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Environmental Interpretation of Sand Grain Surface Textures in the Biyad - Wasia Sandstone Formations in Central Saudi Arabia

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Quartz grain surface texture from the exposed and subsurface sequences of the Biyad-Wasia Sandstone Formations in Central Saudi Arabia have been studied. Their surface textures as revealed by scanning electron microscopy, include features characteristic of desert or aeolion, beach, and river (*i.e.* fluvial) environments as compared with recent sands. However, this writer has concluded that quartz grain surface features are not ideally reliable indicators of their ancient environments.

Within the past decade the use of the scanning electron microscope (S.E.M.) for studying the surface textures of sand grains has provided much evidence concerning the interpretation of sand grains and their various depositional environments. Several distinctive sand grains surface textures have been recognized and assigned to various environments (*i.e.* aeolian, beach, river or fluvial and glacial). Among those contributors are Biederman (1962), Krinsley and Takahashi (1962 a,b), Krinsley and Funnell (1965), Soutendam (1967), Krinsley and Donahue (1968 a,b), Margolis (1968), Krinsley and Margolis (1969), Krinsley and Cavallero (1970), Hodgson and Scott (1970), Margolis and Kennett (1971), Doornkamp and Krinsley (1971), Nordstrom and Margolis (1972), Krinsley and Doornkamp (1973), Margolis and Krinsley (1974), Whalley and Krinsley (1974), Ingersoll (1974) and Subramanian (1975).

Krinsley and Donahue (1968 a) have shown that most of the above environments are characterised by certain surface microtextures of sand grains. Furthermore, they indicated (p. 747) that quartz grains from fluvial environments lack any distinctive characteristic surface textures although Soutendam (1967) had previously shown some electron micrographs of typical river (*i.e.* Fluvial) surface textures (*i.e.* Triangular pits), but

Krinsley and Donahue (1968 b) doubted the validity of this criterion as a fluvial indicator. More recently, Margolis and Krinsley (1974, p.450) have differentiated the numerous surface features of quartz grains on the basis of their chemical or mechanical origin, and have summarised their suggested environments (including fluvial). Moreover, the precise origin of sand grains can only be suggested if certain combinations of diagnostic surface features, rather than a single surface feature, are examined quantitatively to assess the significance of specific textures and only then can interpretation of their ancient environments be established (Margolis and Kennett, 1971 and Margolis and Krinsley, 1974).

Krinsley and Takahashi (1962 b, p. 1263) indicated that grains between 0.5mm and 1.5mm (1.0Ø to –0.5Ø) in diameter reveal a predominance of mechanically produced features, while Margolis (1968, p.252) claimed that grains between 1.0mm and 4.0mm (0.0Ø and –2.0Ø) in diameter contain prevalent mechanically produced features, while grains with diameters less than 1mm (0.0Ø) show a relative abundance of chemically etched features.

In the present investigation, quartz grains (–0.5Ø to 1.0Ø) from both the surface exposures and the subsurface (borehole, PW_3) of the Biyad and Wasia sequences (Fig. 1) have been examined first under the binocular microscope and then prepared for the scanning electron microscope (see method of preparation in Moshrif, 1976, p.137).

It is important to note the following factors which may have altered or modified the surface textures of the quartz grains in these sediments and thus make it more difficult to interpret their original environment.

(1) Some aeolian reworking of sand may have taken place both during initial deposition and on exposure to present day surface conditions.

(2)Disaggregation for size-analysis may have damaged some grain surfaces.

(3) The borehole specimens have been subjected to mechanical abrasion and crushing which are likely to have damaged or altered grain surfaces.

(4) Krinsley and Donahue (1968 a, p.748) have claimed that sands in the fluvial environments are generally poorly preservative of any "impressed" characteristic of surface textures.

Discussion

Several grains, particularly those from the borehole (PW_3) which have been observed under the S.E.M. appear to have frosted surfaces, particularly those grains which are rounded and nearly spherical (see Plate 1A,B,C). Kuenen and Perdok (1962) related frosting to mechanical and chemical processes which generally are most active in the aeolian environment, where chemical action appears to contribute most to frosting. However, Glennie (1970, p.166) has indicated that both pitting and frosting of grain surfaces are the result of collision of grains in an aeolian environment. However, various other phenomena are capable of producing similar effects, *e.g.* pressure solution, thin clay coating, incipient secondary overgrowth, and the marginal replacement of grains by carbonate cement (Carozzi 1960, p.18 and Glennie 1970).

The Biyad/Wasia grains examined under the S.E.M. show rounded, nearly smooth grain surfaces. However, in several parts the surface of the grain is covered by small mounds and pits, and a few oriental V–shaped pits are present, (see Plate 1A,B,C and 2A, Á). Biederman (1962, pp. 183–186) has described and differentiated between water-deposited and aeolian quartz grains based on their characteristic surface textures. He has indicated that water-deposited grains generally are characterised by regular triangular pits which are the results of solution, whilst aeolian grains show irregular surface pitting and rounded ridges which are the result of grain fracture and abrasion. Moreover, Soutendam (1967, p.287) has differentiated between true desert grains and aeolian ones, thus: "a sand grain with both general aeolian textures and the typical desert textures; most likely this grain was transported again after a prolonged time of rest, during which the chemical attack produced the fine uniform texture on the surface of the grain; the aeolian transport afterwards destroyed this texture partly". He attributed this typical desert sand surface texture (*i.e.* the fine uniform texture) as being caused by the chemical action of the desert dew. (Compare Plate 2Á with Soutendam, 1967, Fig. 2). Krinsley and Takahashi (1962a,b) experimentally produced frosted grains in a simulated aeolian environment and their artificial grain surface textures are typified by rounded blocks bounded by conchoidal fractures, features which are poorly displayed by some of the grains examined in the present study, perhaps due to severe abrasion and the extreme smoothness of the grain investigated. Furthermore, Krinsley and Donahue (1968 a) have summarized the surface features on experimentally frosted grains supplied by Kuenen (Kuenen 1960). Thus the surfaces of aeolian grains are characterised by all or most of the following features: small conchoidal fractures, small and large rounded blocks, curved scratches, striations, step-like fractures, arcuate steps, meandering ridges, angular and rounded outlines, low and medium relief, diagenetic etches and irregularly pitted surfaces. Similar combinations of aeolian features are described by Margolis and Krinsley (1974, p.450).

Rounded outlines, low relief, poorly developed and preserved ridges, smooth frosted surfaces, poorly developed small rounded blocks and irregularly pitted surfaces with diagenetic etching and fine textures are the main characteristics recognised on a few of the grains examined (Compare Plate 1A, B, C with that of Margolis and Krinsley 1971, Fig. 1, who described quartz sand grains from various desert environments. Also compare Plate 1A, B, C with Fig. 6A of Nordstrom and Margolis 1972 who describe quartz sand grains from a dune field in California).

The surface textures observed on a number of quartz grains from the Biyad-Wasia sandstone closely resemble those developed on recent (and ancient) aeolian grains, which have been reported by Krinsley and Funnell (1965), Krinsley and Donahue (1968a) and Margolis and Krinsley (1971). Furthermore, a few grