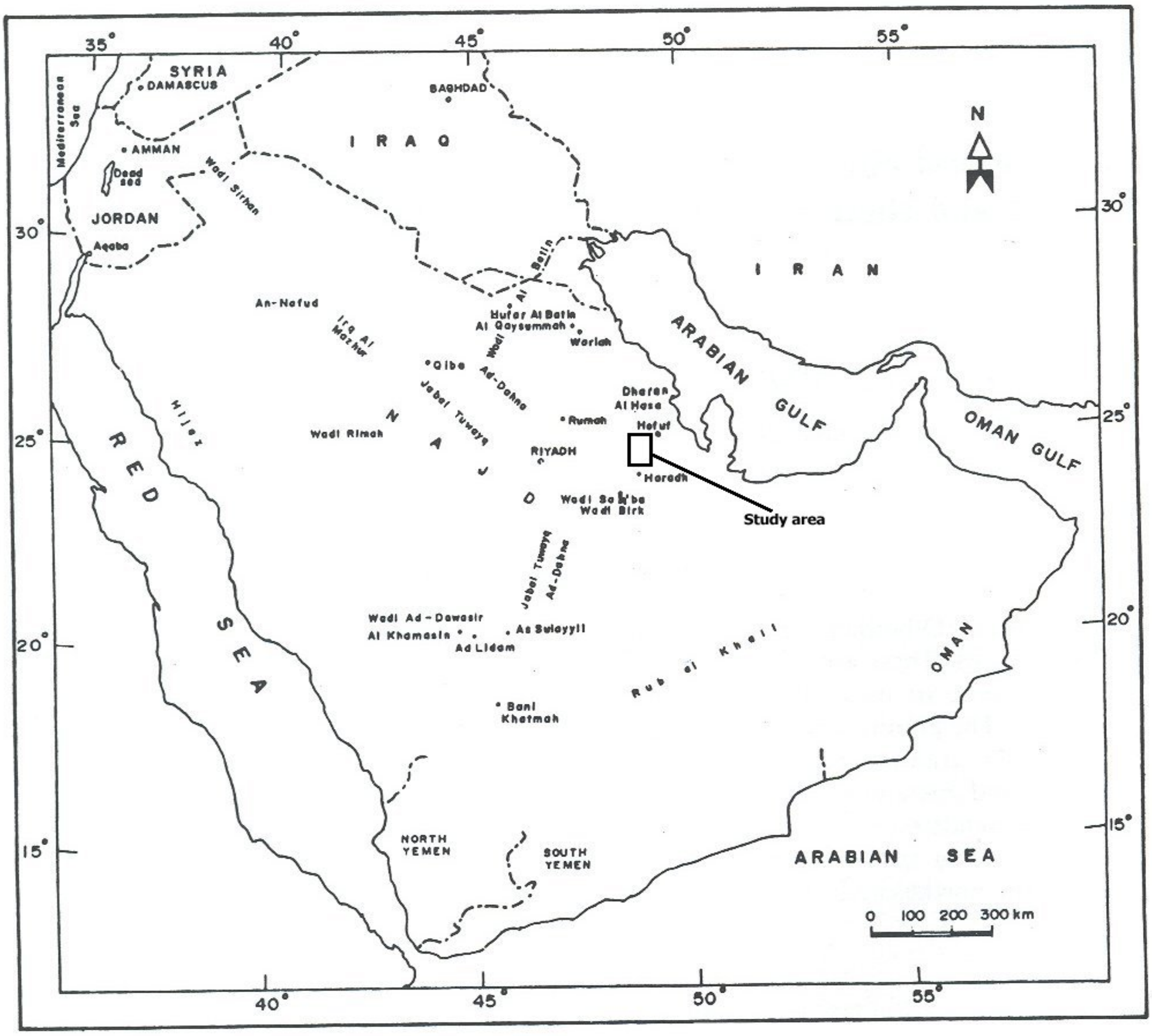

Fig.- 2: Location map of the Study area.

2- Gold in Saudi Arabia:

On the other hand, gold in Pre-Cambrian rocks has been known in the Saudi Arabia since the old times.

The Precambrian rocks of Saudi Arabia make up the Arabian Shield, which consists of belts of contrasting lithology, metamorphic grades and structural history (Jackson and Ramsay, 1980;Vail, 1985). Extensive gold mining from the Arabian Shield is known as much as 3000 years old. Primary gold mineralization has been found only in the Proterozoic Arabian Shield and can be placed in four groups: in coarse-grained igneous intrusions; associated with dikes; in faults and fractures (veins and stock works) in volcano-sedimentary rocks; and in polymetallic stratiform deposits in volcano-sedimentary successions. Secondary gold mineralization is represented by gold enrichment in the oxidized zone developed on sulfide mineralization and by placer accumulations. In half or the examples of primary mineralization reviewed, gold occurs in fractured alteration zones in igneous intrusions of mainly granitic to dioritic composition. Although near surface samples commonly grade 2-12 g/t Au, the volume is rarely substantial and grades decrease below the zone of oxidization generally to under 1 g/t. Exceptionally, better resources are found where the intrusions are cut by shear zones, as for instance at Sukhaybarat mine (6.4 Mt at 2.6 g/t Au) (Collenette and Grainger, 1994).

The gold is hosted in rocks of the Late Proterozoic rocks (basalt, rhyolite, diorite and granite with intensive quartz-veining and base-metal deposits). Gold mineralizations in the Arabian Shield are related to the volcanic activity in island arcs, epithermal mineralizations and porphyry stocks as well as remobilization of the mesothermal gold due to arc accretion and tectonics.

There are more than 700 vein-gold occurrences reported in the Arabian Shield (Sabir, 1991; Agar, R.A., 1992), thirty one of them contain mor than 1000 Kg., ninty nine contain between 100-1000Kg, and the remaining occurrences contain a reserve of less than 100 Kg.(Al-Shanti,1996)(Fig. 3) .

Epithermal gold deposits are associated with volcanic rocks that form the upper part of sub-volcanic potassic intrusives in a subduction-related arc setting (e.g., Al Amar and Mahd adh Dhahab). Mesothermal gold viens are related to either shear zones or to secondary extensional flat dipping thrusts (e.g., the Sukhaybarat, Zalim, Ad Duwayah, Bulgah, Ash Shakhtaliyah, Ghadarah and Hamdah). Pyrite, arsenopyrite, and sericite or chlorite and carbonate alteration are common. Gold is usually invisible and present as very fine, discrete particles (Albino et al., 1995). Country rocks in the gold districts of the Arabian Shield are composed of volcanics, volcanoclastics and epiclastic rocks of intermediate to felsic composition (Worl,et.al., 1986).

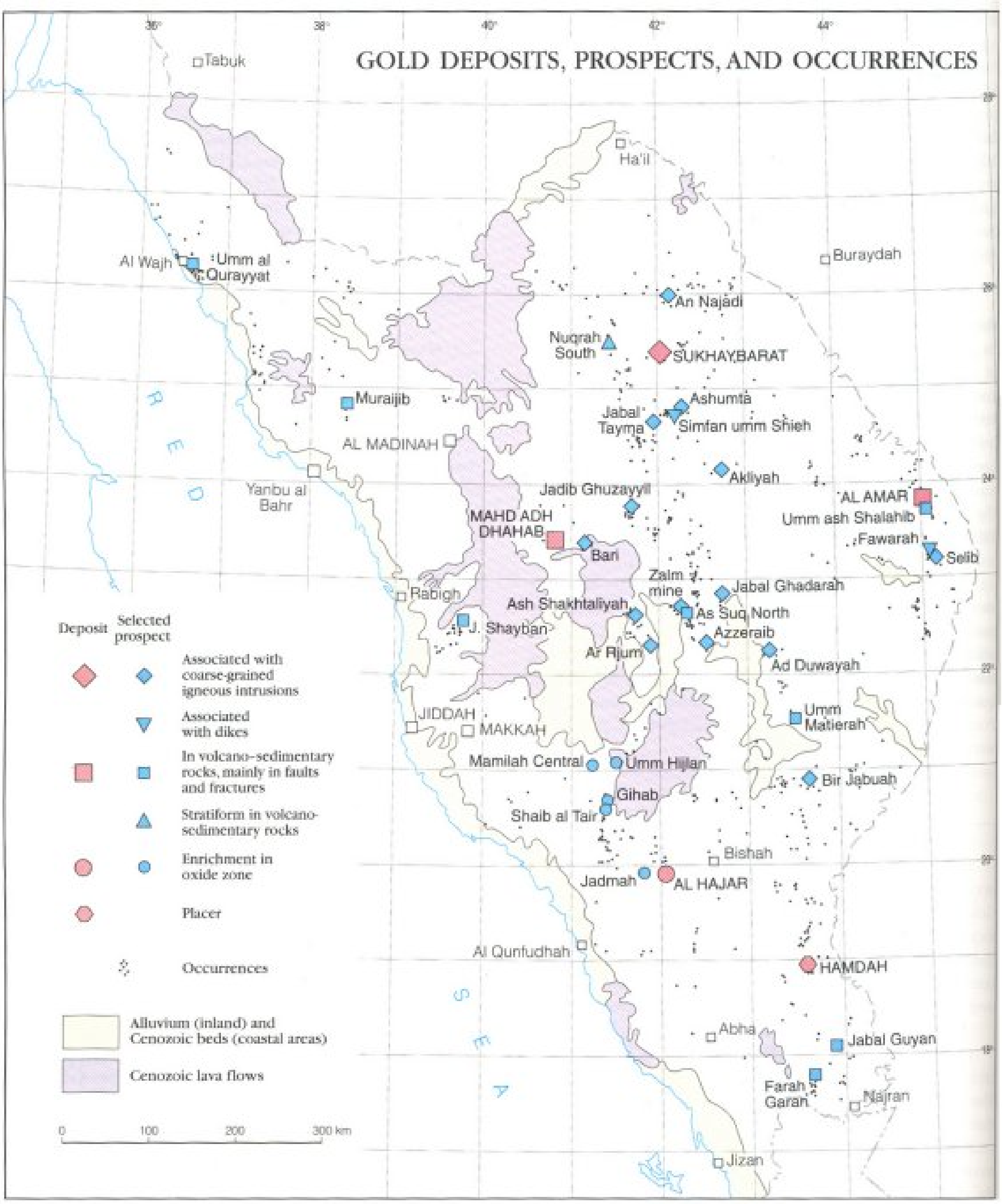

Fig.-3: Gold locations in Saudi Arabia (After Collenette and Grainger, 1994).

In several prospects, gold mineralization is associated with sills or dikes, generally of felsic composition (Huckerby et.al.,1982), but nowhere does it reach commercially minable proportions. At Hamdah the grade is an attractive 18,8 g/t Au but the resource is only 0.06 Mt, and its impotence is as a source of placer gold. The prime example of mineralization in veins and stock works in volcano-sedimentary rocks is the Mahd adh Dhahab deposit, where gold occurs with base metals; reserves are 1.142 Mt grading 31.8 g/t Au. At Al Amar, the North Vein Zone contains 1.077 Mt at 33.1 g/t. However, most occurrences in this group average 3-5 g/t Au near surface in generally narrow structures, decreasing to less than 1 g/t below the zone of oxidization.

Half (15 out of: 30) of the primary deposits and prospects are hosted by coarse-grained igneous intrusions of mainly granitic to dioritic composition. Gold generally occurs in fractures in zones of alteration, commonly 1-5 m wide, with pyrite, arsenopyrite, and in some cases minor amounts of base - metal sulfides; gold values may be as high as 90 g/t Au in surface samples but arc commonly in the range 2-12 g/t Au. Gold grades decrease below the zone of oxidization, generally to less than 1 g/t.

Where the igneous bodies have been cut by shear zones, as at Sukhaybarat, gold mineralization is more widespread and of higher grade, with average values of 25 g/t Au to 130 m depth and 5.2 g/t Au to 90 m depth respectively.

Three of the deposits and prospects are associated with sills or dikes, generally of felsic composition. The best-explored example is at Hamdah, where gold, magnetite, pyrrhotite, pyrite, arsenopyrite. Chalcopyrite, sphalerite, and galena are sparsely disseminated in quartz-carbonate vein lets and in alterated rocks along the margins of aplite sills and to a minor degree in the sills themselves.

Quartz veins and stock works in volcano-sedimentary rocks provide a common environment for gold occurrences in the Arabian Shield. At Mahd adh Dhahab, the richest deposit in the Shield, stock works and vertical vein systems average over 30 g/t Au with low but recoverable amounts of copper, zinc, and silver Gold enrichment in the oxidized zone over sulfide mineralization is known at several localities. Sulfide bodies, exposed by erosion during Tertiary times, were leached of some elements including copper and zinc, resulting in relative enrichment of gold. Several of these gold concentrations have been investigated but are generally too small to be mined commercially except perhaps as part of an integrated operation.

At Al-Hajah, however, the oxide zone is more extensive, and ore bodies in two adjacent hills contain reserves of 1.54 Mt with 3.45 *glt* Au to 45 m and 2.69 Mt with 2.6 *glt* Au to30 m is higher. The ancient miners recovered gold from several placer deposits, although no specific inventory has been made of these.

3- Regional Geology and Tectonics:

Doming of the Arabian-African Shield began in Late Cretaceous-Eocene time and was associated with a crack along the crest of this elongated dome. The Arabian Peninsula has two main geological components. In addition to the 610,000 km2 of the Precambrian Arabian Shield to the west, there is the sequence of overlying continental and shallow-marine sedimentary rocks of the Arabian Platform to the east. This sedimentary sequence consists mainly of sandstones and limestone's, which outcrop in a great curved belt along the eastern margin of the shield, with the less resistant strata eroded into a series of lowland strips.

The general slope of the area was from West to East. This cause eastward rolling of eroded gold-bearing basement rocks. Drainage from the uplifted

Arabian Shield broke through the Mesozoic escarpments of the Interior Homocline to deposit vast amounts of quartzes Clastic sediments, which now form the Miocene Hadrukh and Mio-Pliocene Hofuf Formations (Power et al., 1966). Stream erosion was active at this pluvial time, and sediment transportation was from west to east. The upstream sediments were deposited in a deltaic environment at Al-Hofuf and at Wadi As-Sahba (Haradh fan) (Fig. 4). And along Wadi Al Batin (Figs. 5-6). Wadi As-Sahba alluvial fan, which extends southeastward from Majma'ah through Riyadh, Al-Kharj to cover large parts of the Haradh, Hofuf and southern Qatar, represents the largest of several other non-active fans in central and south Arabia. Evidence put forward suggests that, like other comparable deposits of varying age in the Arabian Peninsula, the Wadi As-Sahba fan was deposited following down dip breaching of a scarp barrier by a large paleo river further to the west which once flowed southeastward down the full width of the Arabian Peninsula. It is the postulated existence of this huge former drainage system, which is seen as the fundamental explanation for the occurrence of the Hofuf Formation in Saudi Arabia and comparable gravels elsewhere on the eastern flank of the Arabian Peninsula (e.g., Kuwait and Qatar).

The Late Miocene to Pliocene gravel deposits in Saudi Arabia belong to the Lower Hofuf Formation. The depositional body of this lower gravel unit shows that it represents part of a large former outwash fan. This fan is the largest of several alluvial fans occurring on the periphery of the Arabian Shield. The fan apex is to the northwest of Al-Kharj and the gravels spread southeastward to Haradh, Hofuf and southern Qatar. Wadi As-Sahba is the main fluvial channel responsible for the deposition of Hofuf alluvial fan. It extends from Qatar to its origin 450 km northwestward where it is referred to as Wadi Nisah (Figs. 7, 8).

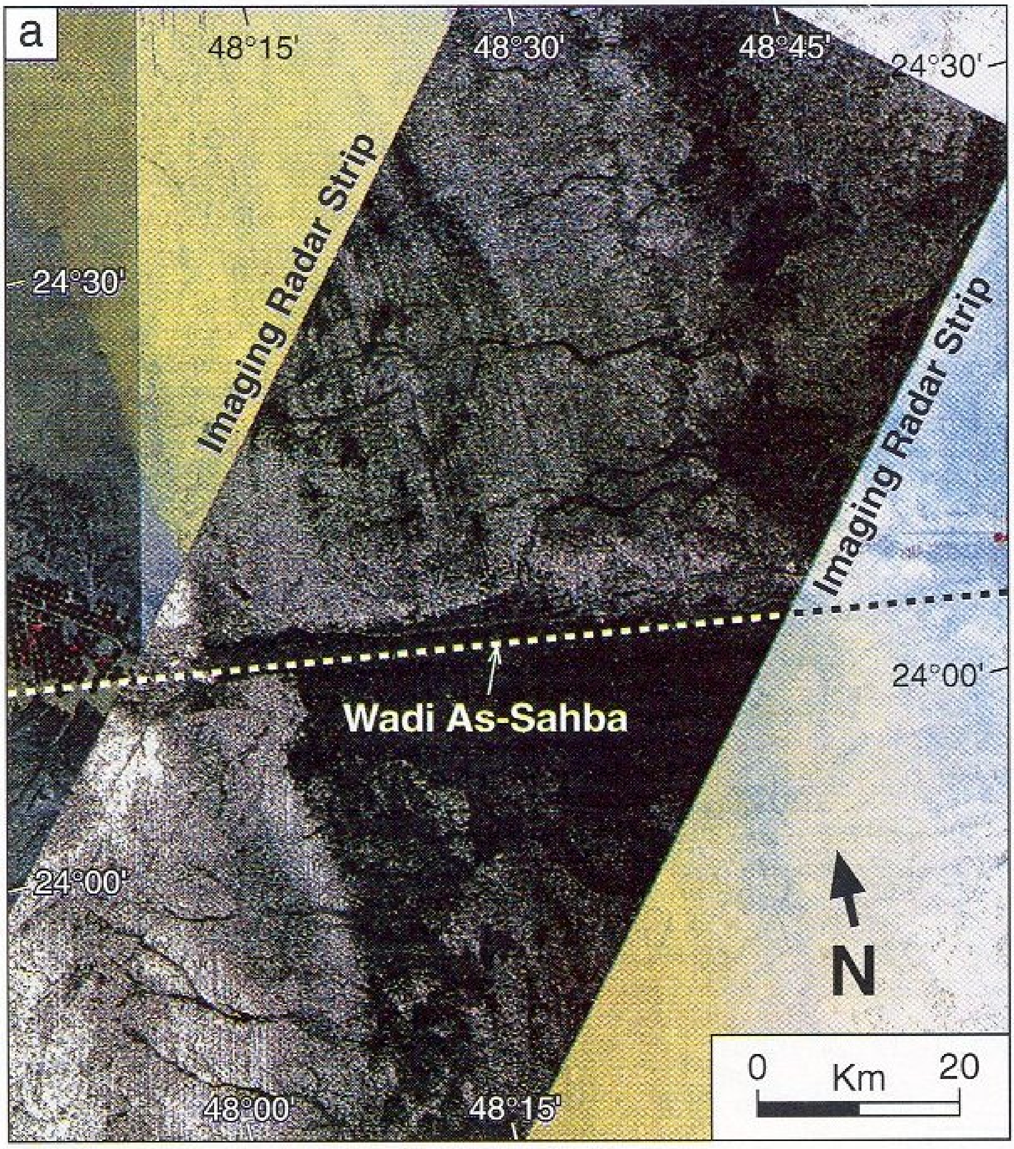

Fig.- 4: Radar sat image showing Wadi As-Sahba (Weijermars, 1998).

In the early Tertiary, tensional stresses were set up which began to rift apart the Nubian and Arabian Shields. The initial breakup was a mid Tertiary event, some 40-36 Ma BP, in the latest Eocene or earliest Oligocene (Bayer, 1984). Intensive block faulting and a complete break took place in the late Oligocene or early Miocene. The Red Sea opened by some 80-100 km during the last 3-5 Ma by the mechanism of sea-floor spreading, which drives plate movement. The opening of the Red Sea to the west is the reason for the tilting. The tilting of the Arabian Shield northeastward of course, accounts for the gentle dip of these strata in that direction.

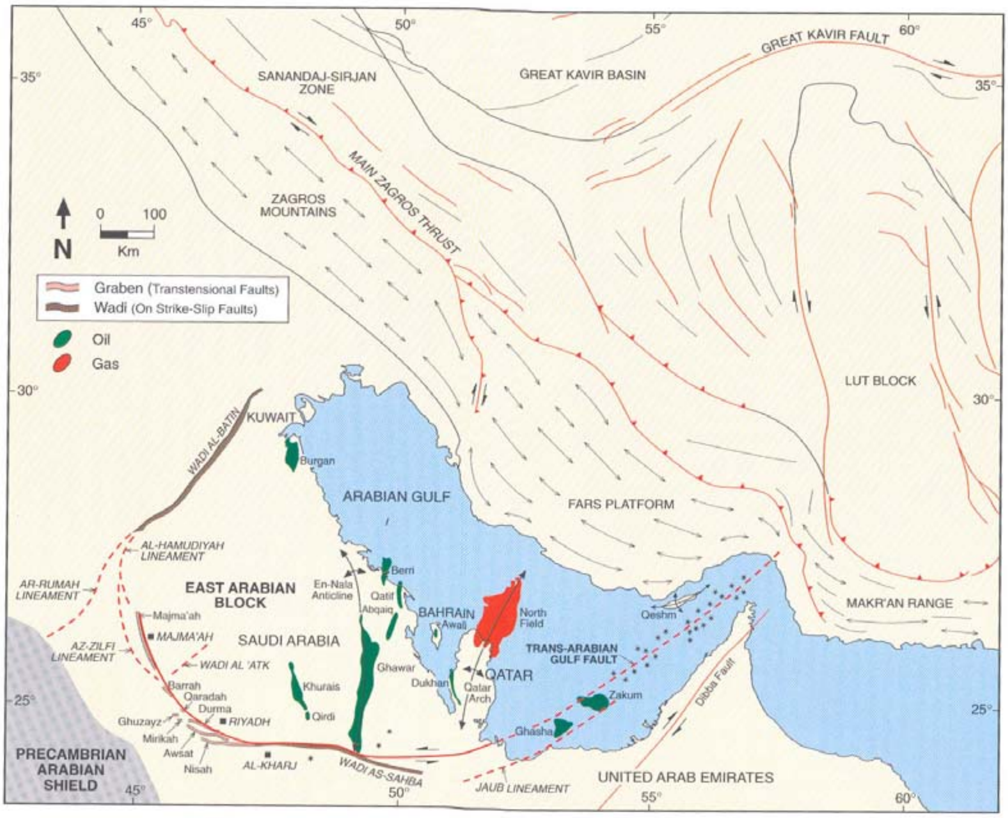

Fig.-5: Overview of the mahor faults and lineaments in the Arabian Platform after (Weijermars, 1998).

In Late Eocene-Oligocene time, NE-SW tension caused normal-step faulting and rifting of the crack and associated monoclinal down-warping the edges. During this time, the northeast separation of Arabia from Africa began. Uplift in the west and exposure of older (pre-Cambrian) silica-rich rocks explains the marked change from carbonate sedimentation , characteristic of the Dammam Formation (Eocene) to the dominantly silicates nature of the Hofuf Formation .

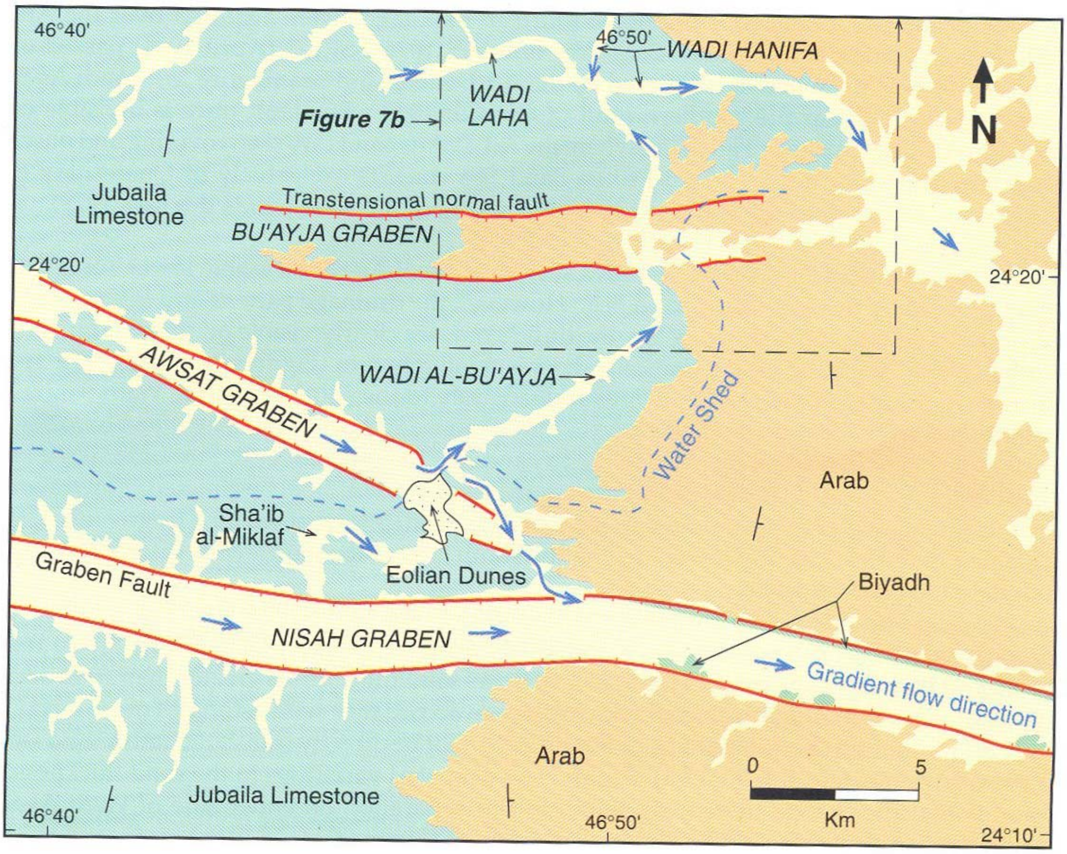

Fig.- 6: Overview showing the Nisah graben (after Weijermars, 1998).

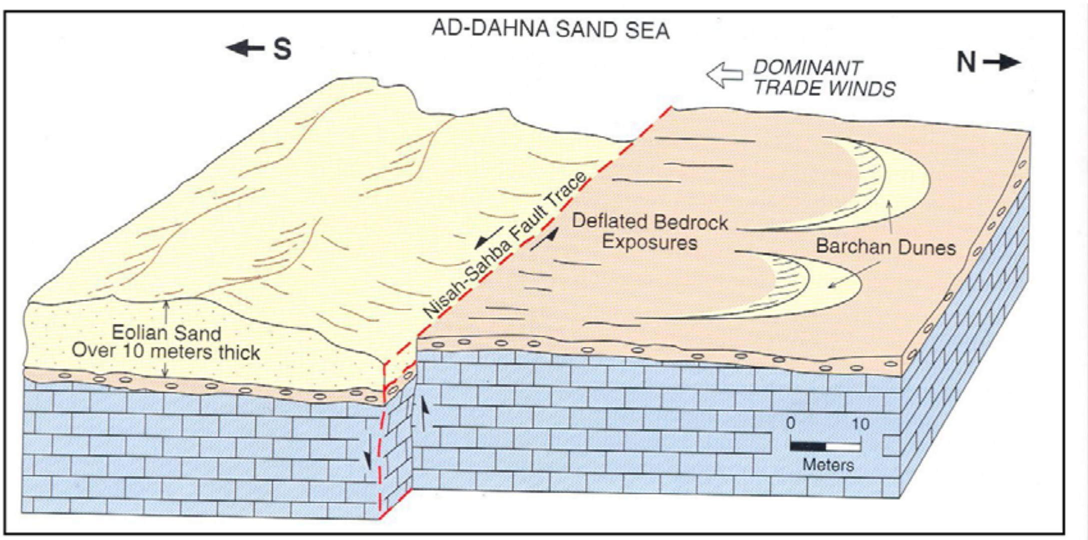

Fig.-7: Trace of Nisah-As-Sahba fault (after Weijermars, 1998).

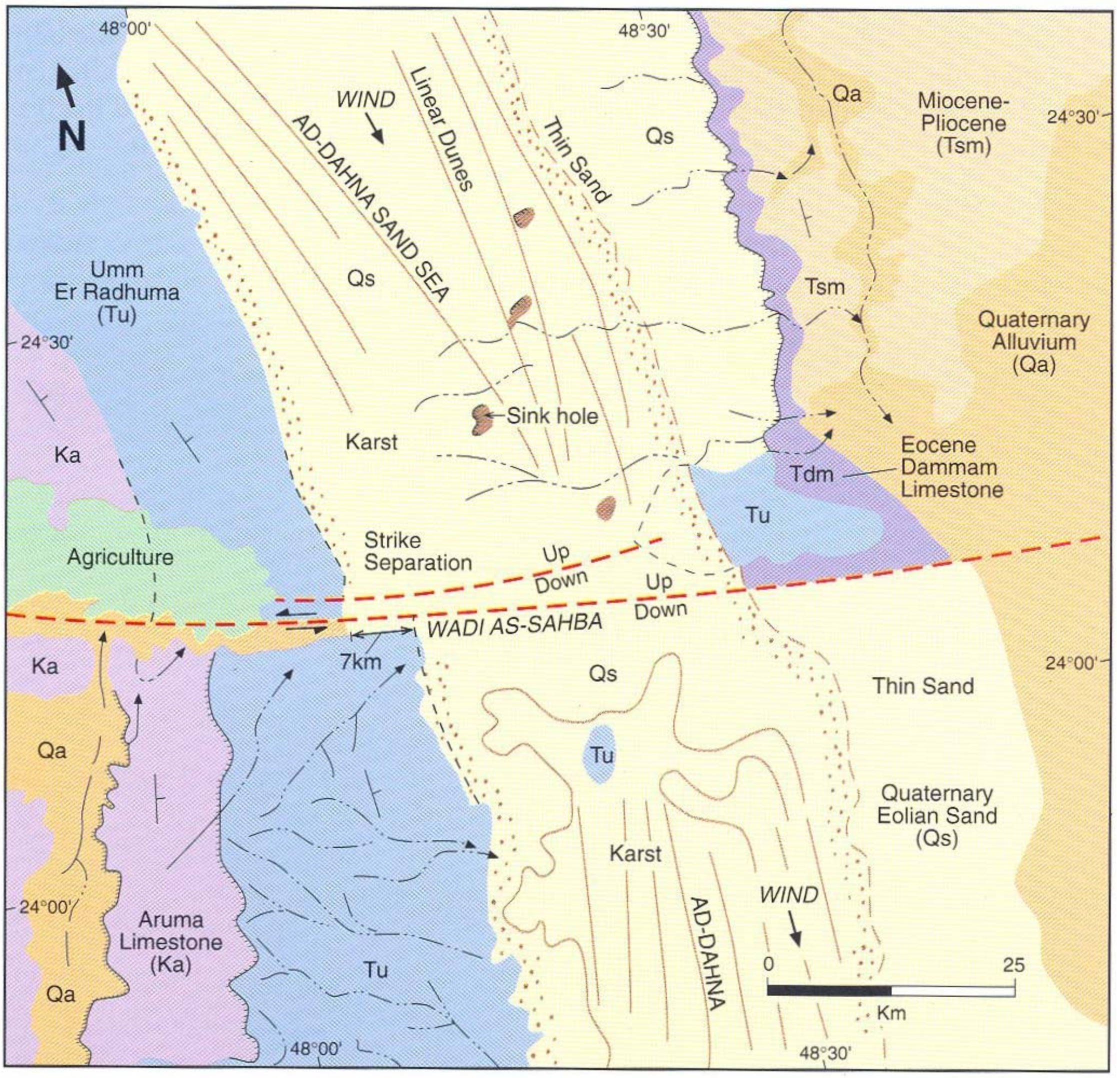

Fig.- 8: Major geologic units along Wadi As-Sahba after (Weijermars, 1998).

4-General Stratigraphy:

The regional Stratigraphy sequence of the Neogene's sediments in the Arabian Gulf region (East Arabian Block) indicates that they were deposited in an elongated NW-SE asymmetrical basin, named Zagros syncline (Fig. 9), (Powers, 1968, Powers et al., 1966; Murris, 1980). The area of this basin was decreasing during the Neogene's Period, probably as a result of global Mid-Oligocene emergence and the major uplift of the region that began during the Oligocene and continued thorough the

Miocene (Weijermars, 1998). The evolution of the Hofuf Formation is related to the formation of the East Arabian Block area during the Neogene. The East Arabian Block is a relatively newly recognized structural element that was first suggested by Hancock and Al-Kadhi (1978), Al-Kadhi and Hancock (1980).New data presented by Weijermars (1998) support the existence of this tectonic block bounded by graben and strike-slip faults and transpressive folds. A Plio-Quaternary age for the central and eastern Arabian graben systems has been suggested by Vaslet et al. (1991) and recently supported by Weijermars (1998).

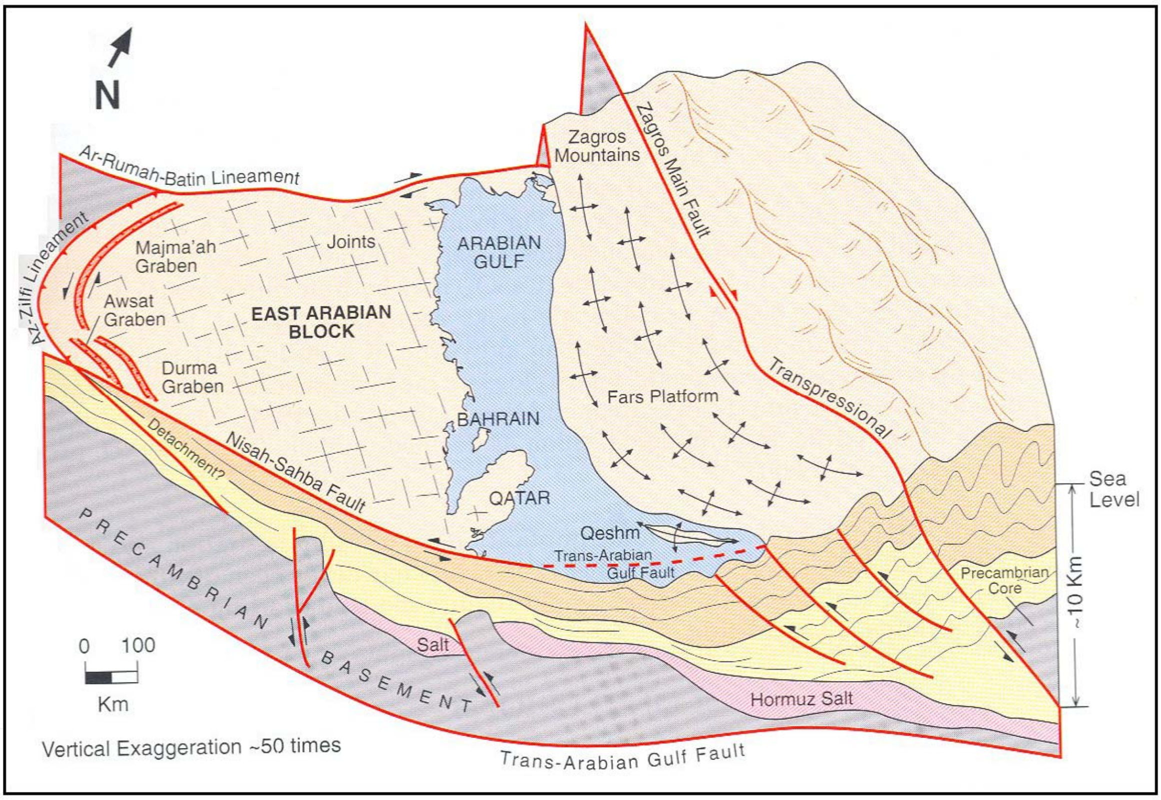

Fig.- 9: The East Arabian Block (Weijermars, 1998).

Sediments related to the Hofuf Formation are confined to the eastern parts of Saudi Arabia. The outcrops of this Formation extend from the Hofuf area to Haradh station and continue westward to Al-Kharj and eastword to Qatar (Fig. 10).

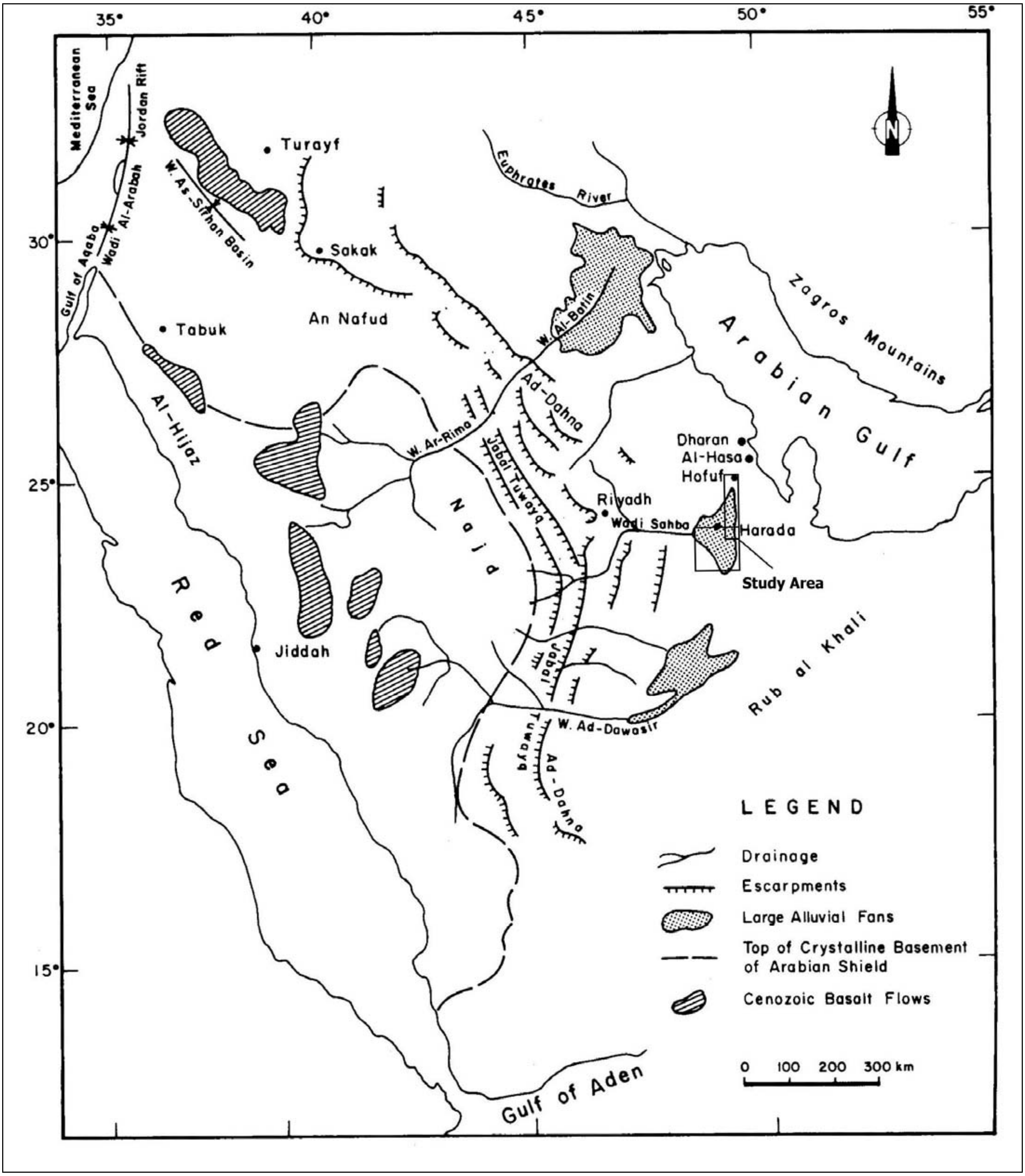

Fig. -10. Location of the Study area, including Hofuf formation outcrop.

The stratigraphic and lithologic classification of Saudi Arabian sedimentary outcrop sequences are shown in Table 1 and Fig. 11. The Hofuf Formation, presumably of Late Miocene to Pliocene age, represent the youngest Neogene deposits in Arabian Gulf region.

An early view, based on comparison with other areas in the Middle East, suggested that the Hofuf Formation is late Miocene, or Miocene and Pliocene (Hudson et aI., 1957). Al Naqib (1967) preferred a younger age of late Miocene and Pliocene. Hoetzl et al. (1978), suggested that gravel deposition postdates marine cliffing of Lower Pliocene sediments at the eastern scarp of the Al-Summan Plateau, near Al-Hasa in eastern Saudi Arabia . Farther south, where gravels occur around the Rub' al Khali, Beydoun (1966) presumed a Pliocene age. Others preferred a Quaternary age. In general, however, Fuchs et al. (1968) are in a minority in preferring a Pleistocene to a Plio-Pleistocene age for the Hofuf.

The Hofuf Formation is named after its type locality, some 15 km NNE of Al-Hofuf town in the Eastern Province of Saudi Arabia. This name was formally used for the first time by Thralls and Hassan (1956). It is equivalent to the Dibdibba Formation of Kuwait (Al-Sulaimi, 1994; Al-Sulaimi and Mukhopadhyay, 2000). The depositional environment of the Hofuf rocks ranges from shallow marine to continental, with the majority of sediments having been deposited under fluviatile to lacustrine conditions (e.g., Al-Sulaimi, 1994; Al-Sulaimi and Mukhopadhyay, 2000).

In Kuwait, the Formation is divided into two members: a Mio-Pliocene Lower Member and a Plio-Pleistocene Upper Member (Al-Sulaimi, 1994;Al-Sulaimi and Mukhopadhyay, 2000).The Lower Member is made up of very coarse-grained, poorly sorted, gritty and pebbly sandstone. The Upper Member is composed of gravelly sand and sandy gravel.

Table -1: Stratigraphical and lithological classification of the sedimentary outcrop equence in Saudi Arabia (Prapared by M.Noory,1980 after Powers et al., 1966 and Otkun,1969).

Age		Formation		Thickness (m)	Lithologic Description
Recent & Quaternary			Surficial Deposits	Varies	Gravel,Sand,Silt,Basalt,….
Tertiary	Miocene & Pliocene	Neogene	Kharj	٣٠	Limestone,Gypsum & Gravel
			Hofuf	٩٥	Sandy Marl & Sandy Limestone
			Dam	٩٠	Marl,Shale,Subordinate Sandstone
			Hadruckh	٨٥	Silty, Sandstone,Sandy Limestone
	Eocene	Dammam	Alat	٥١	Limestone and Dolomite
			Khobar		
			Alevolina Limeston		
			Saila Shale		
			Midra Shale		
		Rus		٥٥	Marl,Shalky Limestone & Gypsium
	Paleocene	Umm er Radhuma		٢٤٥	Limestone and Dolomite
Mesozoic	Cretaceous	Aruma		١٤٠	Limestone Dolomite, and Shale
		Wasia		٤٢	Sandstone,Shale and Local Dolomite
		Biyadh		٤٢٥	Sandstone , Subordinate Shale
		Buwaib		١٨	Biogonic Calcarenite Limestone
		Yamama		٤٦	Biogonic Calcarenite Limestone
		Sulay		١٧٠	Chalky, Limestone
	Jurassic	Hit		٩٠	Anhydrite
		Arab		١٢٤	Calcarenite, Limestone and Some Anhydrite
		Jubaila		١١٨	Limestone & Dolomite Sub. Calc.&Calc. Limestone
		Hanifah		١١٣	Aphanitic Limestone,Sub. Calcarenitic Limestone
		Tuwayq Mountains		٢٠٣	Aphanitic Limestone,Sub. Calcarenitic Limestone
		Dhruma		٣٧٥	Aphanitic Limestone,Sub. Calcarenitic Limestone
		Marat		١٠٣	Shale and Aphanitic Limestone,Sub. Calcarenitic Sandstone
	Triassic	Minjur		٣١٥	Sandstone and Some Shale
		Jilh		٣٢٦	Shale and Aphanitic Limestone Sub.Gypsum
		Sudair		١١٥	
Paleozoic	Permian	Khuff			
		Pre-Khuff			
	Carbonian			Faw	
		Aburwath			
	Devonian	Jauf		Jauf:Limestone,Shale and Sanstone (299m).	
	Silurian	Tabuk	Tawail	Tabuk: Sandstone and Shale (1072m).	
			Qusaiba		
	Ordovician		Middle Tabuk		
			Raan	Saq:Sandstone	
			Lower Tabuk		
			Hanadir		

		Cambrian	Wajid (Sanstone,Gravel and Basement Erratics.
Precambrian			Basement Complex,Igneous and Metamorphic Rocks.

The rocks are represented by irregularly isolated hills and appear with different colors of brown to light yellow and grey to pale white. They are friable and are characterized by fining upward cycles. The gravel forms lenses, thin bands and bars or can be irregularly scattered in the sandy matrix. The gravel lenses lack lateral continuity and their thickness varies from 0.1 m to about 2 m. The size of the gravel particles is in the range of 0.25 and 35 cm in diameter with an average of 7 cm..

In type section in eastern Saudi Arabia, the Hofuf Formation attains a thickness of about 95 m, where it is unconformable overlies a sequence of calcareous sedimentary rocks of the Dam Formation, whereas its top is exposed to erosion or covered by an overburden of recent deposits. The type section in Al-Hofuf area is subdivided into four units (Figs. 12, 1٣):

1) a basal conglomerate formed of pebbles and boulders, including igneous and metamorphic rocks and limestone.
2) calcarentitic limestone
3) argillaceous sandstone
4) Conglomerates.

The main outcrops of the Hofuf Formation in Eastern Province occur in its south-central and southwestern parts (Hofuf and Haradh area). It comprises about 3 % of the exposed rocks and occurs as outliers associated with the Dam Formation. The Haradh fan has a gradient of 1.00-1.10 m km - 1. It extends from an apex at 300 m above sea level (Hoetzl et al., 1978). Further south, the Pliocene Hofuf Formation has a present-day inclination of 1-2 m km -1 (McClure, 1978).

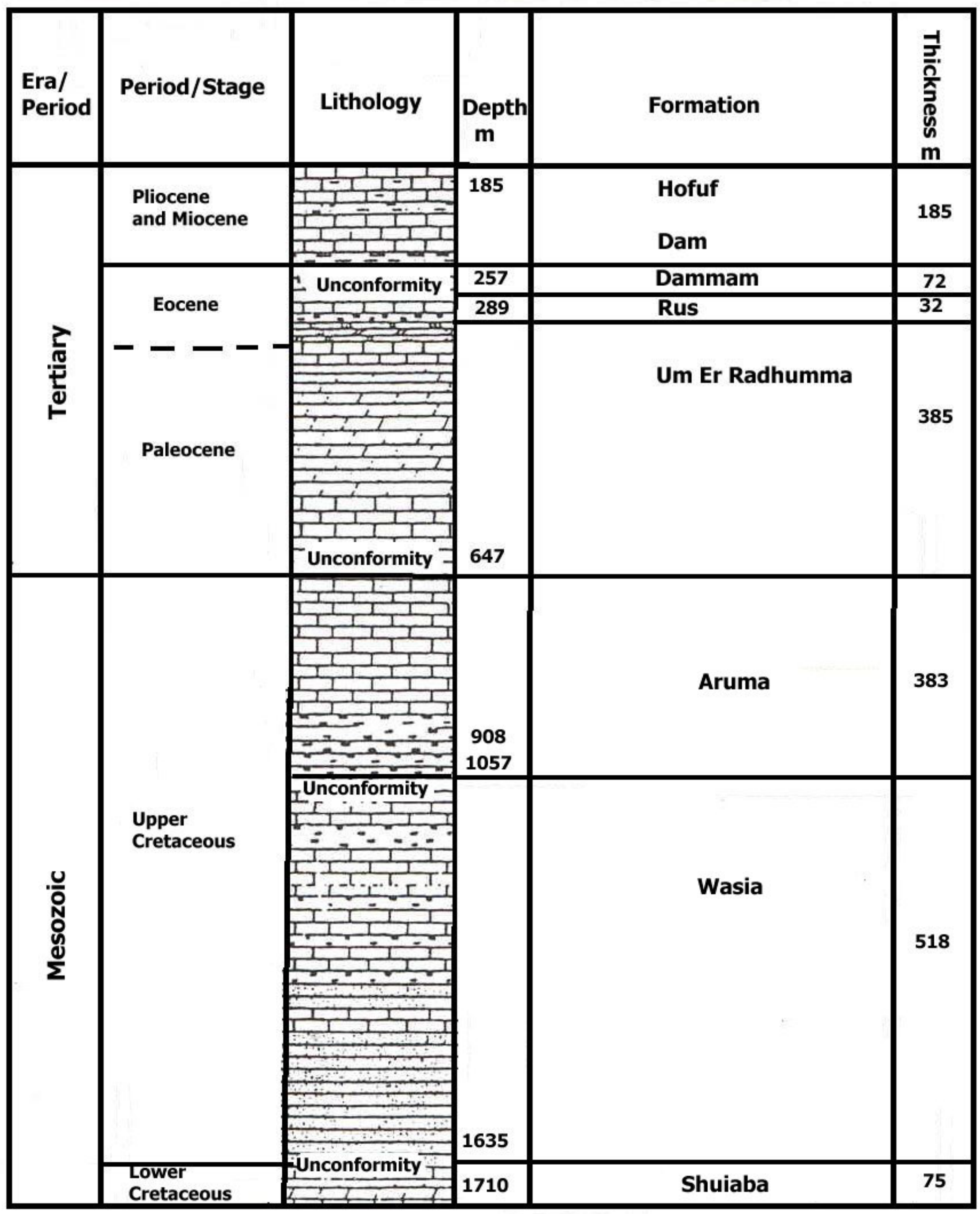

Fig. –1١: General Stratigraphy of the Eastern Province.

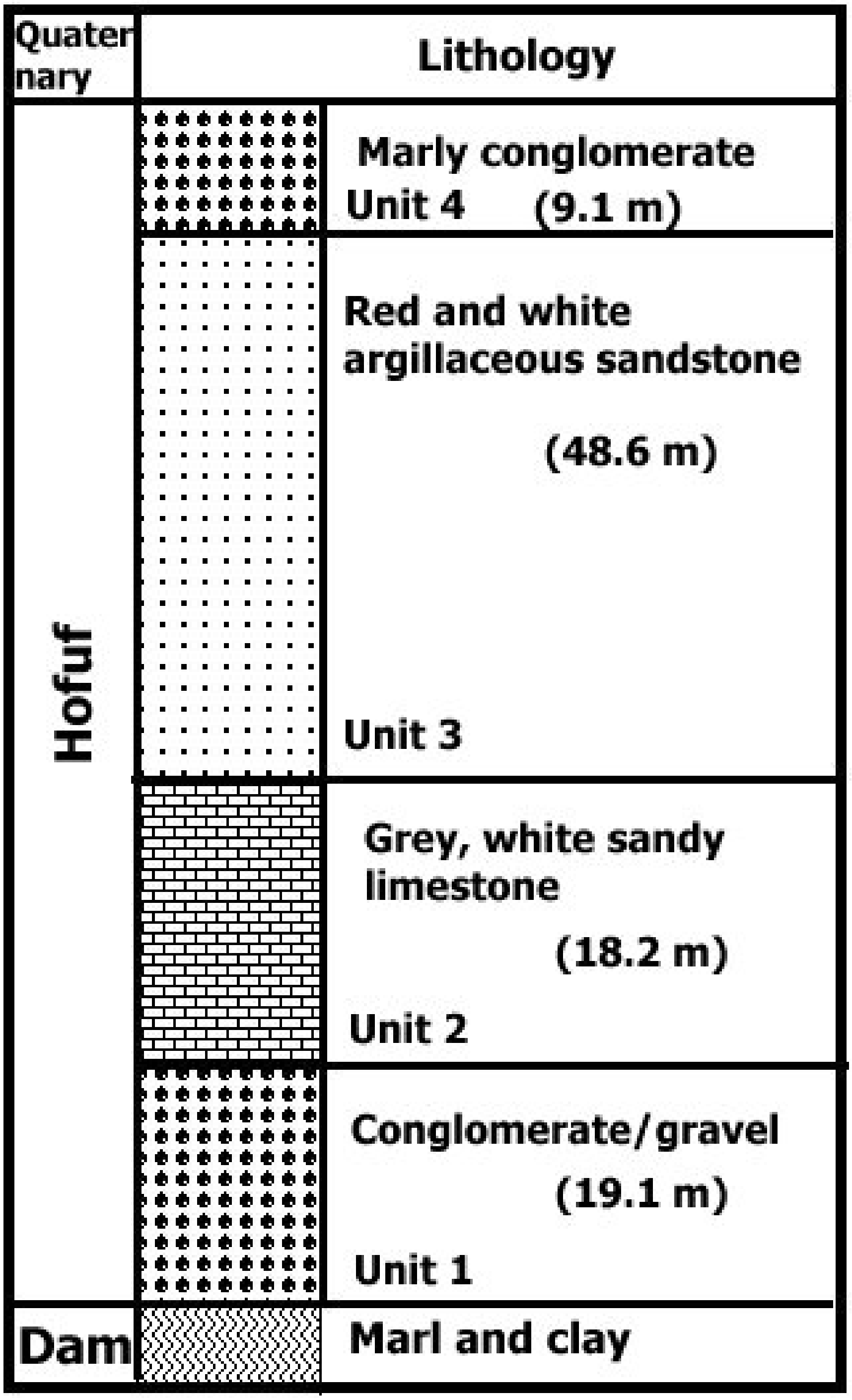

Fig.- 12: Hofuf Formation Type section.

The Hofuf Formation consists dominantly of white to light grey, massive, calcareous (marl) sandstone with intermittent horizons of soft, reddish to yellowish brown marl and clay (Fig.14). The reddish and yellowish brown horizons are often characterized by the presences of trace fossil of plant origin. A thin limestone (up to 2 meters thick) beds cap the sequence (Fig. 15). The Hofuf is marked by a well-developed joint system with the dominant trends to the NNW and NE (Fig. 16).

Fig.- 13: Hofuf Formation Type section area.

Fig.- 14: Yellow to brown marl and clay horizon characterize Unit 2 of the Hofuf Formation.

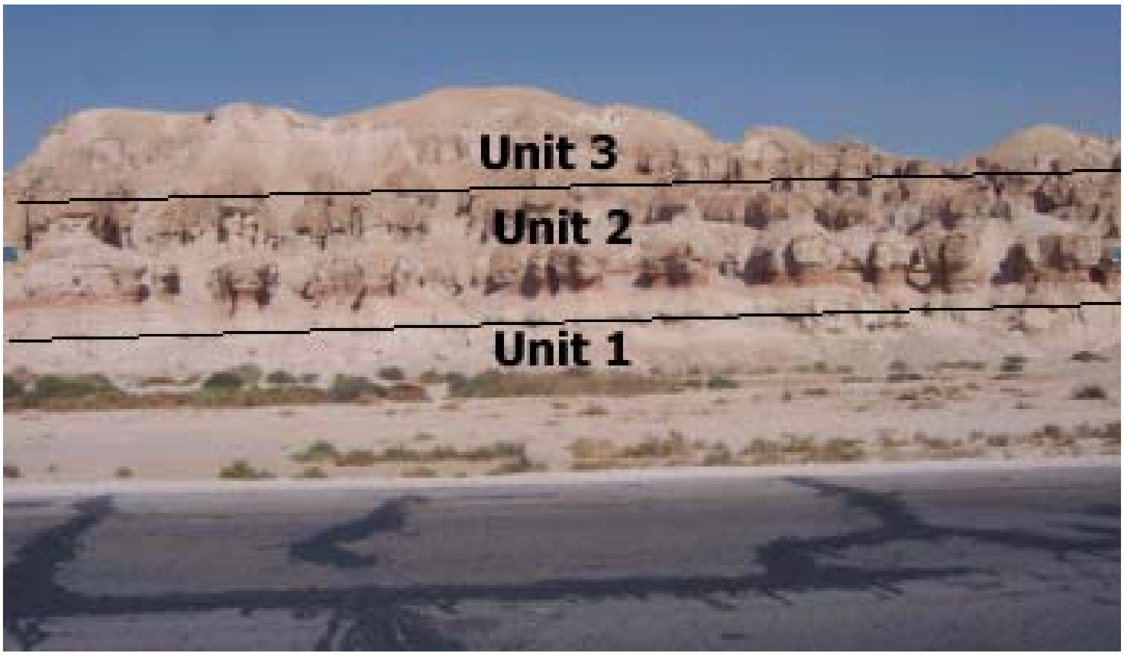

Fig.- 15: Limestone layers cap the Hofuf sequence.

Fig.- 16: Characteristics joint system of the Hofuf Formation.

The lower unit of the Hofuf Formation is extensively exposed in the type section area and at Haradh fan (Fig 17). The second to fourth units are eroded at Haradh area. The basal section of the Hofuf Formation is composed of an approximately 20 meters thick conglomerate bed overlying the marine limestone of the Dam Formation.The first unit is mostly composed of very coarse-grained sand with plenty of scattered pebbles, cobbles and boulders of igneous, metamorphic and sedimentary rocks (Fig. 18). The contact, with the second unit and the lower limestone of the Dam Formation is often well exposed, is very sharp, distinct and mostly erosional. At least 8 sedimentary cycles are present (Figs. 19, 20). Each cycle is composed mainly of sandy gravel and conglomerate followed by coarse-grained sandstone, and ending with bioturbated fine-grained sandstone. The thickness of these cycles ranges between 1.2 to 3.3m.The main sedimentary structures observed in the different lithofacies are cross bedding and Bioturbation (Figs. 21-22-23).

The second unit is formed of brown weathered brown to gray calcarenitic limestone whereas the third unit consists of argillaceous sandstone. Both units are highly cavernous. (Figs.24-25). The fourth conglomerate unit is composed of sandy conglomerate to conglomeritic sandstone.

The Hofuf Formation in the type section area overlies the Early-Middle Miocene argillaceous limestone Dam Formation.

A regional unconformity surface was inferred between the Dam and the Hofuf Formations in the eastern Arabian Peninsula (Powers, 1968).

The oldest rock exposed at Jabal Al-Qarah consists of marine limestone's, marls and clays of the Middle Miocene age Dam Formation (Hotzel el al., 1978) (Fig. 26) , Overlying unconformable on Dam formation is the Hofuf Formation.

Fig. -17: Unit 1 of the Hofuf Formation showing the upper most cycle.

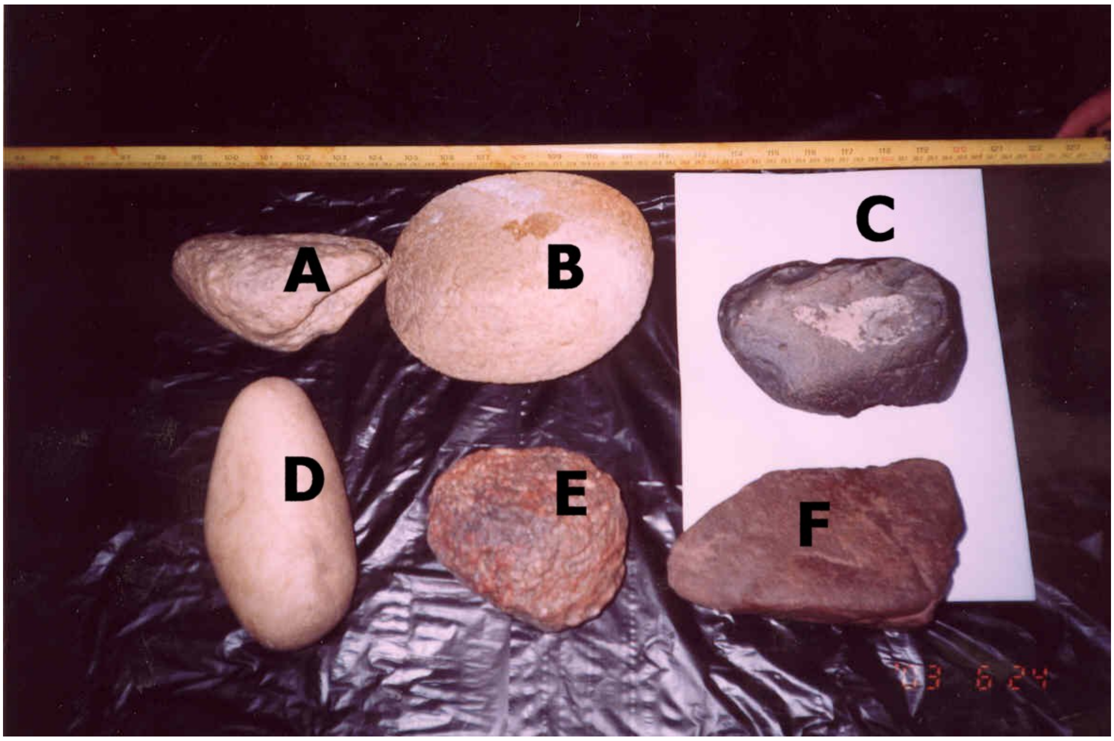

Fig. -18: Igneous, metamorphic and sedimentary pebbles.
A: Mica-gneiss, B: Limestone , C: Basalt, D: Quartzite,
E: Granite, F: Rhyolite.

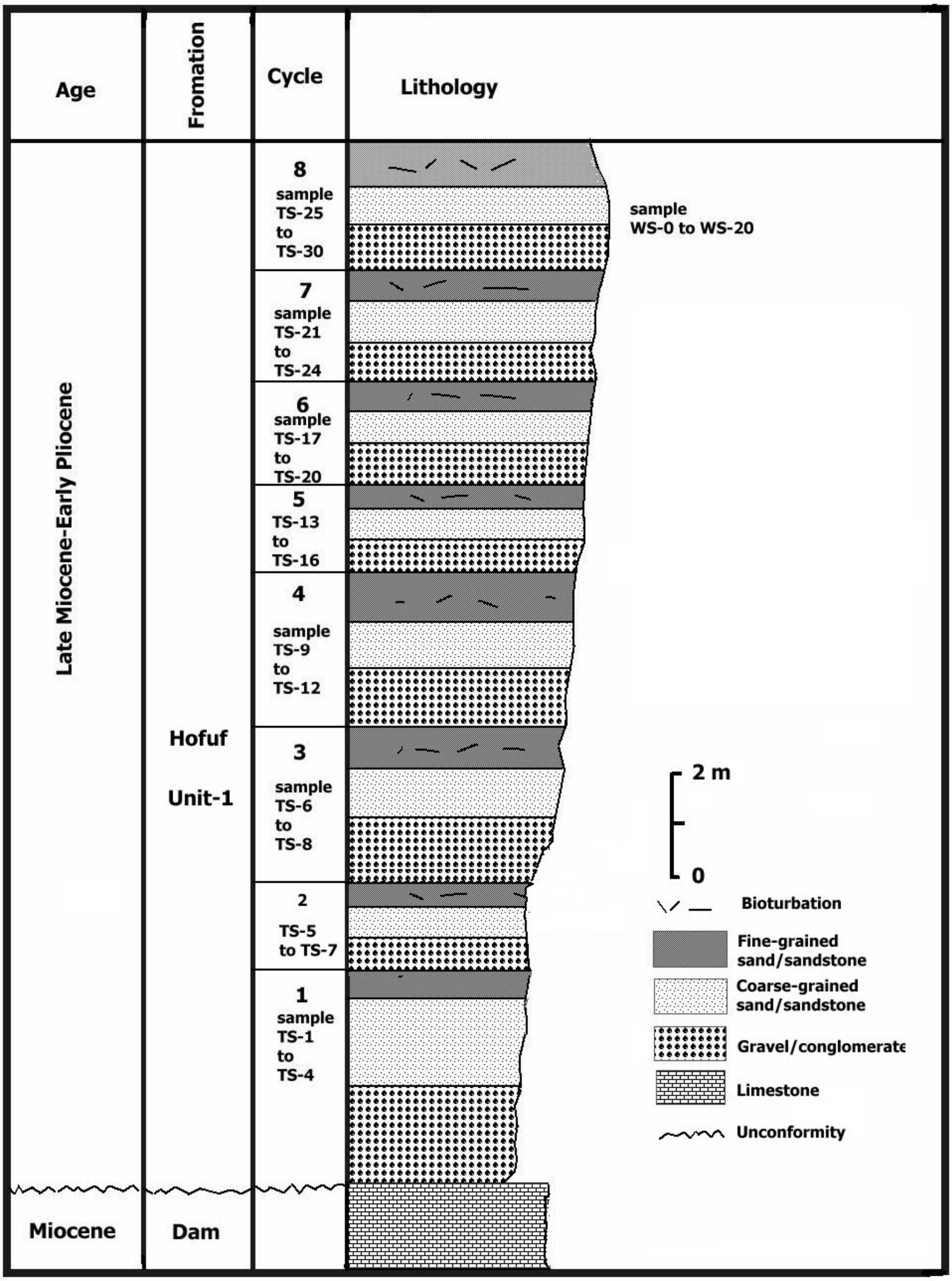

Fig. -19: Hofuf Formation Unit 1.

Fig.- 20: Upper most 3 cycles within the Hofuf Formation.

Fig.- 21: Bioturbation and cross bedding of Unit 1.

Fig.- 22:Cross-bedding within Unit 1 of the Hofuf Formation.

Fig. -23: Bioturbation, lamination and cross-bedding within Unit 1 of the Hofuf Formation.

Fig.- 24: Cavernous nature of Unit 2 and 3 of the Hofuf Formation
(Jabal Qarah).

Fig.- 25 : Cavernous rocks of Unit 2 in the Type section area.

In the State of Qatar, Al-Subaiha area in the southern part of the country represents the best single exposure for the Hofuf rocks (Fig. 27). The Hofuf Formation has been considerably eroded and its thickness ranges between 2 and 18 m, which seems to represent only the lower part of the first unit defined in the reference section at its type locality in Eastern Saudi Arabia (Thralls and Hassan, 1956).

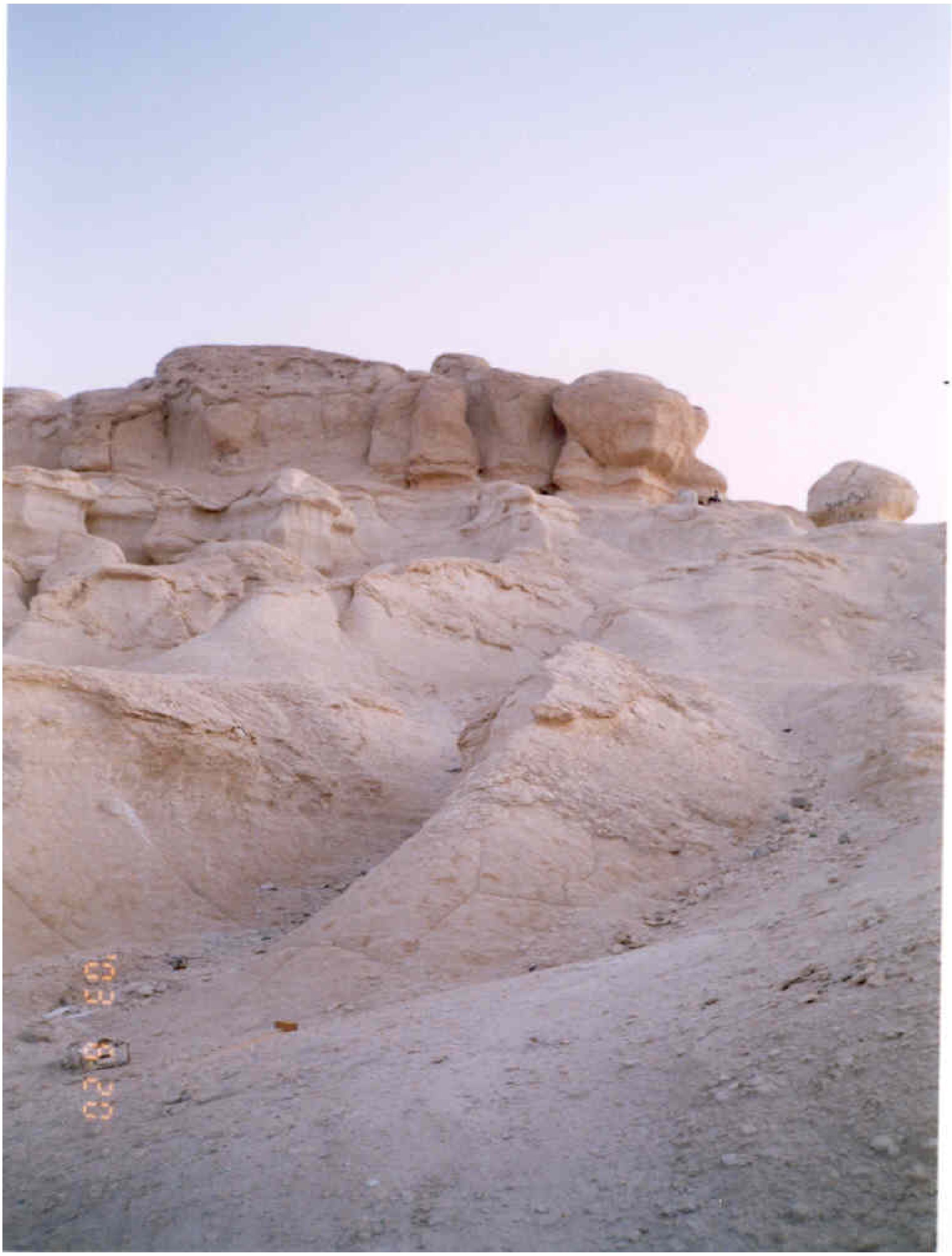

Fig. - 26: Unit 2 of the Hofuf Formation at Jabal Qarah**.**

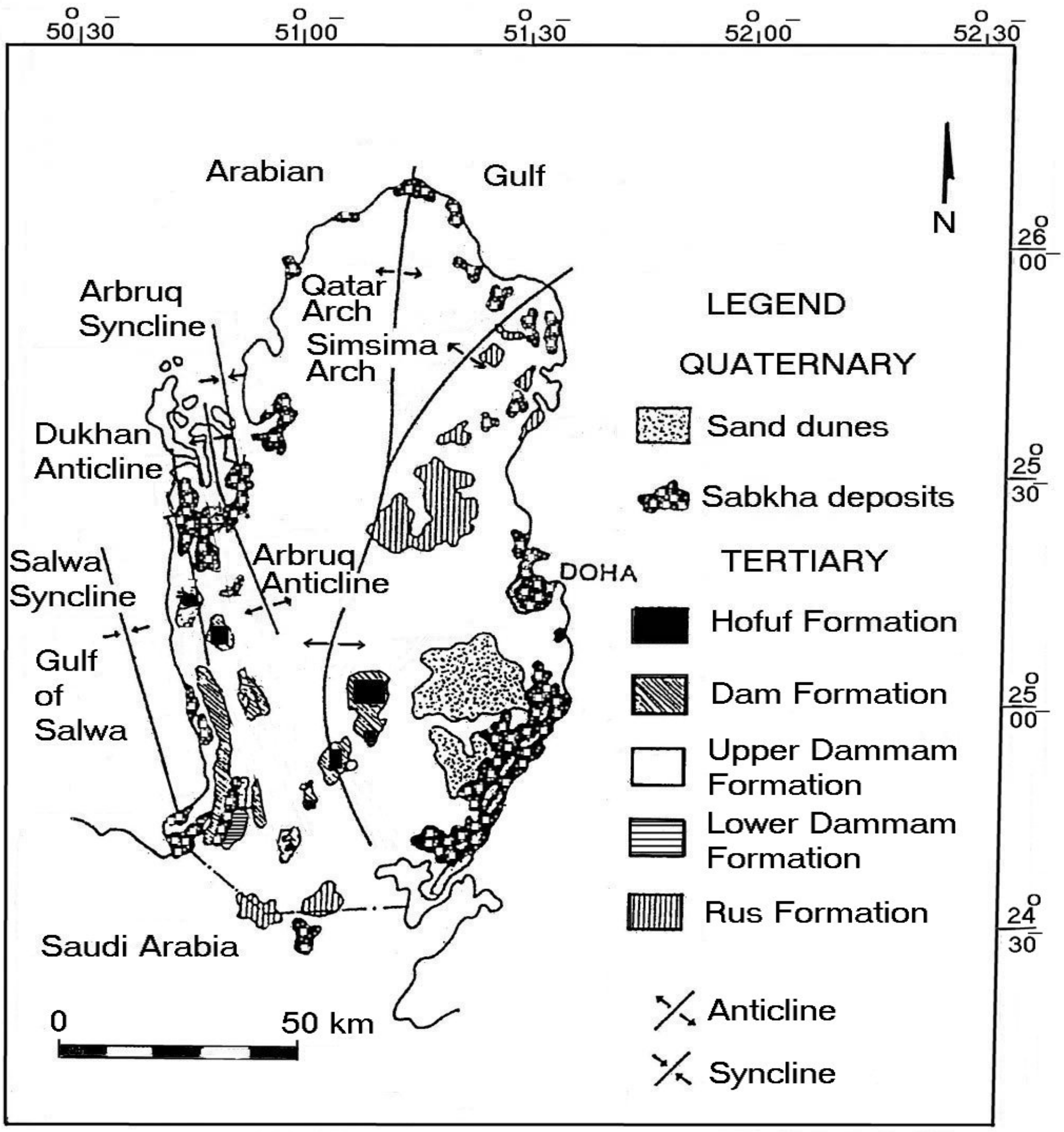

Fig.-27:Location of the Hofuf Formation in Qatar.

5- Sampling and analytical procedure:

For the purpose of this project we have selected three areas for samples collections, namely;

1- Type-section area, vertical traverse :(Sample TS-1 to TS-30)
2- Jabal Qarah, vertical traverse: (Sample Q1-Q9).
3- Haradh fan, horizontal traverses:(Sample WS0-WS6)

(Sample WS7-WS17)

(Sample WS18-WS20)

Sixty samples were collected from the selected areas (30 samples from the type section area, 9 samples from the Qarah area and 21 samples from the Haradh fan area). Sampling was mainly restricted to the lower sand unit of the Hofuf Formation. The Qarah samples are the only exception, as they represent the second and third units of the Hofuf Formation (Q1-Q5 and Q6-Q9, respectively). These samples were collected for comparison purpose.

Sampling in Haradh area was carried out in pits on 20 outcrops representing the survey stations (Fig. 28).

Samples were essentially taken from the deposits at the depth of 20-30 cm from the floor. Each sample was splitted into two parts, about 500 gram each. The first part was used for grain size and chemical analysis, whereas the second part was kept as a reserve for further separation.

A stratigraphic column was established in the type section area and separate sedimentary cycles representing different sedimentary events, were identified and sampled (ca. 2-3 kg). Sampling was carried out on natural outcrops and samples of each sedimentary cycle of the first unit were taken. Concurrently with sampling step, pebble sizes and shapes were measured in the laboratory and descriptive statistics were calculated for a total of 50 samples. In addition to the grain-size analysis, a detailed petrographical study of 30 gravel samples was carried out. For the petrographical study, gravel particles 2 cm in diameter and above were separated from the other constituents by sieving and thin sections were prepared.

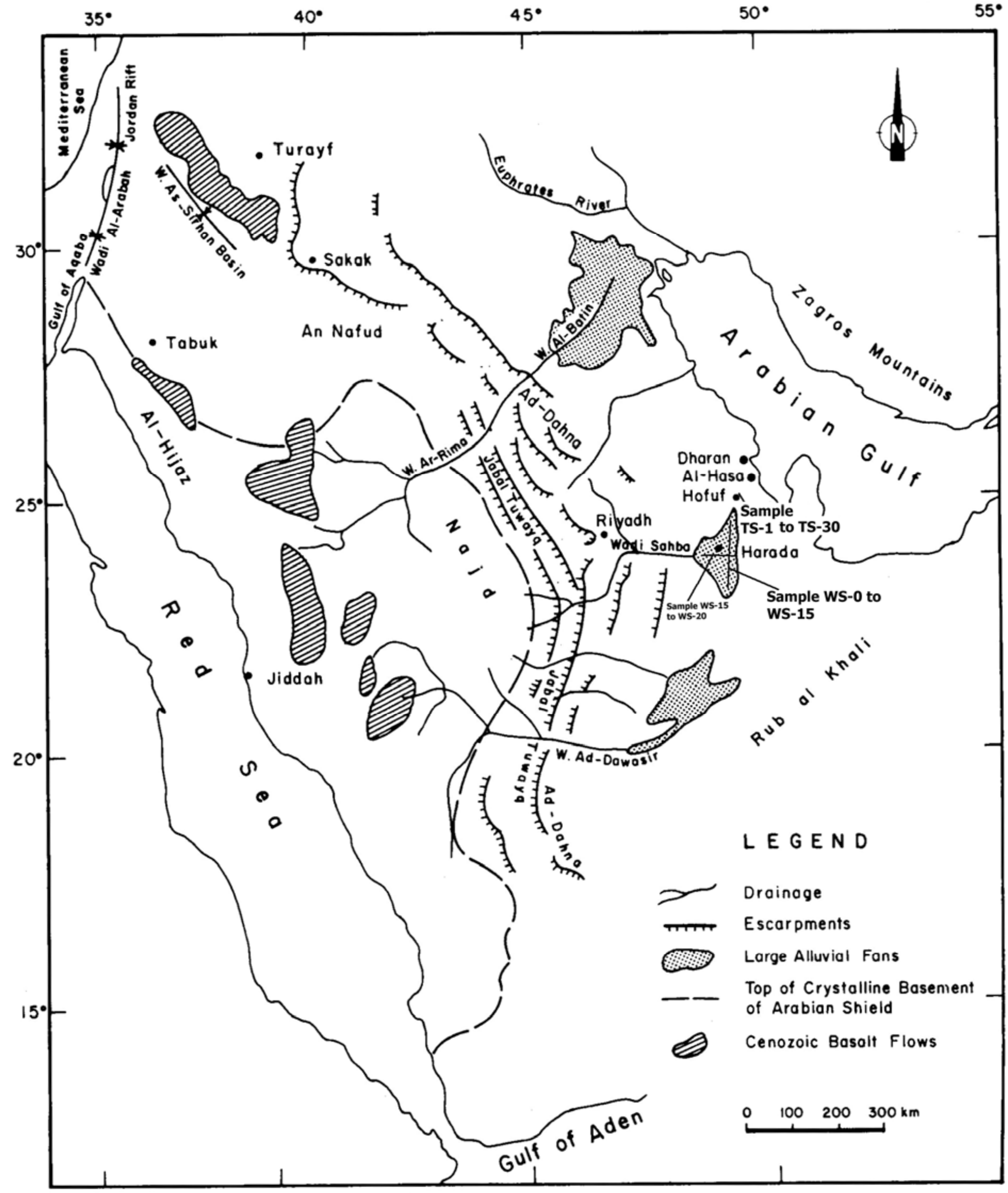

Fig.- 28: Sample location.

The different lithologies of gravel clasts in each sample were identified, and the percentage of each rock type was determined by weighing each rock group individually.

The material was sieved into 4 fractions (medium to coarse 400-250 um, fine 250-125 um, very fine 125-63 um). The fraction over 400 um is rejected. The medium to coarse fraction makes about 50-60 wt.% of the samples whilst the fine fraction ranges between 30-40 wt. % and the very fine fraction makes up to 10-20 wt.% of the samples.

The heavy minerals were obtained from a fraction of 63-250 µm (Friis, 1978), using bromoform. About 300 non-opaque heavy-mineral grains were counted. Most of the investigated fractions were counted in both transmitted and reflected light after mounting in resin and polishing. The heavy mineral percentage in comparison to the light fraction composition was calculated.

For gold analyses, the samples were milled to <100 um fraction size before pre-concentration by lead button Fire Assay. Gold content was determined by ICP-MS at a commercial laboratories in Saudi Arabia.

6- Sedimentology:

In the type section area, the studied section of unit 1 of the Hofuf Formation has a thickness of 20 m. At least 8 sedimentary cycles are present (Fig.19). Each cycle is composed mainly of sandy gravel to sandy conglomerate followed by coarse-grained sandstone, and ending with bioturbated fine-grained sandstone (Fig. 29) .The thickness of these cycles ranges between 1 to 3 m.The main sedimentary structures observed in the different lithofacies are cross bedding and bioturbation (Figs. 21-22-23). Three sedimentary facies can be recognized within the studied sand unit of the Hofuf Formation:

Fig.- 29: Fining up-ward cycles.

Facies A: clast-supported sandy gravel/conglomerate (Fig. 30)

This represents the basal part of the cycle. It occurs as few centimeters to about one meter in thickness. The color is commonly white, brown to dark brown. The sandy gravels/conglomerates are composed of igneous, metamorphic, limestone and quartzite pebbles up to 20 cm in diameter and sandstone lithoclasts.Most of these gravels/conglomerates are plane-bedded, some are grade-bedded.

Fig.- 30: Facies A; sandy conglomerate.

Facies B: coarse-grained sandstones (Fig. 31)

This facies occurs at various levels in the unit 1 of the Hofuf Formation and varies from light brown to light yellow. The thickness range from 0.5 to 1 m. Planar and tabular cross-bedding is the dominant sedimentary structure.

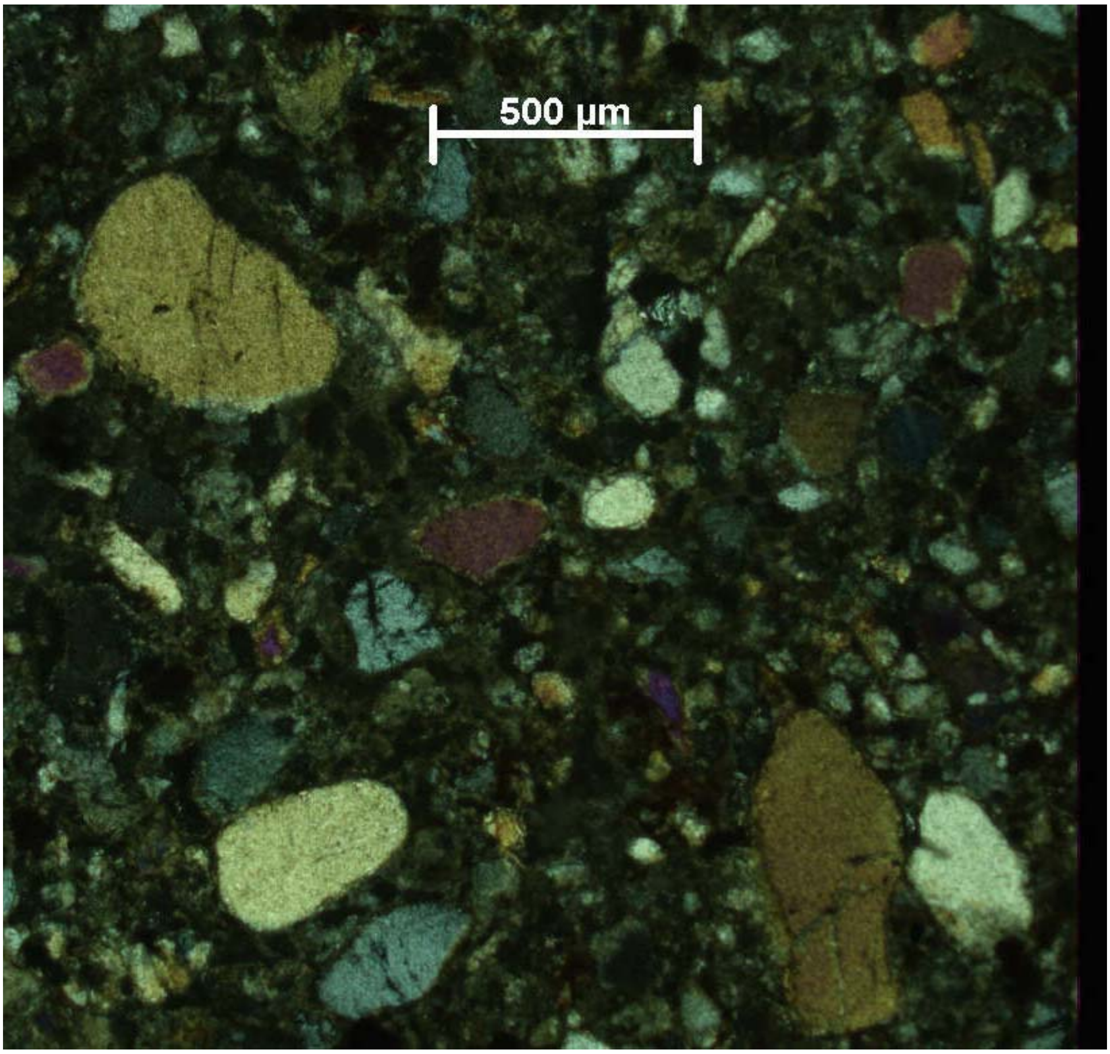

Fig.- 31: Photomicrograph showing Facies B: coarse-grained sandstone.

Facies C: fine-grained sandstones (Fig. 32)

This facies always marks the upper part of a fining upward cycle. Its thickness ranges from 0.5 to about 2 m. The color is light brown to creamy. The facies is characterized by abundant bioturbation, and occurrence of plant fragments and small-scale planar cross-bedding.

Samples representing unit 2 consist of fine-grained quartz and calcite embedded in a carbonate matrix (Fig. 33). Unit 3 samples are composed of quartz grains embedded in a micritic matrix (Fig. 34) .

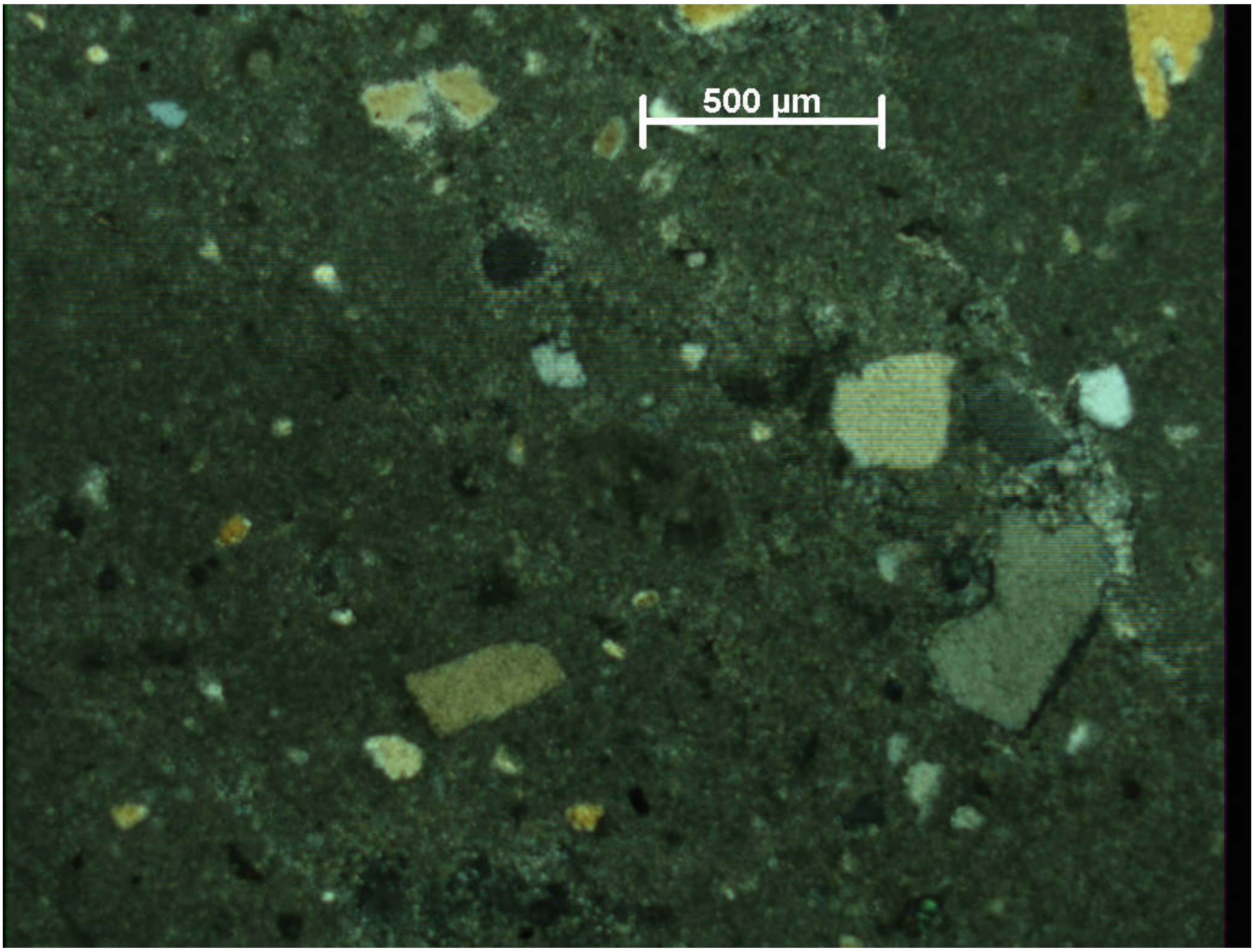

Fig.- 32: Photomicrograph showing Facies c; fine-grained sandstone.

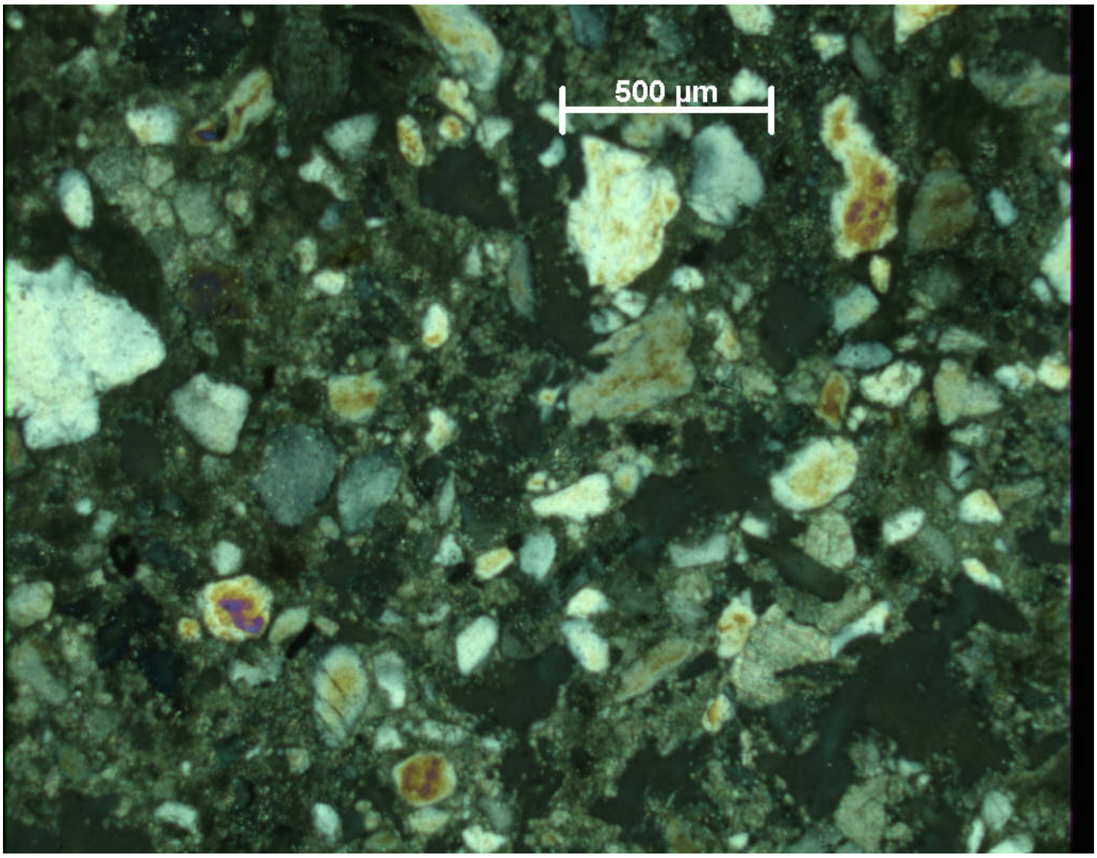

Fig.- 33: Photomicrograph showing a representative sample of calcarenite (Unit 2).

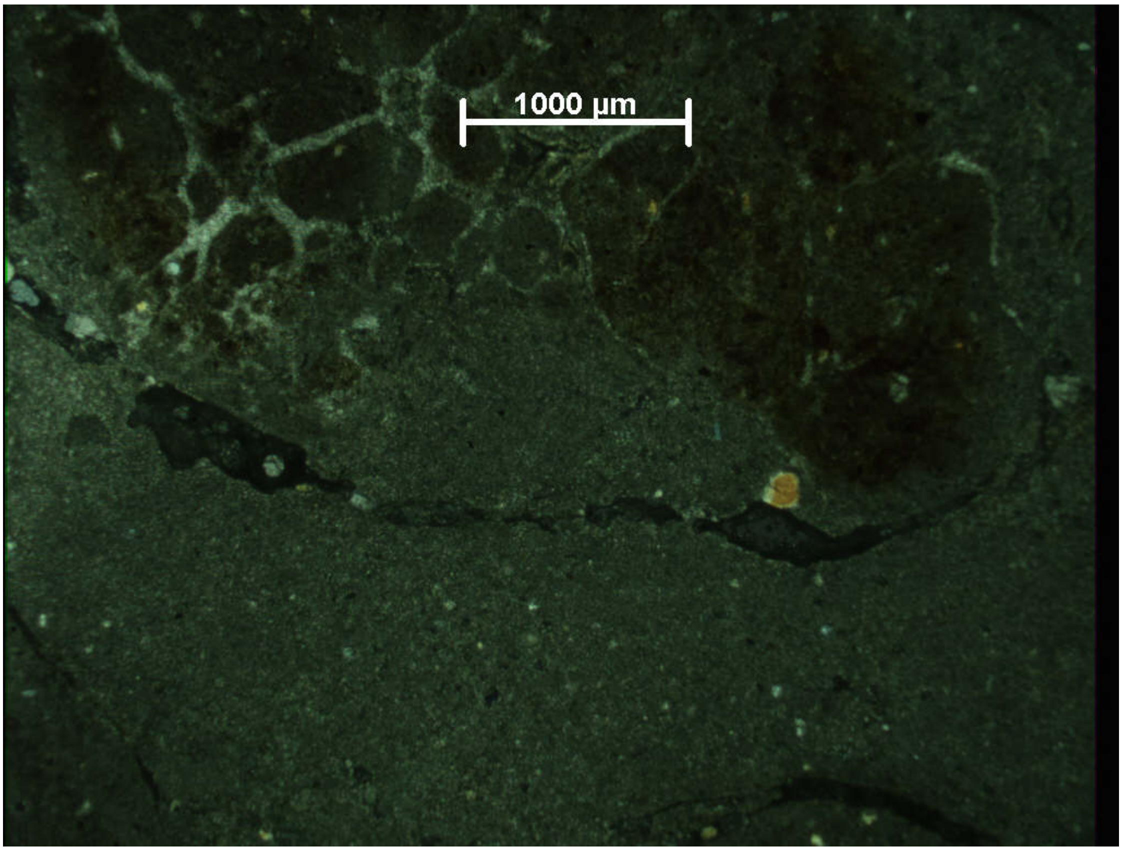

Fig –34: Photomicrograph showing an argillaceous sandstone of Unit 3.

7-Grain-size analysis:

Results of the grain-size analyses are given in Table (2). The sieving data are represented by frequency curves (Fig. 35) and cumulative frequency curves (Fig. 36). Statistical grain size parameters were calculated according to the formulae given by Folk and Ward (1957). Friedman's (1961) moment textural parameters were also calculated (Table 3).These parameters include mean grain size, inclusive standard deviation of sorting, inclusive graphic skewness and inclusive graphic kurtosis as shown in Table 3. Grain size is distinctly variable, being represented by gravely sand and different categories of sands ranging from fine to coarse sand. Coarse sand is the most frequent (40%), whereas the least frequent size is represented by the fine sand. With respect to sorting, the inclusive graphic standard deviation values are indicative of poorly to very poorly sorted material. Scatter diagrams that correlates the mean grain size with inclusive standard deviation can give good information about the environment in which the sediments are developed (Moiala and Weiser, 1968) Data of the Haradh and Hofuf stream sediments given in Fig. 37 shows slight increase of sorting with the decrease of main gian size. Coarse and very coarse sand samples are clustered in the area of poor sorting on the scatter diagram. Very poorly and poorly sorted fractions are common, indicating that Haradh and Hofuf stream sediments are immature from the textural and mineralogical points of view although some samples show very slight tendency to be sub mature. Suite mean is usually equivalent to the composite mean, whereas composite standard deviation, skeweness and kurtosis values can depart significantly from those values of the suite statistics (e.g., Tanner 1991; Balsillie and Tanner, 1999). The size fraction percentages of the investigated samples (Table 3, Fig. 35) indicates that the facies A samples in the type section area (sample TS-15 to TS-20, TS-23 to TS-24, and TS-27 to TS30) and in the Haradh area (sample WS-8 to WS-13) are sandy gravel, the facies B samples from the Type section area (sample TS-21 to TS-22 and TS-25 to TS26) and from the Haradh area (sample WS-15 to WS-20) are gravelly sand, whereas the facies C samples from the type section area (sample TS-7 to TS-14) and from the Haradh area (sample WS-0 to WS-7) are sand. The gravel fraction is mainly composed of cobbles, pebbles and granules. It is present in considerable amounts mainly in the sandy gravel samples (30-35 %), whereas it ranges between 1 and 5 % in the gravely sands and the sandy samples. Size measurements on the gravel, according to the method of Wentworth (1922), indicates that the most abundant gravel fraction is the pebble size which reaches up to 70% whereas the cobble fraction makes up to 30 %. The mud fraction (silt and clay) is less than 2 %. The cumulative curves of the samples (Fig. 36) further illustrate that the suspension subpopulation (mud) constitutes a very small amount of the sediment, whereas the traction subpopulations of facies A (sandy gravel) is mostly distinguished. This may , suggest that most of the material could have been deposited from thick heterogeneous fluvial bed-load.

Mechanical analysis of the investigated samples has shown the following results:

Table-2: Grain size analyses of fine-graind sand samples from Haradh Fan (Wadi As Sahba).

	WS-0	WS-1	WS-2	WS-3	WS-4	WS-5	WS-6	WS-7
-2.5	1.822	3.004	1.749	1.587	1.431	1.991	1.368	2.545
-1.5	2.818	3.725	3.325	3.625	2.66	2.56	1.692	2.977
-0.5	2.854	4.061	4.041	2.348	3.064	2.834	1.849	3.733
0.5	15.824	15.158	16.147	15.124	16.729	14.798	13.87	15.13
1.5	26.125	21.597	23.839	23.588	26.42	25.468	21.994	25.6
2.5	28.26	29.721	30.891	29.63	29.347	32.239	33.96	30.7
3.5	18.654	19.489	16.622	19.237	16.45	16.119	19.7	15.7
4.5	3.69	3.171	3.265	4.595	3.789	3.916	5.476	3.5

Table- 2: continued. Cumulate grain size.

	WS-0	WS-1	WS-2	WS-3	WS-4	WS-5	WS-6	WS-7
-2.5	1.822	3.004	1.749	1.587	1.431	1.991	1.368	2.545
-1.5	4.64	6.729	5.074	5.212	4.091	4.551	3.06	5.522
-0.5	7.495	10.79	9.115	7.56	7.155	7.385	4.909	9.255
0.5	23.318	25.948	25.262	22.684	23.884	22.183	18.779	24.385
1.5	49.443	47.545	49.101	46.272	50.304	47.651	40.773	49.985
2.5	72.704	77.266	79.992	75.902	79.651	79.89	74.733	80.685
3.5	91.358	96.755	96.614	95.139	96.101	96.009	94.433	96.485
4.5	100	99.926	99.879	99.734	99.89	99.925	99.909	99.885

T able -2 :continued. Grain size analyses of medium-graind sand samples from Haradh Fan (Wadi As Sahba).

	WS-15	WS-16	WS-17	WS-18	WS-19	WS-20
-2.5	3.56	3.4	3.6	2.884	3.428	3.07
-1.5	3.06	3.3	3.6	3.26	3.86	3.84
-0.5	4.1	4.6	3.9	3.797	3.845	3.38
0.5	18.066	17.021	15.9	15.812	17.394	16.29
1.5	20.789	20.6	19.69	20.717	20.575	20.054
2.5	28.5	29.576	26.7	29.956	28.274	29.96
3.5	18.4	17.1	20.689	19.343	18.395	19.05
4.5	3.367	4.488	5.867	4.158	4.265	4.271
	99.842	100.085	99.946	99.927	100.036	99.915

Table -2 :continued. Cumulate grain size.

	WS-15	WS-16	WS-17	WS-18	WS-19	WS-20
-2.5	3.56	3.4	3.6	2.884	3.428	3.07
-1.5	6.62	6.7	7.2	6.144	7.288	6.91
-0.5	10.72	11.3	11.1	9.941	11.133	10.29
0.5	28.786	28.321	27	25.753	28.527	26.58
1.5	49.575	48.921	46.69	46.47	49.102	46.634
2.5	78.075	78.497	73.39	76.426	77.376	76.594
3.5	96.075	95.597	94.079	95.769	95.771	95.664
4.5	99.842	100	99.946	99.927	100	99.915

Table -2: continued. Grain size analyses of coarse-graind sand samples from Haradh Fan (Wadi As Sahba).

	WS-8	WS-9	WS-10	WS-11	WS-12	WS-13
-2.5	11.318	9.819	10.085	9.368	10.475	10.342
-1.5	12.125	11.192	13.302	12.5	13.836	12.865
-0.5	13.453	13.654	14.58	12.698	13.571	12.652
0.5	34.432	39.399	31.39	30.943	29.579	26.512
1.5	16.94	17.733	20.189	19.589	20.037	18.764
2.5	7.395	5.194	6.52	9.541	8.498	12.155
3.5	2.891	1.722	2.92	3.314	2.705	4.765
4.5	1.533	0.613	1.059	2.031	1.193	1.851
	100	99.326	100	99.984	99.894	99.906

Table -2 :continued. Cumulative grain size.

	WS-8	WS-9	WS-10	WS-11	WS-12	WS-13
-2.5	11.318	9.819	10.085	9.368	10.475	10.342
-1.5	23.443	21.011	23.487	21.868	24.311	23.207
-0.5	36.896	34.665	37.967	34.566	37.882	35.859
0.5	71.382	74.064	69.357	65.509	67.461	62.371
1.5	88.268	91.797	89.546	85.098	87.498	81.135
2.5	95.663	96.991	96.066	94.639	95.996	93.29
3.5	98.554	98.713	98.986	97.953	98.701	98.055
4.5	100	99.326	100	99.984	99.894	99.906
	WS-8	WS-9	WS-10	WS-11	WS-12	WS-13

Table-2: continued. Grain size analyses of fine-graind sand samples from the type-section area (Al-Hofuf area).

	TS-7	TS-8	TS-9	TS-10	TS-11	TS-12	TS-13	TS-14
-2.5	4.071	2.47	4.878	4.065	5.144	4.218	4.051	5.018
-1.5	3.927	4.98	7.055	7.423	7.219	6.53	5.495	7.546
-0.5	4.52	3.9	7.863	9.306	6.896	7.998	9.382	7.438
0.5	29.4	30.381	32.145	36.078	36.911	33.586	34.301	34.916
1.5	25.206	24.7	27.824	25.486	23.729	26.821	26.841	24.956
2.5	15.8	17.8	11.356	11.415	13.078	13.568	13.379	12.475
3.5	10.621	10.1	5.521	4.553	5.113	5.513	5.216	5.456
4.5	6.443	5.661	3.497	1.695	1.631	1.761	1.347	2.136
	99.988	99.992	100.139	100.021	99.721	99.995	100.012	99.941

Table- 2: continued. Cumulative grain size.

	TS-7	TS-8	TS-9	TS-10	TS-11	TS-12	TS-13	TS-14
-2.5	4.071	2.47	4.878	4.065	5.144	4.218	4.051	5.018
-1.5	7.998	7.45	11.933	11.488	12.363	10.748	9.546	12.564
-0.5	12.518	11.35	19.796	20.794	19.259	18.746	18.928	20.002
0.5	41.918	41.731	51.941	56.872	56.17	52.332	53.229	54.918
1.5	67.124	66.431	79.765	82.358	79.889	79.153	80.07	79.874
2.5	82.924	84.231	91.121	93.773	92.977	92.7211	93.449	92.349
3.5	93.545	94.331	96.642	98.326	98.09	98.234	98.665	97.805
4.5	99.988	99.992	100.139	100.021	99.721	99.995	100.012	99.941

Table-2 :continued. Grain size analyses of medium-graind sand samples from the type section area.

	TS-21	TS-22	TS-25	TS-26
-2.5	3.602	4.42	4.173	5.53
-1.5	8.83	7.8	6.4	7.2
-0.5	13.165	13.23	13.3	13.9
0.5	32.731	31.923	32.3	31.9
1.5	18.764	23.5	21.5	20.5
2.5	12.932	10.93	12.3	11.9
3.5	6.753	5.1	6.9	5.8
4.5	3.166	3.1	3.116	3.267
	99.943	100.003	99.989	99.997

Table -2 :conitnued. Cumulative grain size

	TS-21	TS-22	TS-25	TS-26
-2.5	3.602	4.42	4.173	5.53
-1.5	12.43	12.22	10.57	12.73
-0.5	25.6	25.45	23.87	26.63
0.5	58.328	57.37	56.17	58.53
1.5	77.092	80.87	77.67	79.03
2.5	90.02	91.8	89.97	90.93
3.5	96.777	96.9	96.878	96.74
4.5	99.943	100	99.994	100

Table -2 : conitnued. Grain size analyses of coarse-graind sand samples from the type secion area.

	TS-15	TS-16	TS-17	TS-18	TS-19	TS-20	TS-23	TS-24	TS-27	TS-28	TS-29	TS-30
-2.5	11.695	11.9	10.95	11.4	9.614	9.7	11.294	12.384	11.5	10.8	11.6	12.8
-1.5	13.278	14.4	14.222	15.3	15.1	14.8	15.3	17.266	15.755	14.6	15.5	15.9
-0.5	12.688	16.963	15.587	16.915	13.277	14.1	14.134	14.169	13.169	14.487	14.887	15.668
0.5	26.699	27.826	31.712	26.325	28.6	30.6	28.158	28.214	32.3	30.7	30.9	29.7
1.5	14.956	11.63	14.612	13.4	13.9	14.5	15.498	13.839	13.196	13.1	14.95	12.9
2.5	10.487	9.4	7.469	9.4	10.09	10.078	9.277	8.489	7.4	9.4	8.2	9.7
3.5	5.217	5.6	3.118	4.4	5.722	3.924	4.159	3.637	3.718	4.331	2.639	2.146
4.5	4.431	2.241	2.317	2.84	3.681	2.316	2.163	1.787	2.955	2.264	1.281	1.117
	99.451	99.96	99.987	99.98	99.984	100.018	99.983	99.785	99.993	99.682	99.957	99.931

Table-2 :conitnued. Cumulative grain size.

	TS-15	TS-16	TS-17	TS-18	TS-19	TS-20	TS-23	TS-24	TS-27	TS-28	TS-29	TS-30
-2.5	11.695	11.9	10.95	11.4	9.614	9.7	11.294	12.384	11.5	10.8	11.6	12.8
-1.5	24.973	26.3	25.172	26.325	24.714	24.5	26.59	29.65	27.255	25.4	27.1	28.7
-0.5	37.661	43.26	40.759	43.615	37.991	38.6	40.728	43.819	40.424	39.887	41.987	44.368
0.5	64.36	71.089	72.471	71.94	66.591	69.2	68.886	72.033	72.724	70.587	72.887	74.07
1.5	79.316	82.719	87.083	83.34	80.491	83.7	84.384	85.872	85.92	83.687	87.837	86.968
2.5	89.803	92.119	94.552	92.74	90.583	93.778	93.661	94.361	93.281	93.387	95.993	96.762
3.5	95.02	97.719	97.67	97.14	96.305	97.702	97.82	97.998	96.999	97.718	98.632	98.908
4.5	99.451	99.96	99.987	99.98	99.986	100	99.983	99.785	99.993	99.682	99.957	99.931

Table -3: Grain-size statistical parameters of the sieved sand samples from the Haradh fan.

Samples	First Moment	Variance	Second Moment	Third Moment	Fourth Moment	Graphic Mean	Graphic Standard deviation	Graphic Skewness	Graphic Kurtosis
WS-0	1.89	2.02	1.42	-0.69	3.68	1.6	1.43	-0.04	1.14
WS-1	1.82	2.39	1.55	-0.81	3.47	1.47	1.46	-0.07	0.92
WS-2	1.83	2.06	1.44	-0.69	3.51	1.5	1.38	-0.13	1.16
WS-3	1.95	2.11	1.45	-0.71	3.6	1.6	1.35	-0.04	1.08
WS-4	1.807	1.79	1.34	-0.72	3.72	1.5	1.28	-0.06	1.15
WS-5	1.9	1.97	1.4	-0.76	3.94	1.77	1.4	-0.32	1.16
WS-6	2.12	1.82	1.35	-0.74	4.04	1.57	1.31	0.04	0.82
WS-7	1.81	2.13	1.46	-0.76	3.75	1.57	1.47	-0.07	1.39
WS-8	0.25	2.54	1.6	0.07	2.81	-0.1	1.25	0.29	0.51
WS-9	0.2	2.03	1.42	-0.14	3	-0.3	1.08	0.25	0.6
WS-10	0.25	2.42	1.55	0.03	2.73	-0.1	1.16	0.45	0.36
WS-11	0.41	2.66	1.63	0.05	2.72	-0.13	1.2	0.18	0.52
WS-12	0.27	2.56	1.6	0.015	2.59	-0.13	1.25	0.36	0.51
WS-13	0.45	2.97	1.72	0.018	2.41	0.03	1.38	0.44	0.41
WS-15	1.76	2.45	1.56	-0.75	3.39	1.17	1.83	-0.26	1.02
WS-16	1.77	2.5	1.58	-0.71	3.34	1.43	1.63	-0.17	1.25
WS-17	1.87	2.7	1.64	-0.74	3.27	1.43	1.68	-0.17	1.13
WS-18	1.86	2.38	1.54	-0.78	3.5	1.5	1.55	-0.12	1.09
WS-19	1.78	2.55	1.6	-0.72	3.3	1.43	1.53	-0.17	1.02
WS-20	1.84	2.47	1.57	-0.78	3.43	1.4	1.38	-0.16	1.06
Average	1.39	2.33	1.52	-.51	3.31	1.01	1.4	0.01	0.91

Table -3 : continued. Grain-size statistical parameters of the sieved sand samples from the type section area.

Samples	First Moment	Variance	Second Moment	Third Moment	Fourth Moment	Graphic Mean	Graphic Standard deviation	Graphic Skewers	Graphic Kurtosis
TS-7	1.4	2.63	1.62	-0.18	3.06	0.93	1.46	0.16	1.71
TS-8	1.42	2.39	1.55	-0.12	3.05	1	1.54	0.21	1.7
TS-9	0.94	2.39	1.55	-0.09	3.22	0.74	1.7	0.18	1.7
TS-10	0.82	2.04	1.43	-0.11	3.31	0.42	1.24	-0.11	1.6
TS-11	0.85	2.2	1.48	-0.19	3.22	0.48	1.55	0.07	1.41
TS-12	0.94	2.12	1.45	-0.21	3.25	0.7	1.5	0.14	1.45
TS-13	0.92	2	1.41	-0.21	3.31	0.7	1.44	0.1	1.12
TS-14	0.87	2.27	1.51	-0.16	3.17	0.55	1.49	0.03	1.21
TS-21	0.86	2.5	1.58	0.13	2.82	0.6	1.79	0.07	1.17
TS-22	0.81	2.37	1.54	0.09	3.08	0.43	1.54	-0.12	1.12
TS-25	0.91	2.42	1.56	0.07	2.96	0.43	1.59	-0.05	1.12
TS-26	0.8	2.56	1.6	0.07	2.93	0.43	1.56	-0.13	1.02
TS-15	0.45	3.47	1.86	0.22	2.44	-0.12	1.51	0.62	0.57
TS-16	0.25	3.11	1.76	0.3	2.53	-0.25	1.33	0.58	0.49
TS-17	0.2	2.69	1.64	0.28	2.88	-0.18	1.36	0.6	0.74
TS-18	0.25	3.1	1.76	0.32	2.58	-0.07	1.33	0.55	0.49
TS-19	0.43	3.2	1.8	0.26	2.51	0.08	1.66	0.68	0.48
TS-20	0.33	2.85	1.67	0.21	2.64	-0.05	1.56	0.64	1.06
TS-23	0.27	2.96	1.72	0.21	2.55	0.17	1.58	0.37	0.84
TS-24	0.13	2.91	1.71	0.27	2.55	0.2	1.68	0.32	0.75
TS-27	0.22	2.96	1.72	0.33	2.78	-0.23	1.23	0.41	0.36
TS-28	0.27	2.94	1.71	0.24	2.63	-0.03	1.3	0.33	0.79
TS-29	0.14	2.6	1.61	0.17	2.64	-0.27	1.33	0.39	0.35
TS-30	0.08	2.65	1.64	0.19	2.52	-0.23	1.3	0.41	0.57

Average	0.69	2.64	1.62	0.09	2.86	0.27	1.48	0.27	0.99

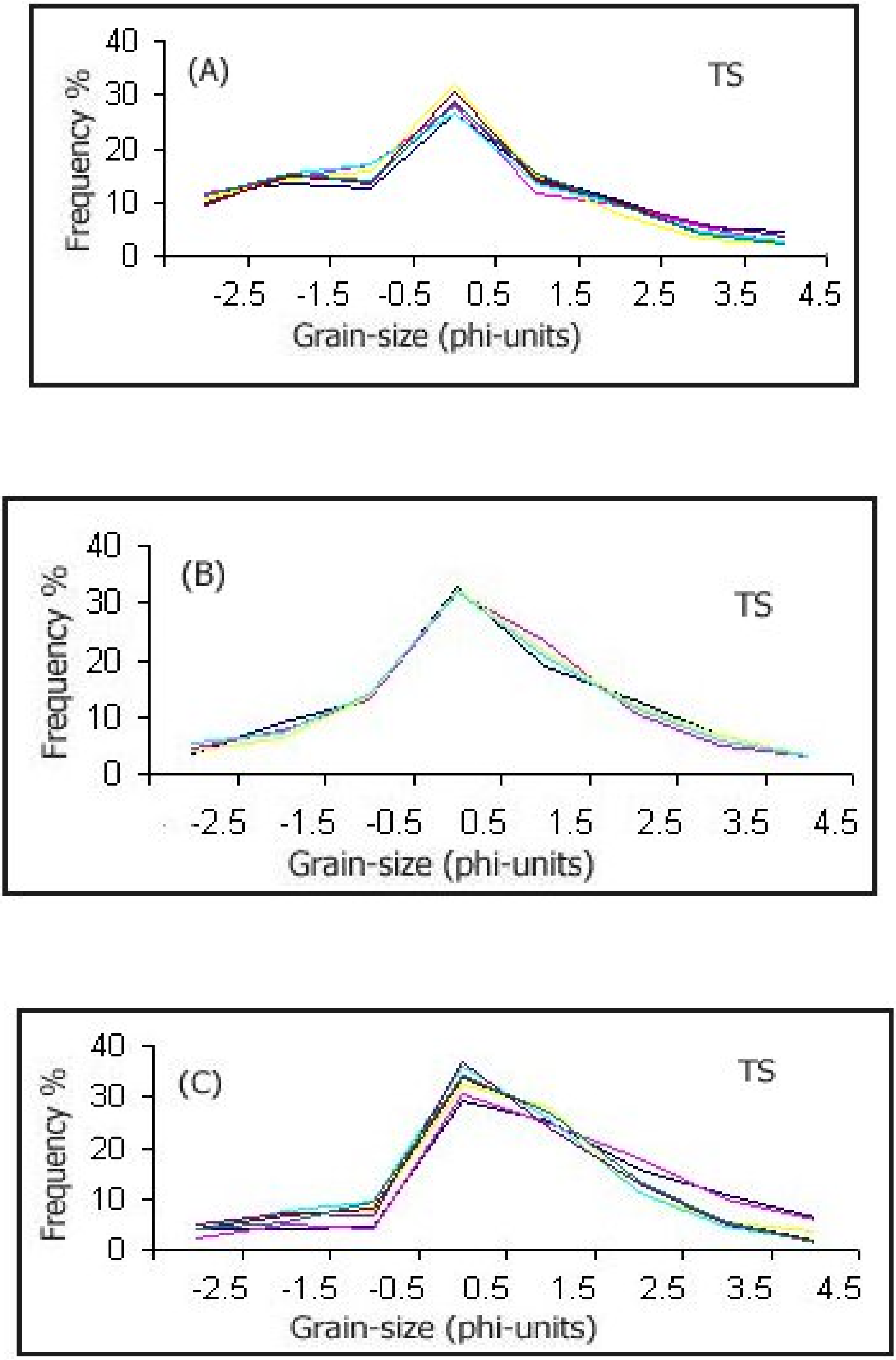

Fig.- 35a: Frequency curves of grain-size data for the Hofuf type section samples.A: sandy gravel, B: coarse-grained sandstone, C: fine-grained sandstone.

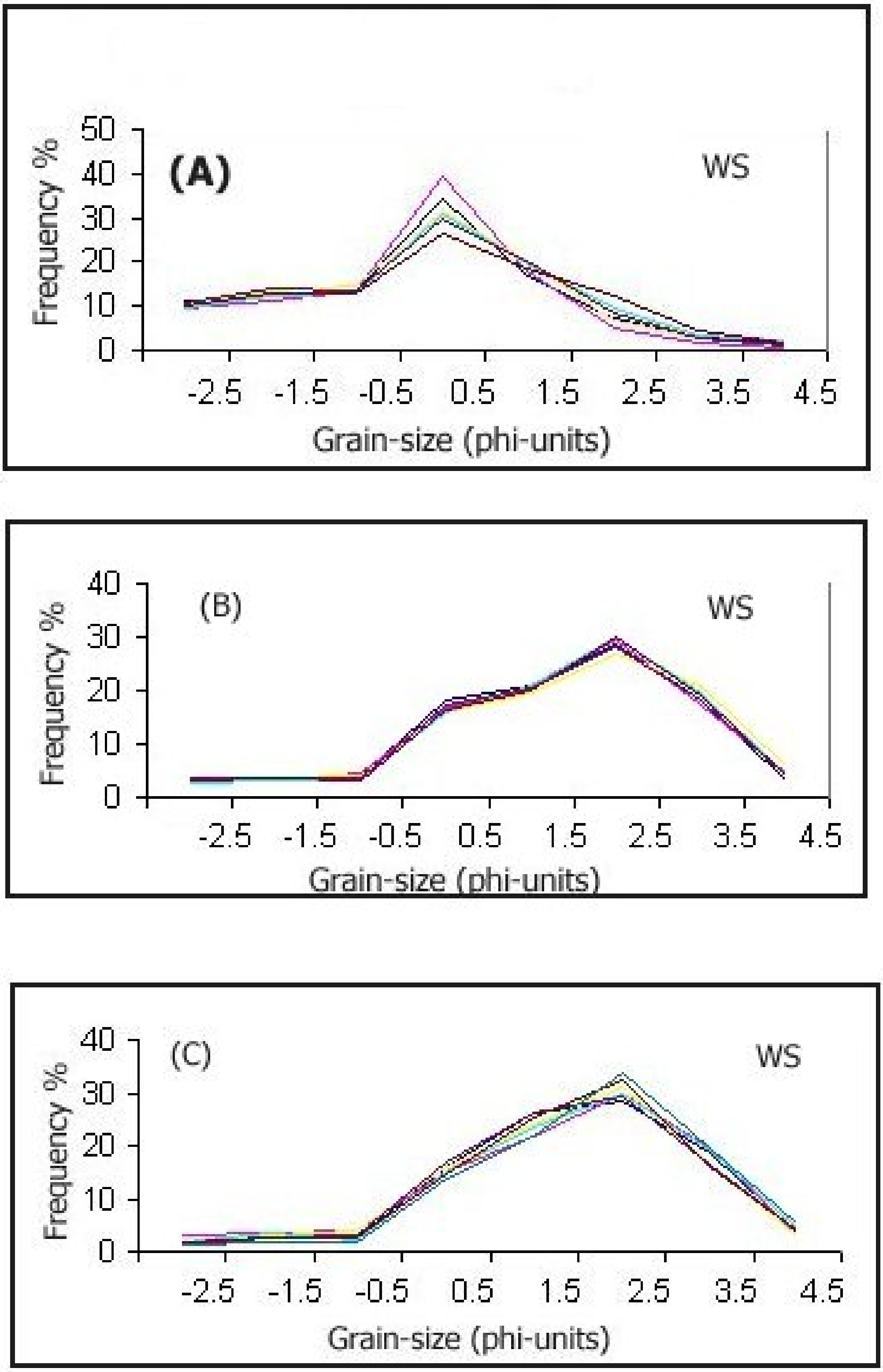

Fig.- 35b:Frequency curves of grain-size data for the Haradh samples.
A: sandy gravel,B: coarse-grained sandstone, C: fine-grained sandstone.

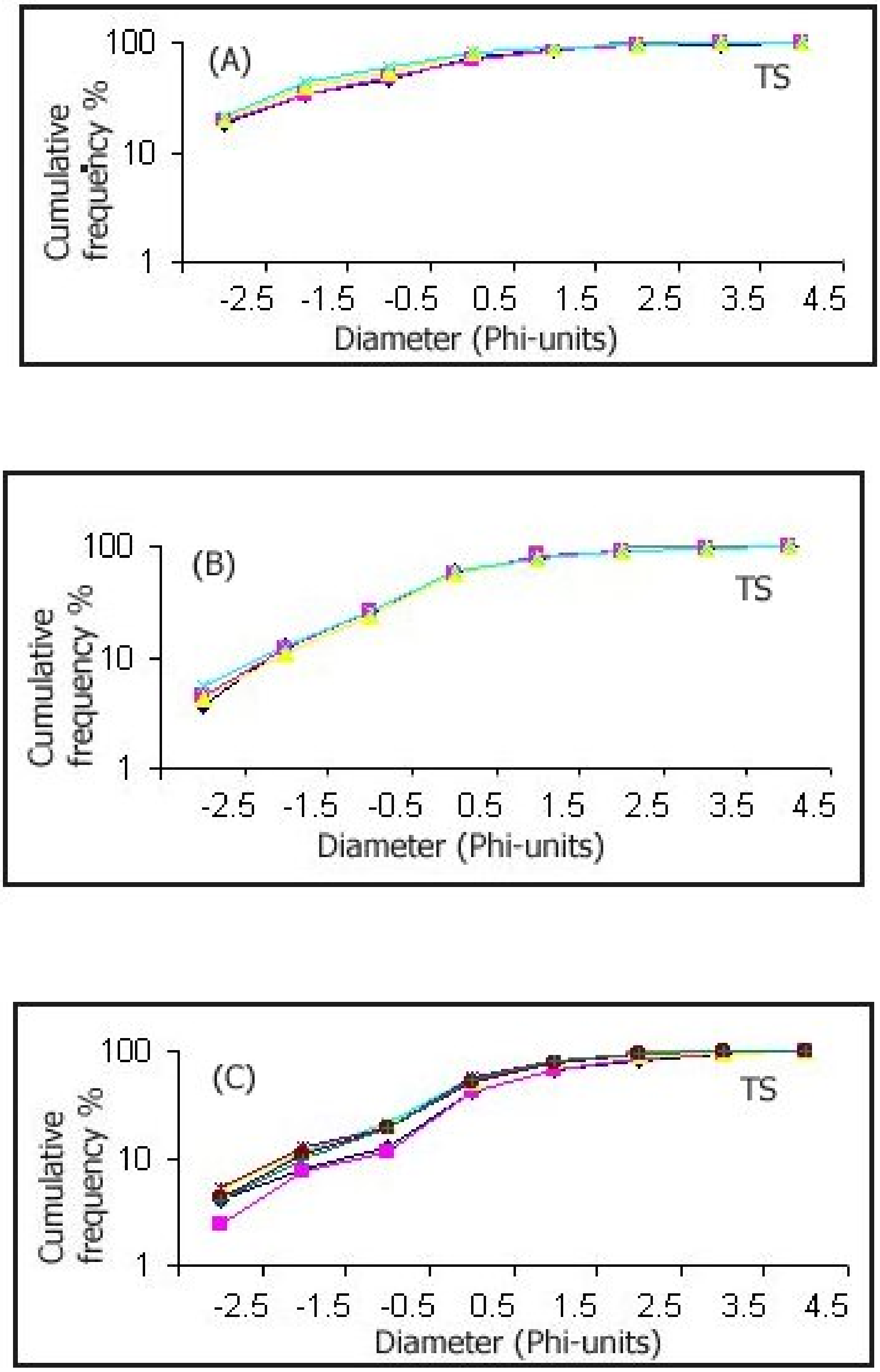

Fig-36a: Cumulative frequency curves for the Hofuf type section samples.
A: sandy gravel,B: coarse-grained sandstone, C: fine-grained sandstone.

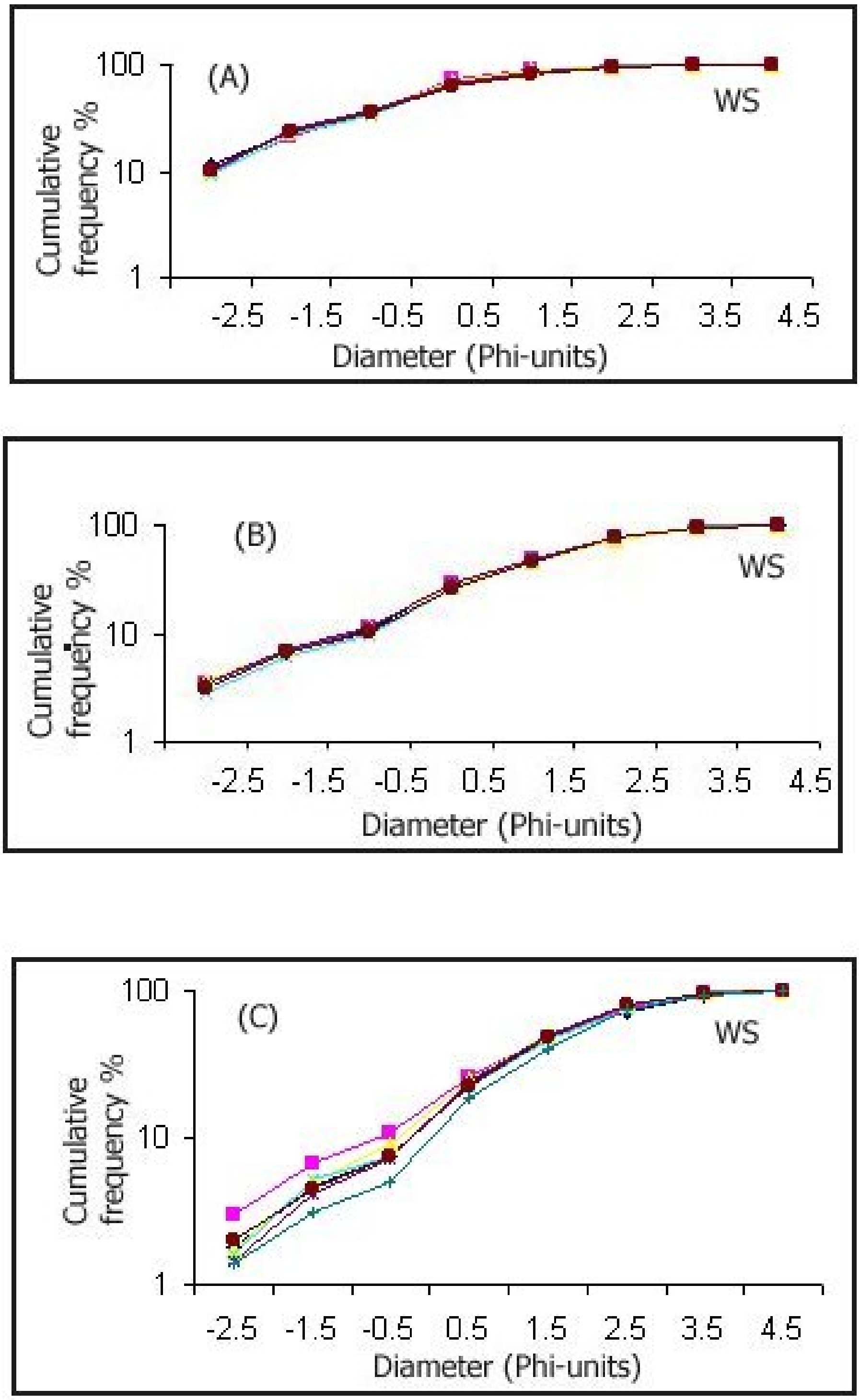

Fig.-36b: Cumulative frequency curves for the Hofuf type section samples.
A: sandy gravel, B: coarse-grained sandstone, C: fine-grained sandstone.

7-1- Mean size:

The inclusive graphic mean size of the studied samples from the type section area ranges between -0.27ø (very coarse sand) to 1.0 ø (coarse sand) with an average of 0.27ø (coarse sand). The samples from the Haradh area indicate a finer sand size. The graphic mean size ranges between -0.3 (very coarse sand) to 1.8 (medium sand) with an average of 1.0 (medium to coarse sand). Relatively similar results are also obtained from the moment method (Type section: 0.08-1.42 ø range, 0.61 ø average, Haradh: 0.2 to 1.9 ø range and 1.39). The frequency distribution of the mean values (Fig. 37) shows bimodal curves indicating the non-uniformity of the fluviatile processes responsible for the sediments of unit 1 of the Hofuf Formation. The increase of grain size of facies A samples suggests a rather increasing in energy of river relative to group C samples (fine-grained sand) (Visher, 1969).

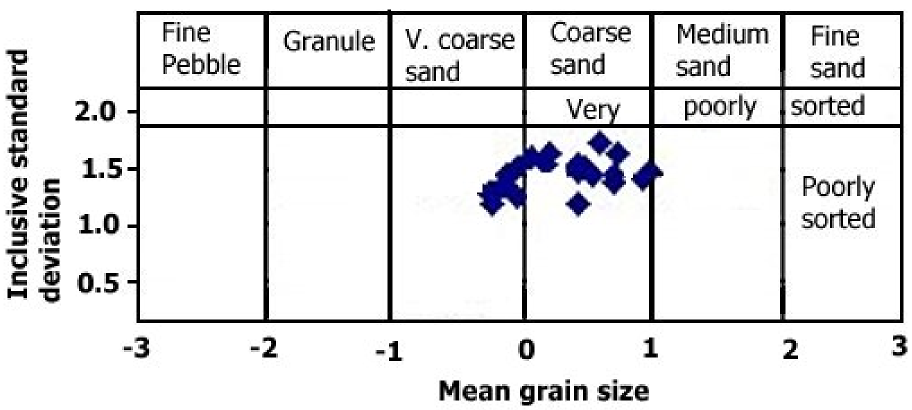

Fig.-37a: Relation between Mean grain size and standard deviation for the Type section samples.

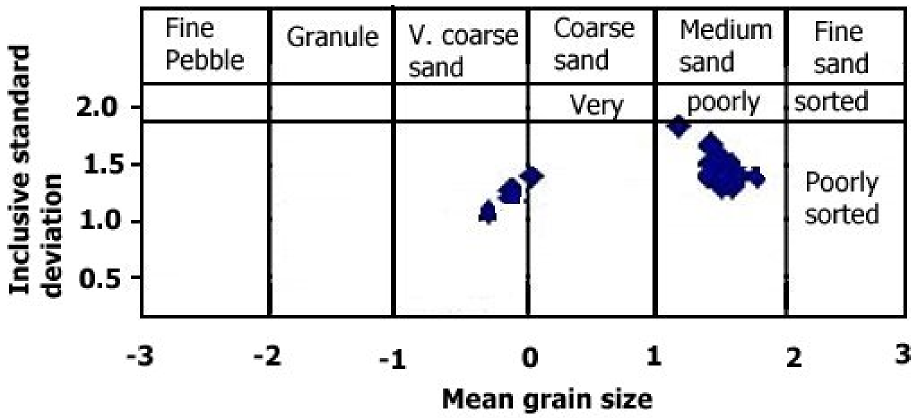

Fig.-37b: Relation between Mean grain size and standard deviation for the Haradh samples.

7-2 -Standard deviation (sorting):

Sorting of the Hofuf sandstones from the type section and Haradh areas can be described according to the formulas of Folk and Ward (1957) as poorly sorted. This sorting is reflected from the wide spread of the grain-size distribution curves (Fig. 38). The sorting values range between 1.2 to 1.8 ø and average at 1.48 ø, in the type section sands and ranges between 1.08 to 1.83 ø and average at 1.4 ø. These values are in agreement with those of most river sand, that are generally above 0.5 ø (Friedman, 1961). Results obtained from the moment method range between 1.3 to 1.86 ø and average at 1.57 ø in both of type section and Haradh areas.

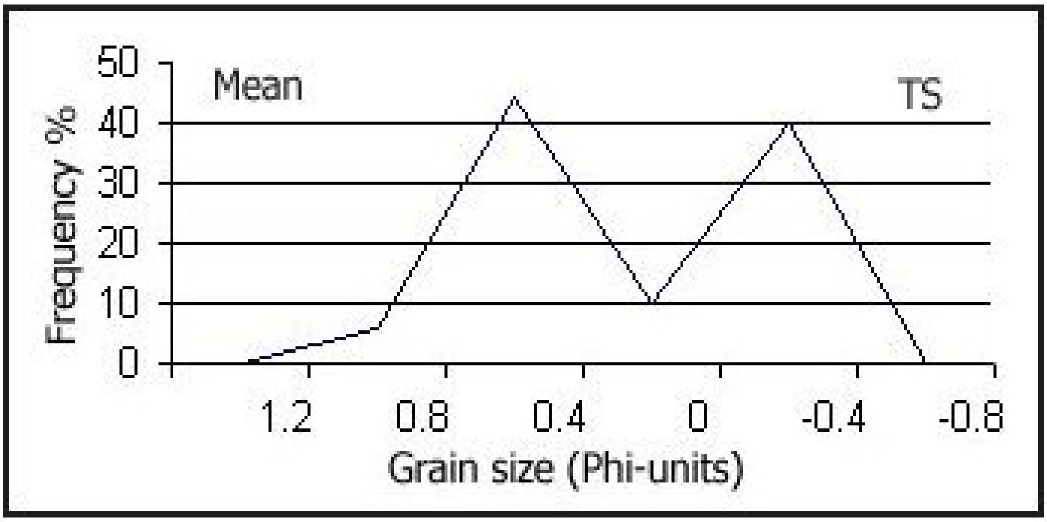

Fig.- 38a: Frequency distribution curves for the values of graphic mean of type section samples.

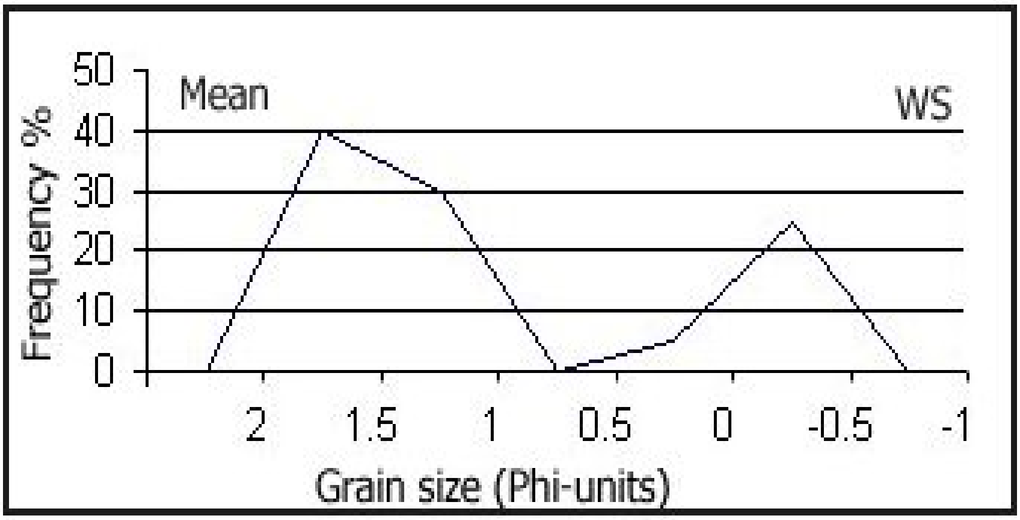

Fig.- 38b: Frequency distribution curves for the values of graphic mean of Haradh samples.

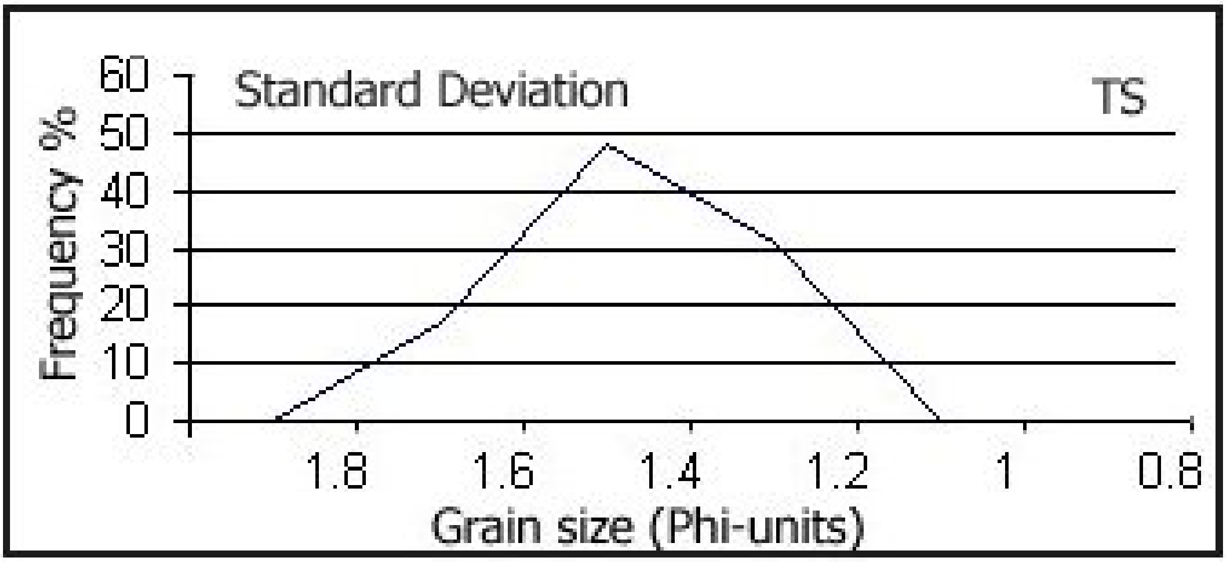

Fig.- 39a: Frequency distribution curves for the values of graphic standard deviation of type section samples.

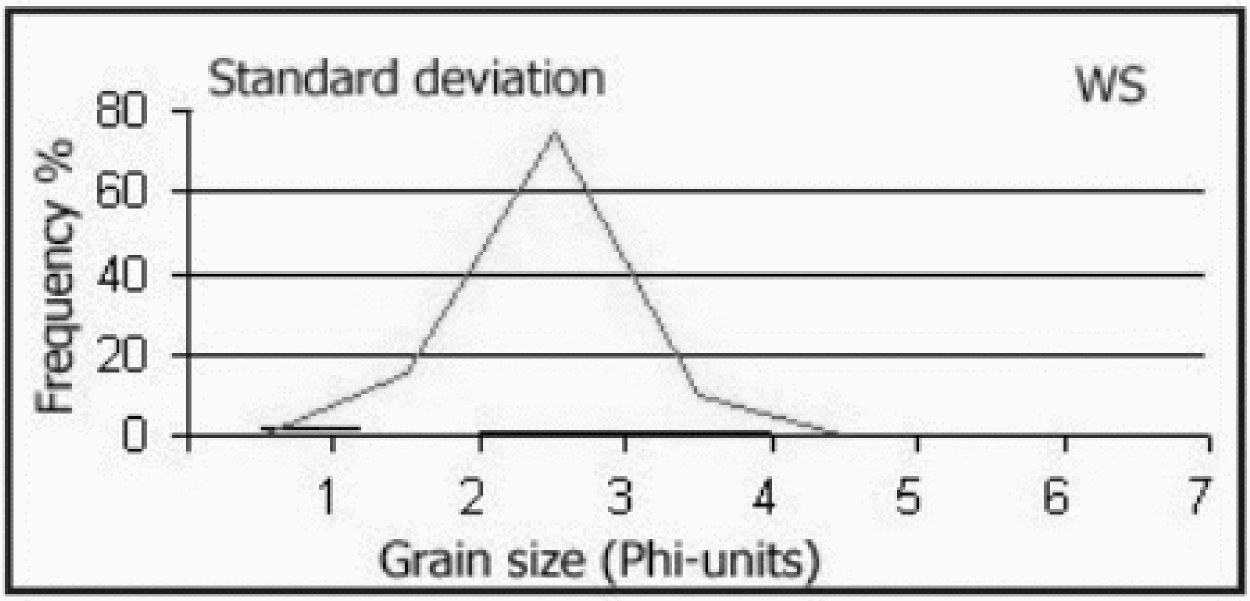

Fig.- 39b: Frequency distribution curves for the values of graphic standard deviation of Haradh samples.

7-3- Skewness:

The values of inclusive graphic skewness fluctuate between -0.13 (coarse skewed) to 0.68 (strongly fine-skewed) and average 0.27 (fine-skewed), which indicates a wide range of variation in depositional energy. The frequency distribution curve of the skewness values show two negative mode located at -0.1 (facies A) and at 0. 0.3 (facies B and C) for the Haradh samples and a single mode located at 0.1 for the type section samples (Fig. 40). The low and negative skewness value is due to an excess of coarse grains during early stages of flood (e.g., Friedman, 1967).

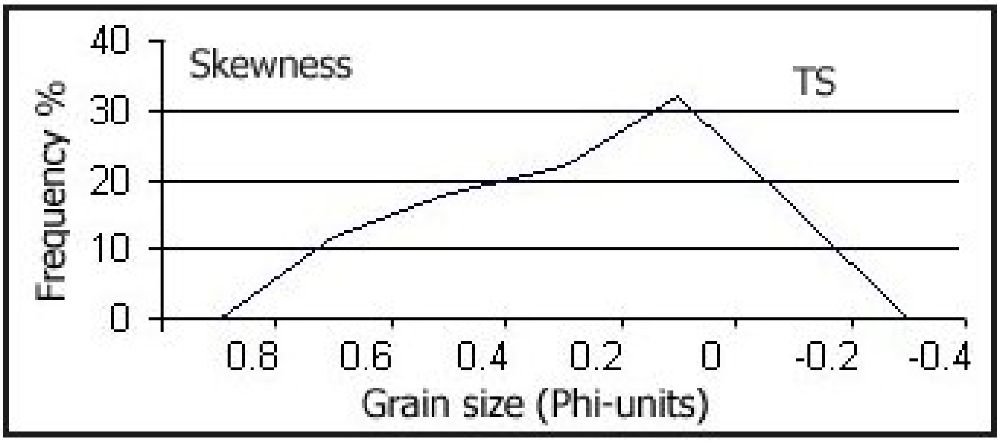

Fig.- 40a: Frequency distribution curves for the values of graphic skewness of type section samples.

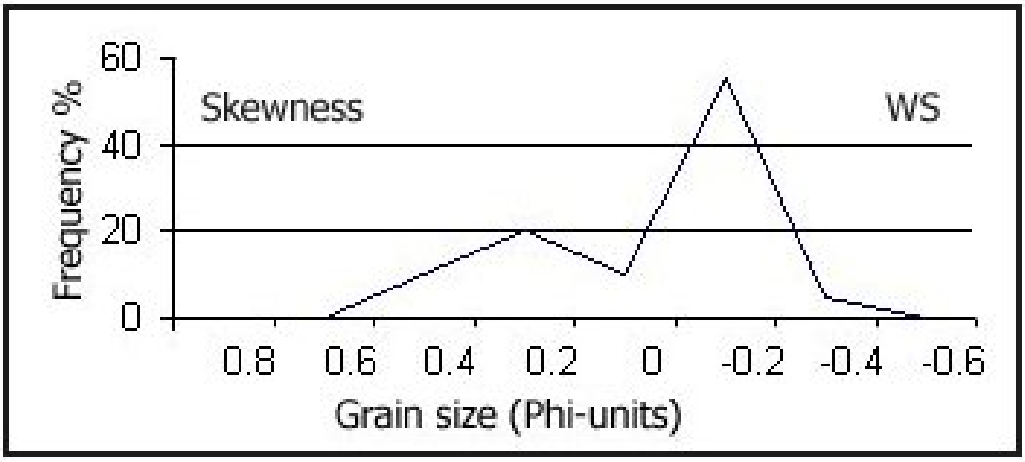

Fig.- 40b: Frequency distribution curves for the values of graphic skewness of Haradh samples.

7-4- Kurtosis:

The graphic kurtosis values show also a wide range of fluctuation (Fig. 41). They range from 0.35 (very platykurtic) to 1.7 (very leptolurtic) and average 0.99 (mesukurtic) in the type section samples and between 0.36 (very platykurtic) to 1.39 (leptolurtic) and average 0.91 in the Haradh samples. This result is also reflected by the frequency distribution curve of the kurtosis values (Fig. 42), which is also bimodal with two principal modes at 0.6 and at 1.8 in the type section area and at 0.5 and 1.1 in the Haradh area.

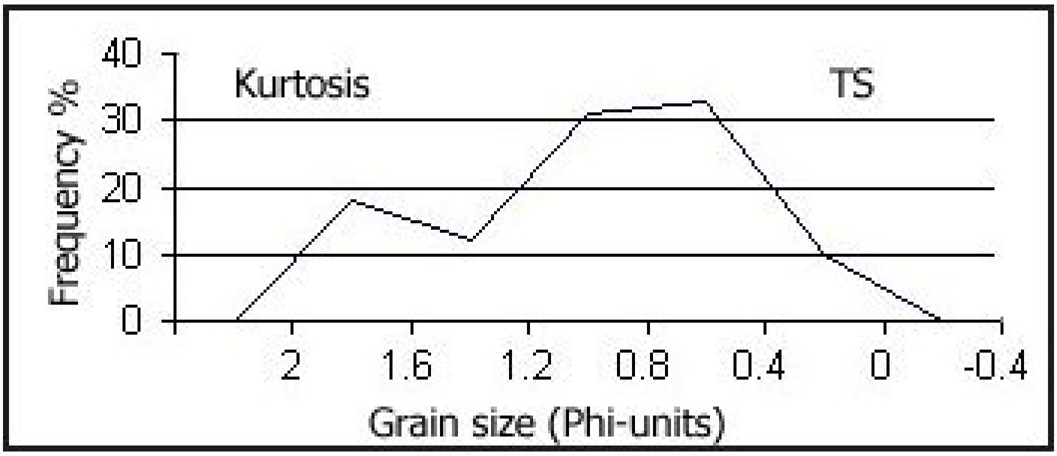

Fig.- 41a: Frequency distribution curves for the values of graphic kurtosis of type section samples.

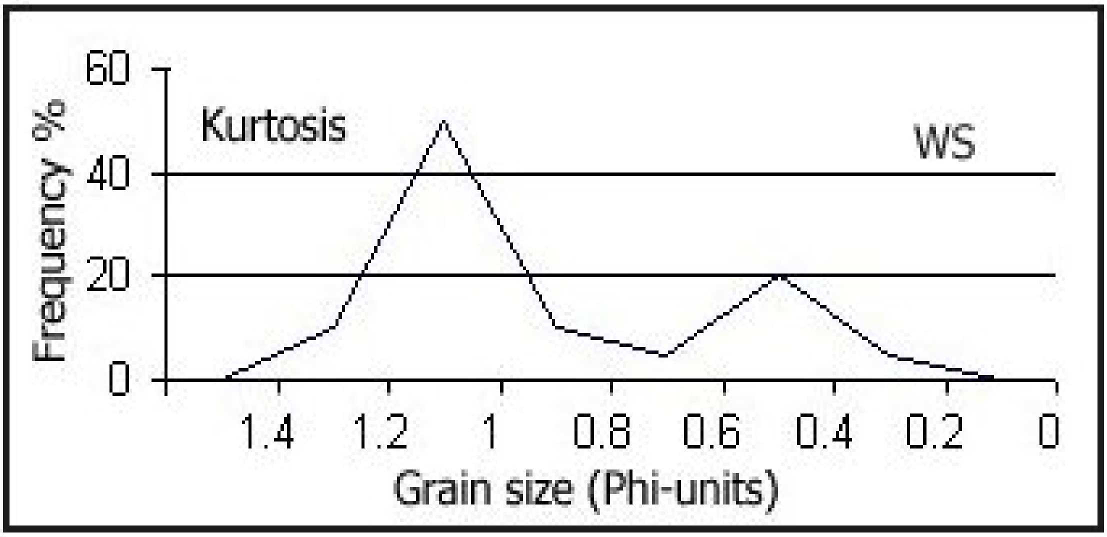

Fig. -41b: Frequency distribution curves for the values of graphic kurtosis of Haradh samples.

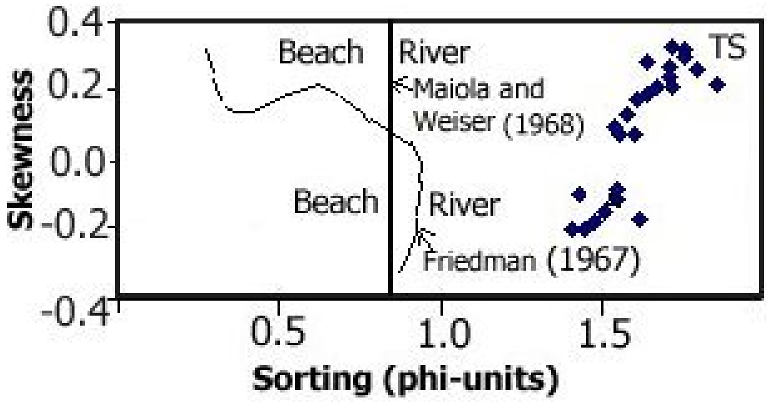

Fig.-42a:Biavariant discrimination plot of sorting versus skewness (Type section samples).

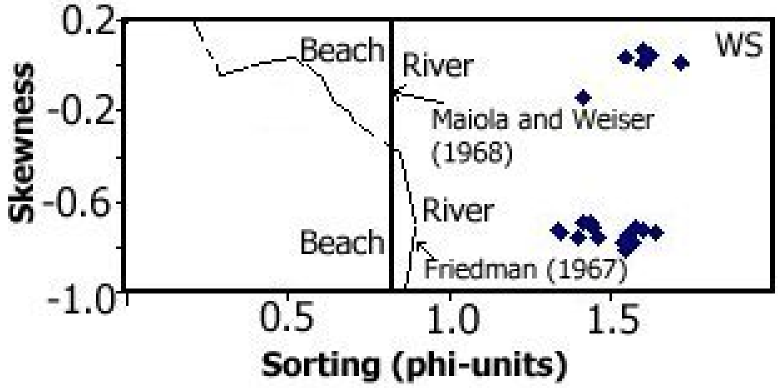

Fig. -42b : Biavariant discrimination plot of sorting versus skewness (Haradh samples).

7-5- Bivariate relationships of grain-size parameters:

Plots of sorting, skewness, and mean size are considered by several authors to be the most sensitive parameters to discriminate among depositional environments. (e.g., Folks and Ward, 1957; Friedman, 1961; Moiola and Weiser, 1968; Friedman and Sanders, 1978). Friedman (1967) used a scatter diagram of sorting versus skewness to discriminate between fluvial and marine depositional environments. Figure. 42 show that most of the samples fall within Friedman's (1967) river field. Similar results are also obtained when constructing the diagram of graphic mean versus graphic sorting (Moiola and Weiser, 1968) (Fig. 43).

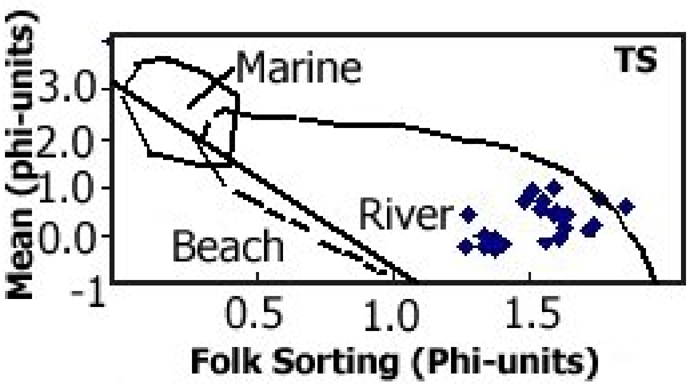

Fig.- 43a: Biavariant discrimination plot of graphic sorting versus graphic mean.(Type section samples).

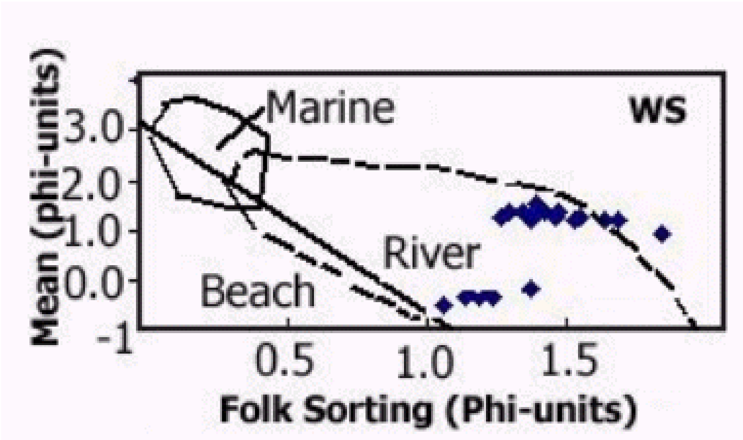

Fig.- 43b:Biavariant discrimination plot of graphic sorting versus graphic mean. (Haradh samples).

7-Petrography:

7-1- Gravel:

The petrographic study revealed that Hofuf gravels contain four petrographically distinct groups of clasts. These are: (a) volcanics; (b) granitic rocks; and (c) sediments and (d) metamorphic. The granitic and related rocks, which are the most abundant, consist of granites, pegmatite's, aplitic, granophyres and vein quartz. The volcanic and related rocks forming the second abundant rock group consists of alkali basalts, rhyolite, porphyritic rhyolites, andesites and dacites. Igneous rocks pebbles are similar petrographically to those described from the Arabian Shield (e.g., Drysdall et al., 1984; Jackson et al., 1984; Stoeser, 1986). They correlate fairly well with those of Nugrah Formation of the Hulayfah Group of Saudi Arabia.

In hand specimens the rhyolites are characterized by their color, which ranges from light brown to black, depending on the type and amount of felsic minerals present and the degree of alteration. The andesite is dark brown, gray or black with white phenocrysts of feldspar, whereas dacite usually shows a greenish color.The granite rock type shows a coarse-grained equigranular texture composed of quartz , K-feldspar , albite The pegmatite rocks are characterized by their very coarse-grained texture (> 1cm).

Metamorphic rock pebbles are quartzite and amphibolit, similar to the metamorphic rocks that outcrop in the Arabian Shield (Church, 1979; Reischmann et al., 1984). Quartzites are characterized by their light brownish color. The amphibolites are greenish color and consist of tremolite quartz and feldspar.

The sediments are least abundant and consist mainly of micritic and biomicritic limestones similar to Mesozoic and Tertiary carbonates of the Arabian Peninsula. The distribution of the various groups of clasts shows that there is no systematic change in composition or percentage of the gravels across the Hofuf Formation in the different locations.The composition is remarkably constant. Even the least predominant groups (sedimentary and metamorphic rocks) are present at every site investigated.

Disc, spherical, blade and rod shapes were recognized according to the classification of Zingg (1935). The spherical and disc-shaped pebbles are the most abundant. The rod-shaped pebbles are the least abundant. The blade-shaped pebble comes third in abundance, mainly composed of basalt and limestone. Granitic, rhyolitic, quartzite and some limestone pebbles occur mainly in spherical, disc and rod-shape.

8-2- Sand:

Thin section shows that the dominant lithology of the Hofuf is calcareous sandstone composed of fine to medium grained quartz sand embedded in a calcareous matrix. The sand is poorly sorted and shows bimodal grain-size distribution. The quartz grains are largely angular to sub-rounded and shows poor sorting.

Microscopic study showed the Hofuf sandstones are immature arkosic to subarkosic according to the classification of Pettijohn et.al., (1972).

Mineralogical compositions show a uniform framework dominated by monocrystalline quartz (65-85 vol.%) and feldspar (5-20 vol.%), pyroxene and amphibole (0-5%) with less abundant polycrystalline quartz, calcite, micas and igneous, metamorphic and sedimentary rock fragments (Table 4). Most grains are sub angular to sub rounded, and poorly sorted. Quartz occurs mainly as monocrystalline grains, some of which (~25 %) have undulatory extinction. Others (~10 %) are polycrystalline (4-6 units per grain). Feldspars are mainly albite and orthoclase, with some sandstone containing minor amounts of microcline. Most of the albite shows multiple-twins. Limestone occurs as rounded micritic to biomicritic grains. The sandstones contain a wide range of rock fragments, including metamorphic (quartz-muscovite schist and gneiss), volcanic (basalt and rhyolite), granitic (quartz-orthoclase) and sedimentary (limestone and chert). Granitic and rhyolitic fragments are the most abundant. Mica, mainly muscovite, occurs in minor amounts.Dickinson et al. (1983) suggested several QFL (quartz-feldspar-lithics) diagrams to identify tectonic setting of source areas for detrital grains. The QFL compositions of the investigated sandstones lie in the transitional, craton interior, and recycled orogen fields (Dickinson et al., 1983) (Fig. 44).

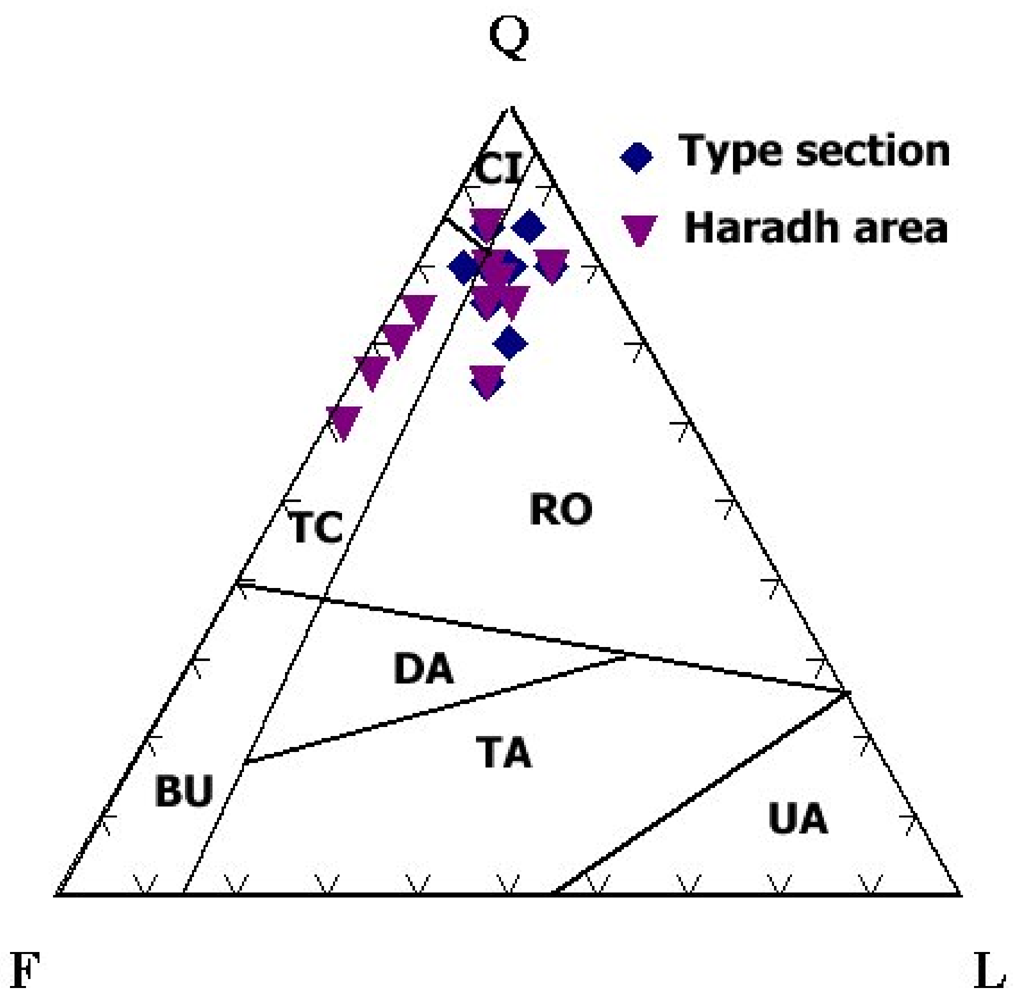

Fig.- 44: Q-F-L plot of the Hofuf samples. CI: craton interior, TC: transitional. Continental, BU: basement uplift, RO: recycled orogen, DA: dissected arc, TA: transitional arc , UA: undissected arc. Provenance fields after Dickinson et al (1983).

Table -4: Proportion of light minerals in the sandstones from the Hofuf Formation.

Sample No.	Quartz	Feldespar	Pyroxene	Amphibole	Mica	Calcite	Rock Fragments
TS-07	٦٥	٢٠	٢	٣	١	٨	١
TS-08	٨٥	٥	٢	١	-	-	٢
TS-09	٨٠	١٥	١	-	-	-	٢
TS-10	٨٥	١٠	٢	-	-	-	٣
TS-11	٨٠	١٠	٣	-	-	-	٢
TS-12	٨٠	٥	٣	٢	٣	٢	٣
TS-13	٨٥	١٠	٢	١	-	-	٢
TS-14	٨٠	١٠	٣	١	-	٢	٤
TS-15	٨٠	١٥	١	١	-	-	٣
TS-16	٦٥	٢٠	٥	٢	٢	-	٦
TS-17	٧٥	١٥	٥	٢	-	-	٣
TS-18	٧٠	١٥	٥	٢	-	٤	٤
TS-19	٨٠	١٠	٥	-	-	-	٥
TS-20	٨٥	٥	٢	١	-	-	٢
WS-01	٨٥	٥	١	-	-	-	٤
WS-02	٧٥	١٥	٢	١	٣	٣	٢
WS-03	٧٠	١٥	٥	١	١	١	٤
WS-04	٨٠	١٥	-	-	-	-	٥
WS-05	٦٥	٢٠	٥	٢	٣	٣	٥
WS-12	٧٥	١٥	٥	-	٢	٢	٣
WS-13	٧٥	١٥	٥	-	٤	٤	١
WS-16	٨٥	١٠	-	-	-	-	٥
WS-18	٨٥	١٠	٢	-	-	-	٣
WS-20	٨٠	٥	٥	٢	٣	٣	٥

8-3- Heavy minerals:

Table 5 shows that the Hofuf sediments are poor in heavy minerals. The heavy minerals range between 0.2 and 1.0 wt. % of the samples. The majority of opaque grains are identified as magnetite and limonite, with lesser amounts of hematite and limonite. The opaque occur as sub angular to sub rounded grains. They vary between 15-35 vol.% of the heavy minerals. Major transparent minerals are zircon (15-35 %), tourmaline (5-20 %), hornblende (15-35 %), pyroxene (15-45 %) and epidote (1-4 %). Minor minerals include and rutile (0-3 %) and apatite (0-2 %) . Trace minerals are garnet, kyanite, andalusite, sphene and staurolite. Amphiboles and pyroxenes (ortho- and clino-) are the dominant non-stable heavy minerals. Pyroxenes are represented by irregular to surrounded prismatic augite, diopside and enstatite in sub-equal amounts. The grains are colorless, light green and subhedral. Amphibole occurs in two varieties: green and brown basaltic. Green hornblende is the most frequent. Amphiboles occur as prismatic and subhedral corroded grains. Sub rounded greenish yellow grains represent epidote. Zircon is found in all samples as subhedral, prismatic, oval and rounded colorless grains. The tourmaline grains are brown and/or green, subrounded, and pleochroic. Garnet occurs as angular to subangular pink grains in traces. Apatite occurs in traces (< 2 %) as colorless, elongate prisms or angular to sub-angular grains. Rutile grains are reddish-brown and oval.

Table -5: Proportion of heavy minerals in the sandstones of the Hofuf Formation.

Sample No.	HM Wt.%	Opaques Vol.%	Non- Opaques Vol.%								
			Amph.	Pyrx.	Epid.	Gar.	Zir.	Tour.	Rut.	Apat.	Others
TS-07	0.6	30	٢٠	٤٠	٢	-	٣١	٦	-	١	t
TS-09	٠,٢	٢٨	٢٢	٣٥	٢	t	٢٥	١٠	٣	٣	t
TS-10	١	١٨	٢٣	٤٠	٢	-	٢٥	٨	١	١	-
TS-13	٠,٨	٢٥	٢٥	٣٥	٢	-	٣٠	٥	١	٢	-
TS-15	٠,٤	٢٥	٣٠	٤٥	١	t	١٥	٧	١	١	-
TS-18	٠,٥	٢٨	٢٥	٤٠	٤	t	٢٥	٦	-	-	-
TS-22	٠,٥	٢٥	٣٥	٢٨	٢	-	١٨	١٢	٣	-	t
TS-28	٠,٦	٣٥	٣٠	٣٠	٤	-	٢٥	٩	١	١	t
WS-01	٠,٩	٣٥	٢٥	٢٥	٣	-	٣٠	١٢	٢	٣	-
WS-03	٠,٤	١٦	١٩	٤٣	١	t	٢٢	١٣	-	١	-
WS-07	٠,٧	٣٠	٣٠	٣٥	١	-	٢٥	٧	١	١	-
WS-11	٠,٦	٣٥	٢٥	٤٠	١	-	٢٠	١٠	٣	١	-
WS-15	٠,٧	٢٨	٢٥	٣٥	١	t	٢٠	١٥	٢	٢	t
WS-17	٠,٨	١٥	١٥	٣٠	٢	-	٣٠	٢٠	٣	t	t
WS-19	٠,٤	١٥	١٥	٣٠	١	-	٣٥	١٩	-	t	t

HM: Heavy minerals, Amph: amphiboles, Pyrx: pyroxenes, Epid: epidotes, Gr:garnet Zir: zircon, Tour:tourmaline, Rut: rutile, Apat: apatite, a<0.1 others: sillimanite, kyanite, topaz,monazite.

9- Geochemistry:

9-1- Geochemical dispersion halos of Gold:

A result of gold analysis is given in Table 6. The Au dispersion anomaly at the studied area is of a limited extent in the type section area. Gold was found only within the sieved fine fractions of the samples TS-17 to TS-20, TS-28 to TS-30, and TS-22 and TS-23, which represent facies A and B respectively.

These samples represent the two upper cycles of the sand in the type section area. The highest contents (1.87 ppm) occur in the fine grained fraction (<125 um) of the uppermost cycle (sample TS-30) whilst Au content decreases in the lower samples of the upper two cycles and ranges between 0.14-1.33 ppm. The rest of the samples in the lower cycles contain a low gold content (<0.1 ppm). Total sample analyses indicate a low gold contents (<0.1 ppm) when compared to the fine grain fractions of the samples. However, the weight percentage of the fine grain fractions in the investigated samples do not exceeds 25 % of the total sample. Analyzed samples from the Haradh area represent the upper most cycle. Samples were taken from small pits at the sand surface and represent horizontal traverses within the Haradh area. High amounts of gold (4.8 to 24.2 ppm) were detected in three samples (WS-1, WS-3 and WS-19). The gold content is expected to be much higher within the fin grain size of these samples. The rest of the samples contain only a very limited amounts of gold (<0.1 ppm). No analyses have been done for the sieved fractions of the sample. We are expecting that the fine grain size fraction to contain more than 0.1-ppm gold, similar to the fine grain size from the type section area.

Table-6a: Gold analyses: Type section area (Total sample).

Sample No.	Gold ppm
TS-01-Total	<0.1
TS-03-Total	<0.1
TS-07-Total	<0.1
TS-08-Total	<0.1
TS-09-Total	<0.1
TS-10-Total	<0.1
TS-11-Total	<0.1
TS-12-Total	<0.1
TS-13-Total	<0.1
TS-14-Total	<0.1
TS-16-Total	<0.1
TS-17-Total	<0.1
TS-19-Total	<0.1
TS-21-Total	<0.1
TS-23-Total	<0.1
TS-24-Total	<0.1
TS-26-Total	<0.1
TS-28-Total	<0.1
TS-30-Total	<0.1

Table- 6b: Gold analyses: Haradh Area (Total sample).

Sample No.	Gold ppm
WS-01- Total	**12.683**
WS-03- Total	**4.833**
WS-05- Total	<0.1
WS-07- Total	<0.1
WS-08- Total	<0.1
WS-09- Total	<0.1
WS-10- Total	<0.1
WS-11- Total	<0.1
WS-12- Total	<0.1
WS-13- Total	<0.1
WS-14- Total	<0.1
WS-15- Total	<0.1
WS-17- Total	<0.1
WS-18- Total	<0.1
WS-19- Total	**24.221**

Table -6c: Gold analyses: sandy marl from the Qarah area, (Total sample)**.**

Sample No.	Gold ppm
Q1-Total	<0.1
Q4-Total	<0.1
Q6-Total	<0.1
Q7- Total	<0.1
Q8- Total	<0.1
Q9- Total	<0.1

Table- 6d: Gold analyses: Type section area , Qarah area and Haradh Area (sieved samples; F: fine, M: medium, G: coarse).

Sample No.	Gold ppm	Sample No.	Gold ppm	Sample No.	Gold ppm
TS-07-F	<0.1	TS-15-M	<0.1	TS-23-G	<0.1
TS-07-M	<0.1	TS-15-G	<0.1	TS-24-F	<0.1
TS-07-G	<0.1	TS-16-F	<0.1	TS-24-M	<0.1
TS-08-F	<0.1	TS-16-M	<0.1	TS-24-G	<0.1
TS-08-M	<0.1	TS-16-G	<0.1	TS-25-F	<0.1
TS-08-G	<0.1	**TS-17-F**	**0.65**	TS-25-M	<0.1
TS-09-F	<0.1	TS-17-M	<0.1	TS-25-G	<0.1
TS-09-M	<0.1	TS-17-G	<0.1	TS-26-F	<0.1
TS-09-G	<0.1	**TS-18-F**	**1.33**	TS-26-M	<0.1
TS-10-F	<0.1	TS-18-M	<0.1	TS-26-G	<0.1
TS-10-M	<0.1	TS-18-G	<0.1	TS-27-F	<0.1
TS-10-G	<0.1	TS-19-F	**<0.70**	TS-27-M	<0.1
TS-11-F	<0.1	TS-19-M	<0.1	TS-27-G	<0.1
TS-11-M	<0.1	TS-19-G	<0.1	**TS-28-F**	**0.76**
TS-11-G	<0.1	**TS-20-F**	**0.76**	TS-28-M	<0.1
TS-12-F	<0.1	TS-20-M	<0.1	TS-28-G	<0.1
TS-12-M	<0.1	TS-20-G	<0.1	TS-29-F	**0.80**
TS-12-G	<0.1	TS-21-F	<0.1	TS-29-M	<0.1
TS-13-F	<0.1	TS-21-M	<0.1	TS-29-G	<0.1
TS-13-M	<0.1	TS-21-G	<0.1	**TS-30-F**	**1.87**
TS-13-G	<0.1	**TS-22-F**	**0.16**	TS-30-M	<0.1
TS-14-F	<0.1	TS-22-M	<0.1	TS-30-G	<0.1
TS-14-M	<0.1	TS-22-G	<0.1		
TS-14-G	<0.1	**TS-23-F**	**0.46**		
TS-15-F	<0.1	TS-23-M	<0.1		

9-2-Geochemistry of sand:

Eight representative sand samples from different parts of the sand unit of the Hofuf Formation in the type section and Haradh area were analyzed (Table 7). The analyses indicate that the sands a similar composition in both area. They are generally rich in SiO2 (83.2-85.9 wt. %) and low in other elements.

Table-7: Analyses of representative sandstone samples.

Sample No.	TS-01	TS-03	TS-12	TS-18	WS-05	WS-10	WS-12	WS-20
Location	Type Section				Haradh			
SiO_2	٨٥,٩٢	٨٤,٥٦	٨٤,٤٣	٨٧,٥٠	٨٣,٦٦	٨٥,٧٥	٨٤,٥	٨٣,٢٥
TiO_2	٠,١٠	٠,١٠	٠,٠٥	٠,٠٥	٠,٠٥	٠,٠٢	٠,٠٢	٠,٠٢
Al_2O_3	٤,٠٨	٤,٥٢	٠,١٠	١,٦٥	١,٨٥	٣,٤٥	٤,٨٤	٤,٦٧
Fe_2O_3	٠,٧٢	٠,٦٢	٠,٦٩	٠,٨٥	٠,٩٠	١,٢٠	١,٠٥	٠,٨٥
MnO	٠,١	٠,١٠	٠,١٠	٠,١٠	٠,١٠	٠,١٠	٠,١٠	٠,١٠
MgO	٠,٥٦	٠,٨٢	٠,٧٥	١,٤٥	١,٢٣	١,٠٥	٠,٨٧	٠,٦٦
CaO	٣,٣٠	٣,٨٥	٦,٠٨	٤,٩٥	٤,٣٤	٥,٥٠	٥,١٢	٤,٨٧
Na_2O	٠,٧٦	٠,٥٥	٠,٥٠	٠,٤٥	٠,٥٤	٠,٢٣	٠,١٥	٠,٢٢
K_2O	٠,٠٢	٠,١١	٠,٠٩	٠,٤٣	٠,٢٢	٠,١٣	٠,١٥	٠,٢١
P_2O_5	٠,٠٢	٠,٠٥	٠,٠٥	٠,٠٤	٠,٠٤	٠,٠٦	٠,٠٦	٠,٠٢
L.O.I.	٣,١٠	٣,٢٢	٥,٥٤	٣,١٠	٣,٢٠	٤,١٠	٢,٩٠	٢,٩٠

10- Discussion:

At an early Mio- Pliocene stage, there were probably several north-south-flowing streams within the Arabian Peninsula, following the various scarp-and-vale grooves, and carrying gravels and sand from local sources. Further to the west, a huge north-south-flowing paleoriver is postulated, fed from catchments much further north and carrying a wider lithological range of pebbles, including crystalline materials derived from the Arabian Shield. Progressively, the escarpments forming the eastern watersheds of these rivers "chased" each other eastward by downdip shift, with periodic downdip breaching suddenly enlarging the headwaters of another drainage system to the east. Further, once a particular escarpment had been breached, the possibility of a later diversion further upstream always remained. Thus, a sequence of downdip breaches would occur at progressively upstream locations along a particular scarp. During this progressive diversion of the southern extent of such drainage systems, a succession of Hofuf gravels flooded into areas to the east.

Geomorphologically, the area to the west and south of Haradh and Al-Hofuf area is characterized by its rugged topography that has been formed due to continuous erosion and development of the drainage pattern. The Precambrian rocks of the Arabian shield are traversed by numerous wadis that have been surveyed for their stream sediments

A palio-Quaternary age for the central and eastern Arabian graben systems has been suggested by Vaslet et al. (1991) and recently supported by Weijermars (1998). During this time, the northeast separation of Arabia from Africa began. In Late Miocene-Pliocene time, renewed activity caused by the breaking of the basement crust and the start of the Red-Sea floor spreading. The Alpine movement of the Zagros mountain range during Tertiary have raised the gradient of the Arabian shield and platform from west to east and large areas were subjected to denudation. The effect of repeated basement uplift and tilting associated with the Red Sea rifting and faulting led to the development of a continental slope that initiated a series of drainage systems flowing toward the east during the Pliocene and Pleistocene (e.g., Al-Sulaimi, 1994; Al-Sulaimi and Pitty, 1995; Al-Sulaimi and Mukhopadhyay, 2000). The Hofuf gravels and coarse-grained sands of Eastern Province, Saudi Arabia and the Dibdibba gravel of Kuwait, present the deposits laid down by such streams, running from the western highland of the Arabian shield across the scarpland into the eastern part of Saudi Arabia at the Hofuf area, the State of Eastern Province and the northern part of the State of Kuwait. It seems to be evident from the volume of Neogene sediment deposited that a pluvial and humid climate prevailed during the Miocene and Pliocene (Whybrow and McClure, 1981; Edgell, 1989).

It is easy to agree that the action of exceptional floods in extreme fluvial conditions was involved in the deposition of Hofuf gravels. Fuchs et al. (1968) thought that powerful rivers were involved. It is much less easy to envisage the circumstances under which these extreme conditions arose.

McClure (1978) supposed that a period of rainfall, considerably greater in magnitude than any of the Pleistocene would seem necessary to have carved out the main through-flowing wadis of the Arabian Peninsula. Anton (1984) introduced circularity into the argument by supposing that a semi-arid climate probably can explain the required erosion and necessary trans-portational competence. Elsewhere, he then supposed that coarse formations, as along the Wadi As-Sahba, indicate the former existence of a semi-arid environment. In such regimes, it would be the occasional flash flood with great competence for debris transport that was involved. Hoetzl and Zoetl (1984) envisaged a different prevailing climate, arguing for a tropical, hyper-humid regime during the transition from late Pliocene to early Pleistocene.

Holm (1960), one of the first to generalize about major paleowadis in the Arabian Peninsula, referred to the crystalline uplands and the sedimentary steppes of the northern Najd as a source area. Milton (1967), also suggested a source in the Najd and the Hijaz areas near the western edge of the Arabian Shield as the possible source for a group of highly rounded pebbles. These are composed of quartz and metamorphic rocks, with lesser amounts of silicic igneous rocks.

The light and heavy minerals in the Hofuf Formation reveal a main mineralogical province dominated by quartz and feldspar and zircon, tourmaline and silicates (pyroxene, amphibole, epidote, garnet). The parent rocks provided the initial control on the composition of the heavy mineral suite. If the heavy minerals in the source area are sufficiently distinctive, the grains can be traced into the adjacent sandstones. The mineralogical assemblage is characteristic of mixed sediments from two types of source rocks: acidic plutonic rocks (zircon, tourmaline and rutile) and basic igneous and metamorphic rocks (amphiboles, pyroxenes, epidotes). The unstable heavy minerals, with much hornblende, pyroxene and epidote, indicate an elevated metamorphic and magmatic terrain. Transport was fast and without intensive weathering, thus preserving much of the composition of the source rocks. However, the predominance of quartz in the fine-grained sandstone facies may indicate severe chemical weathering, and possibly long transport distance. Petrological data indicate variable composition of the pebble. Igneous and metamorphic pebbles were eroded from the Arabian shield, whereas chert and carbonates could have been derived from the Phanerozoic succession of the Arabian platform. Quartz-types (mostly mono-crystalline and non-undulatory) indicate that the Hofuf sandstone was derived from plutonic source rocks (e.g., Basu et al., 1975). The petrographical characteristics of the sand and volcanic and plutonic clasts in the in unit 1 of the Hofuf gravels indicate that they are derived from the same source. These sands and gravels came from the basement complex of the northeastern area of Saudi Arabia in sheet floods and were deposited in the alluvial fan of Wadi As-Sahba fault system (Weijermars, 1998).

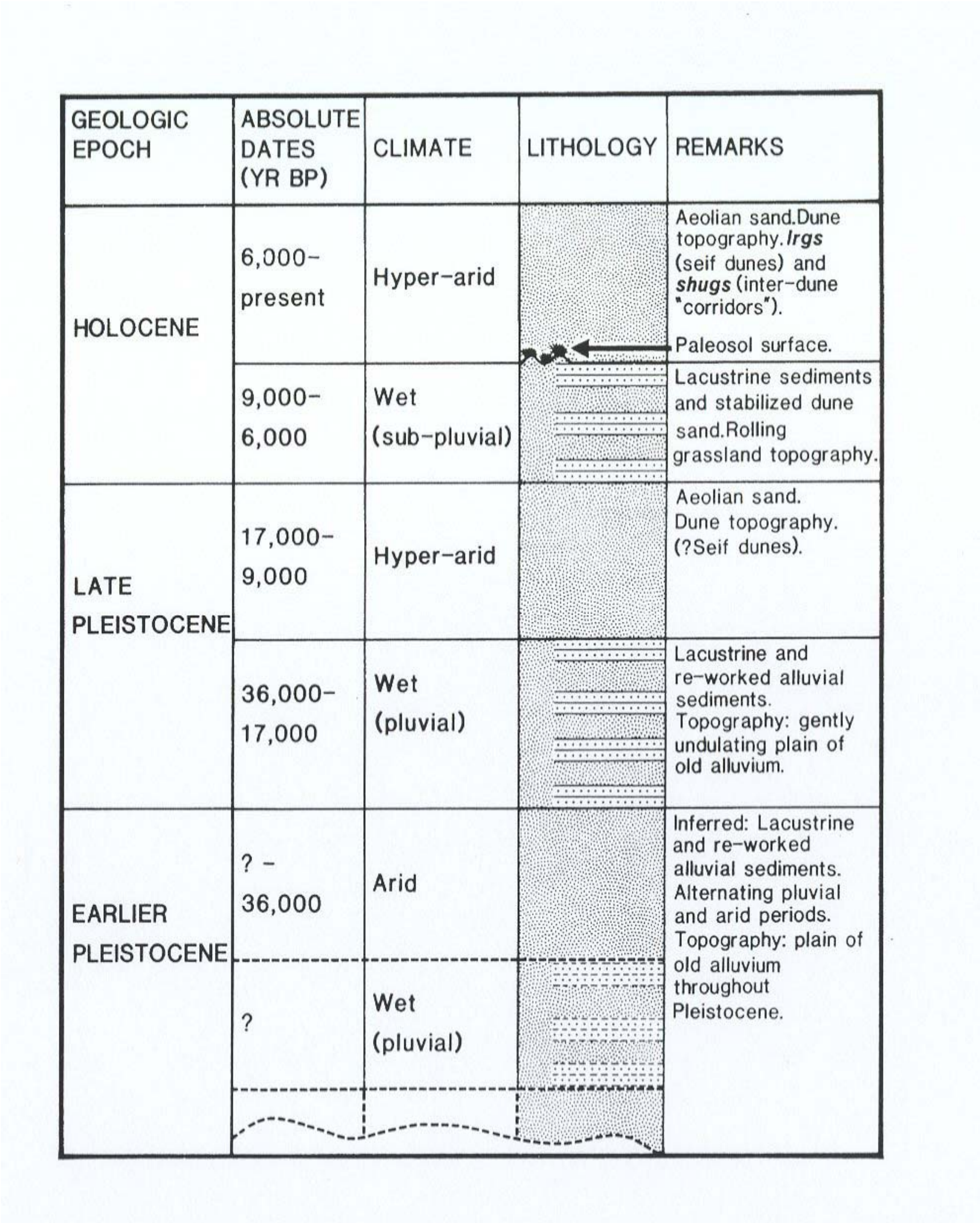

Fig.- 45: Paleoclimate in Saudi Arabia.

Paleotectonic reconstructions by Beydoun (1991) (Fig. 46) show that during the time when Hofuf Formation was being deposited. the northeastern part of the Arabian Peninsula was located close to the equatorial belt. While the northeastern edge of the Arabian Plate was still within the realm of carbonate deposition (between 30° north and south of the equator), humid climate coupled with collision and uplift of The Zagros crush zone created favorable conditions for increasing clastic influx in the depositional basin. Paleogeographic reconstruction of the Middle East by Murris (1980) shows that most of the Arabian Peninsula was dry during this period with well-established network of drainage showing flow to the northeast The dominant lithology of the Hofuf Formation at the Type section area is calcareous sandstone with abundant fine to medium-grained quartz. The sand is poorly sorted and shows bimodal grain-size distribution. The nature and distribution of the sand indicate derivation from more than one source. Based on the grain-size disuibution, paleogeography including the drainage, a westerly provenance (Arabian Shield and older clastic sequences) is a strong possibility. The subsidiary source should be the molasses type sediments that were shed from the rising Zagros and Taurus ranges to the northeast. Sedimentological evidences including presence of rhizocretions of mangrove origin suggest a fluvial flood plain to coastal depositional setting.

The QFL composition of the Hofuf sandstones (Fig. 44) indicates that the sediments were derived from craton interior through transitional continental and recycled orogense sources. In such provinces, granites and high-grade metamorphic rocks crop out in an area of low topographic relief subjected to deep weathering and might be associated with wrench tectonics' (Dickinson et al., 1983; Lee and Sheen, 1998; Anani , 1999). This is consistent with the steep change in curvature of the wrench fault in the basement beneath the Nisah-As-Sahba graben. Field studies have revealed the presence of large , shallow-marine gravel fan-delta deposits, dated at Late Pliocene to Early Pleistocene, emanating from Wadi As-Sahba (Weijermars, 1998). This implies that the Nisah-Sahba fault, which controls the course of Wadi As-Sahba, probably had already been initiated in the Late Pliocene. A length of 450 km has been established for the Nisha-Sahba fault Zone (Weijermars, 1998). The eastern segment of the Nisha-Sahba fault has been interpreted as a sinistral-strik-slip zone, with minimum lateral displacement of 5 to 8 km, accompanied by a minor up throw of the northern wall of only a few meters (Weijermars, 1998).The Alpine movement of the Zagros mountain range during Tertiary have raised the gradient of the Arabian shield and platform from west to east and large areas were subjected to denudation. Wadi Sahba is a witness for the tectonic movement of the eastern Arabian block which contributed to the sedimentation of the Hofuf formation. The Arabian shield includes granitic, rhyolitic, sedimentary and metamorphic rock assemblages that may have provided the rock fragments of the Hofuf.

The initial assumption in developing a paleowadi model is that the land surface and its relationship to underlying rocks and structures is broadly similar to that of the present day. Possibly, the Arabian Shield was slightly less exposed and more gently tilted, with the dip in the scarp lands to the east, perhaps even flatter too. With scarps less dissected, it is also assumed that the dominant initial drainage was strike-controlled, following the lithologically weaker zones between the scarps.

The area considered is several hundreds of kilometers in extent (Fig. 47). There are many parallel escarpments, each with several breaches and associated gravel fans at their downstream outlets Of the escarpments, the most striking is the sequence forming the Jabal Tuwayq. The largest and most persistent of these is formed by the Tuwayq Mountain Limestone Formation. It extends in a curve, concave to the west, over a distance of some 1200 km from south to north (Fig. 11).

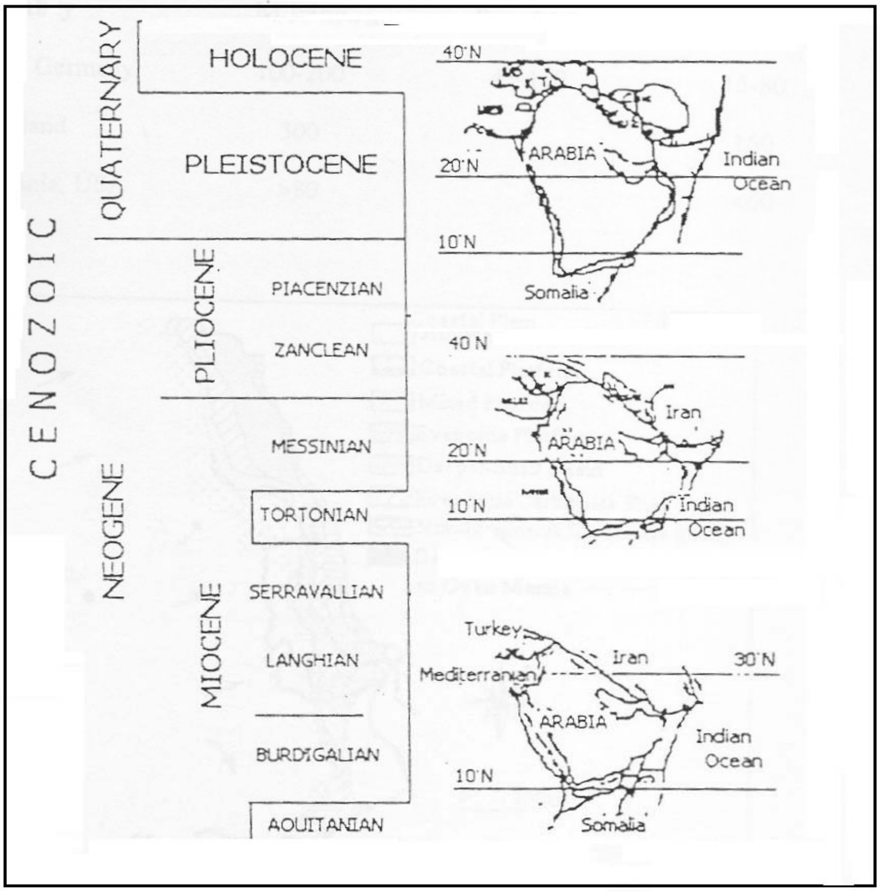

Fig.- 46: Paleotectonic position of the Arabian Plate (After Beydoun, 1991).

Escarpments farther east include that of the Aruma Formation, which outcrops from 200N to beyond the Saudi-Iraq border, a distance of over 1600 km. Its outcrop belt is breached by a superficial cover at only a few places (Powers et aI., 1966).

Although it is postulated that the deposition of the Hofuf gravels was from different source, it is also suggested that their deposition occurred within a comparatively short geological time span, linked to the Zagros orogeny, which culminated about 3.3 Ma ago. This considerable and rapid uplift to the north and northeast of the Arabian Peninsula probably increased significantly the headwater gradients of the major paleoriver. Equally, the actual increase in altitude in such areas would also have induced much heavier orographic precipitation. Thus, the steeper gradients and greater discharge probably combined to substantially increase the transportation power of the paleoriver.

In Upper-Pliocene time, tectonic movements caused the formation of Salwa syncline and Dukhan anticline in Eastern Province. Continuous wind-erosion created mesa structures and deflation of the upper horizon of the Hofuf deposits. In the Late Pleistocene time, a major pluvial phase occurred (McClure, 1984), coinciding with the last glacial maximum. During this pluvial phase, the whole Hofuf area was an inland lake and a great river flow from Arabian shield to the Arabian Gulf, mainly south Eastern Province (Holm, 1960; McClure, 1984; Edgell, 1989), also noted by the Greek geographers as the Aftan River (Golden, 1984). The drainage channel of this river was fault-controlled

The sediment structures indicate an enormous fluvial transport. The abundant pebbles suggest transportation by vigorous floods and the cyclic sedimentation indicate variation in the depositional media and in the energy of the river during wet and dry periods. It seems evident from the volume of Neogene sediment deposited that a pluvial and humid climate prevailed during the Miocene and Pliocene (Whybrow and McClure, 1981; Edgell, 1989). Stream erosion was active at this pluvial time, and sediment transport was from west to east. The upstream sediments were deposited in a deltaic environment at Hofuf and at Wadi As-Sahba in southern Eastern Province.

Petrological data of the Hofuf rocks indicate variable composition of the pebble. Igneous and metamorphic pebbles were eroded from the Arabian shield, while chert, carbonates could have been derived from the Phanerozoic succession of the Arabian platform. Quartz-types (mostly mono-crystalline and non-undulatory) indicate that the Hofuf sandstone was derived from plutonic source rocks. Modal composition of the sandstones indicates a transional continental to a craton interior and recycled orogene provenance. Wadi As-Sahba is a witness for the tectonic movement of the eastern Arabian block, which contributed to the sedimentation of the Hofuf formation. Field studies have revealed the presence of large, shallow-marine gravel fan-delta deposits, dated at Late Pliocene to Early Pleistocene, emanating from Wadi As-Sahba (Weijermars, 1998). A length of 450 km has been established for the Nisha-Sahba fault Zone (Weijermars, 1998). In the Late Pleistocene time, a major pluvial phase occurred (McClure, 1984). During this pluvial phase, a great river flow from Arabian shield to the Arabian Gulf, mainly south Eastern Province (Holm, 1960; McClure, 1984; Edgell, 1989), also noted by the Greek geographers as the Aftan River (Golden, 1984).The abundant pebbles suggest transportation by vigorous floods and the cyclic sedimentation indicate variation in the depositional media and in the energy of the river during wet and dry periods. The unstable heavy minerals in the Hofuf sands, with much hornblende, pyroxene and epidote, indicate an elevated Metamorphic and Magmatic terrain. Transport was fast and without intensive weathering, thus preserving much of the composition of the gold-bearing source rocks. However, the predominance of quartz in the fine-grained sandstone fraction may indicate severe chemical weathering, and possibly long transport distance.

Gold content in the same size fractions of the sampled sedimentary cycles showed that the highest gold concentrations are found in the upper alluvial units (cycle 7 and 8). The highest geochemical response of gold is found in the fine (<125 um) fractions of the upper tow cycles of the type section area. The dispersion trend decreases in the lower cycles, possibly due to an increase in discharge energy with time. Higher gold content is documented at Haradh area, which is nearer to the source area.

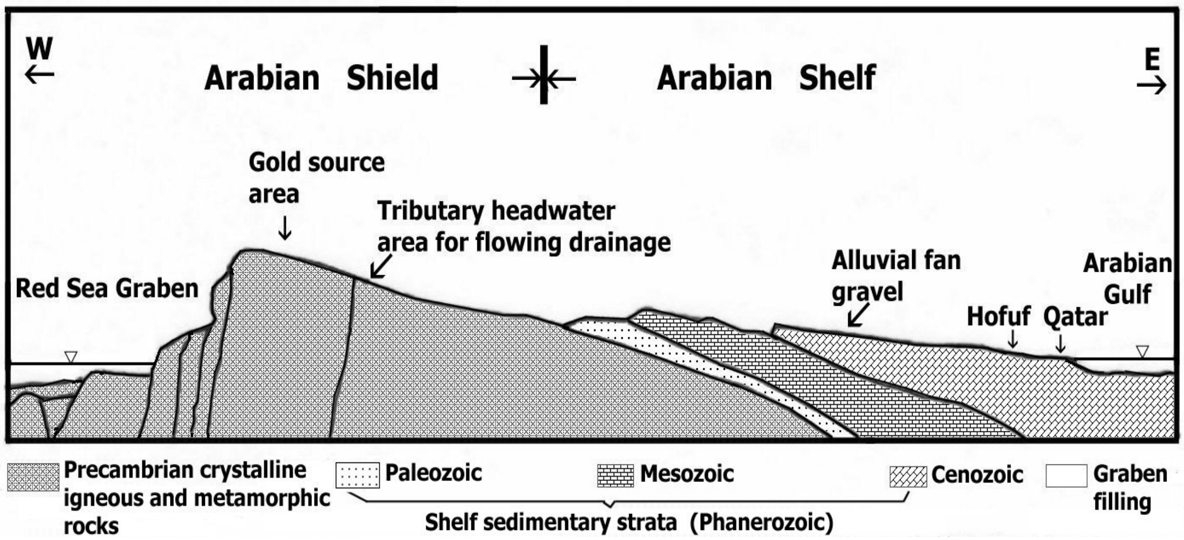

Fig.- 47:Geological cross-section of the Arabian Peninsula (After Chapman, 1978).

11-Conclusions:

The Sandstones of the Hofuf Formation were deposited largely on stream channel along Wadi As-Sahba over a total distance of 450 kilometer. Hofuf gravels and sands are the creation of the westward diversion, through escarpment breaking, of a large paleo-river. It seems evident from the volume of Neogene sediment deposited that a pluvial and humid climate prevailed during the Miocene and Pliocene of Arabia. Stream erosion was active at this pluvial time, and sediment transport was from west to east. The upstream sediments were deposited in a deltaic environment at Hofuf and Haradh at Wadi As-Sahba in southern Eastern Province. This suggests that the Hofuf gravels and sands are the creation of the westward diversion, through escarpment breaking, of a large paleoriver. The drainage channel of this river was controlled by the As-Sahba fault. The gold of the Hofuf Formation is probably related to weathering and transport of gold-bearing igneous rocks from the Arabian Shield. A detailed investigation on gold dispersion in the sands of the Hofuf Formation of Saudi Arabia and Kuwait is recommended in order to study the dispersion trend of gold near the source area. The Haradh alluvial fan, part of which is the lower unit of Hofuf Formation, is the product of a dynamic past. The Haradh fan is the creation of a large paleoriver that once flowed southward down almost the full width of the Arabian Peninsula. Its headwaters could have been as far west as the Hijaz Mountains.

The gold content in unit 1 of the Lower Hofuf Formation is encouraging in all aspects. However, this research represents a pilot study. A detailed program of sampling along the whole area of the Haradh fan, Wadi As-Sahba and the type section area has to be carried out in order to give more reliable picture of gold dispersion and its economic potential.

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التوضعات المكانية للذهب ضمن تشكيلة الهفوف المتكشفة في الجزء الشرقي من المملكة العربية السعودية

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الملخص:

تتكشف في الجزء الشرقي من المملكة العربية السعودية بمنطقتي الهفوف و حرض توضعات لحقية من الحجر الرملي الكونغلوميراتي الناعم إلى الحصوي تعود بأعمارها إلى الميوسين الأعلى و البليوسين . تشكل هذه التوضعات اللحقية الرملية الكونغلوميراتية ما يسمى محلياً بتشكيلة الهفوف ، التي ترسبت غالباً و بجزء كبير منها ضمن قنوات نهرية ضخمة امتدت على طول وادي السهبا و لمسافة تصل إلى ٤٥٠ كم . تعكس البنية الجيولوجية لوادي السهبا بنية انهداميه صدعيه تشكلت نتيجة مجموعة من الصدوع الانزياحية الحركية و الطيات الجانبية المرافقة والتي تعود بتشكلها إلى عصري البليوسين و الرباعي ، لذا فإن تطور تشكيلة الهفوف يرتبط ارتباطاً و ثيقاً مع التطور التكتوني للجزء الشرقي من الصفيحة العربية في عصر النيوجين ، و تمثل رسوباتها غير الناضجة شواهد لتصنيف ميكانيكي سيئ و رديء و تعتبر أجزاء مشتقة من الصخور الغرانيتية إضافة إلى بعض الصخور البركانية و الصخور المتحولة و الرسوبية العائدة لصخور المرتكز البريكامبرية و الصخور الفانوروزوية.

تتضمن تشكيلة الهفوف الرملية ثلاثة سحنات ليثولوجية تتميز عن بعضها البعض هي مجموعة الحصى و الكونغلوميرات ، حجر رملي متوسط الحبيبية و حجر رملي ناعم الحبيبية.

يظهر تركيب الحجر الرملي وفرة و سيطرة البلورات المستقلة من الكوارتز و الصفاح و بشكل أقل تتواجد تجمعات بلورية من الكوارتز و الكالسيت و الميكا إضافة لأجزاء حطامية تعود لصخور مغماتية ، متحولة و رسوبية ، يعود مصدر الكوارتز بشكل أساسي للصخور المغماتية البلوتونية ، كما تتميز تركيبة الفلزات المعدنية الثقيلة بوفرة الفلزات غير الثابتة خاصة فلزي الهورنبلند و البيروكسين. تمثل الحصوات الكبيرة أجزاءً من صخور الصفيحة العربية ، تشتمل على بقايا صخور مغماتية - (غرانيت،ريوليت،بازلت،أنديزيت و بغماتيت كوارتزي) ، صخور متحولة- و صخور رسوبية التركيب. يشير مخطط التركيب النموذجي للحجر الرملي لتشكيلة الهفوف إلى بيئة تشكل انتقالية تتراوح بين النمط القاري و النمط المتطور في النطاقات الأوروجينية الداخلية.

تبلغ سماكة الوحدة السفلى لتشكيلة الهفوف الرملية المتكشفة في المنطقة الشرقية من المملكة العربية السعودية حوالي العشرين متراً و تتألف على الأقل من ثمانية دورات ترسيبية ، تتألف كل دورة ترسيبية

من الرمال و الحصى و الكونغلوميرات ، أي بشكل دقيق من حبيبات رملية خشنة كونغلوميرات يتبعها حجر رملي متوسط الحبيبية فحجر رملي أركوزي ناعم الحبيبية ، تتميز توضعات الحصى و الكونغلوميرات بغناها بحصيات متنوعة من الصخور النارية و المتحولة (غرانيت، بازلت، شيست ، كوارتزيت و أمفيبوليت) و المشتقة غالباً من صخور الدرع العربي الغنية بخام الذهب ، بالإضافة إلى حصيات من صخور الحجر الشيرتي ، الجيري ، الدولوميتي و المارلي و المشتقة غالباً من صخور السطيحة العربية الفانوروزوية .

تم جمع و نخل و تخزين ستون عينة ممثلة لتشكيلة الهفوف المتكشفة في الجزء الشرقي من المملكة العربية السعودية في منطقتي الهفوف (جبل قارة و منطقة المقطع الرئيس النموذجي) و حرض بهدف تحديد محتوى عنصر الذهب بها كمؤشر جيوكيميائي لتوضعات الذهب و التي تم الكشف عنها في الوحدة السفلى من تشكيلة الهفوف.

تم نخل كافة العينات المأخوذة من المقطع الرئيس النموذجي لتشكيلة الهفوف و من منطقة حرض من أجل استبعاد الأجزاء التي تزيد أقطارها عن الـ> Φ٤٠٠ ، ثم قسمت العينات إلى جزأين ، يمثل الجزء الأول كامل العينة ، بينما تم نخل الجزء الثاني إلى ثلاثة مجاميع هي (٤٠٠-٢٥٠ Φ ، ٢٥٠-١٢٥Φ و < ١٢٥Φ) . أما بالنسبة لعينات منطقة جبل قارة فلم تخضع لعملية النخل بسبب صلادتها و تماسكها الشديد.

حللت ١٧٤ عينة تمثل معظم العينات المأخوذة من منطقة حرض و المقطع الرئيس النموذجي و عينات جبل قارة(العينات الكلية و عينات ناتج النخل الثلاثة) من أجل تحديد عنصر الذهب بها . و أظهرت النتائج أن الأجزاء الناعمة < ١٢٥Φ للعينات الممثلة للدورتين العلويتين من المقطع الرئيس لتشكيلة الهفوف الرملية (TS-17 إلى TS-23 و TS28 إلى TS-30) تحتوي على الكميات الأعلى (التراكيز الأكبر) من الذهب تتراوح بين (٠,١٦- ١,٨٧ غرام/طن) ، بينما تحتوي أجزاء الرمل متوسطة الحبيبية أو الخشنة لعينات المقطع الرئيس النموذجي على كميات قليلة من الذهب لا تتجاوز ٠,١ غرام/طن ، كذلك تحتوي العينات الممثلة للدورات الترسيبية السفلى من المقطع الرئيس النموذجي لتشكيلة الهفوف على كميات قليلة من الذهب لا تتجاوز ٠,١ غرام/طن ، لذلك يمكن القول بأن محتوى الذهب الأكثر تركيزاً يكون في الدورتين الترسيبيتين العلويتين TS-17 إلى TS-23 و TS28 إلى TS-30 و يتناقص في الدورات الترسيبية السفلى الممثلة بالعينات من TS-1 إلى TS-16 .

جمعت العينات المأخوذة من منطقة حرض WS مباشرة من على السطح الخارجي و على طول امتداد وادي السهبا ، و من الأجزاء العليا للدورة الترسيبية الأخيرة ، تشير نتائج تحليل عنصر الذهب في عينات منطقة حرض إلى تشتت شواذات هذا العنصر بشكل كبير خاصة في ثلاثة مواقع ممثلة بثلاثة عينات هي WS-19 التي تحتوي على نسب مرتفعة من الذهب تصل إلى 24.22 غرام/طن ، بينما تحتوي العينة

WS-1 و ٣-WS على التوالي 12.58غرام/طن و 4.٨٣ غرام/طن من الذهب ، و تحتوي بقية العينات على كميات قليلة من الذهب لا تتجاوز ٠,١ غرام/طن.

أظهرت نتائج تحليل العينات الصخرية الجيرية و الغضارية و الرملية العائدة للوحدتين الثانية و الثالثة من تشكيلة الهفوف الرملية و التي أخذت من منطقة جبل قارة أنها تحتوي على كميات قليلة من الذهب لا تتجاوز ٠,١ غرام/طن.

إن النتائج الأولية لهذه الدراسة ، خاصة المينرالوجية منها توصي بأن الرسوبات اللحقية النهرية لتشكيلة الهفوف المتكشفة في منطقة المقطع الرئيس النموذجي و حرض قد تمثل هدفاً واعداً لاستكشافات جيوكيميائية للعديد من العناصر الكيميائية خاصة الذهب.

لقد بينت نتائج تحليل العينات المدروسة إلى احتواء عنصر الذهب بنسب تزيد عن ٢٤ غرام/طن و هي قيم اقتصادية واعدة ، كما أن تغير الخلفية الطبيعية لتركيز عنصر الذهب و التغيرات الليثولوجية المرافقة توحي إلى وجود عدة مصادر متعددة للذهب.

فالمصدر الرئيس للذهب المتواجد في رسوبات تشكيلة الهفوف الرملية يعود بشكل محتمل إلى تجوية صخور الدرع العربي النارية أو المتحولة البروتوروزوية القديمة الحاوية على خام الذهب و انتقالها و من ثم تركزها ضمن المكونات الرسوبية الناعمة < Φ١٢٥ ، لذلك يوصي هذا البحث بمتابعة و تكثيف الدراسات التعدينية على المكونات الرسوبية الناعمة.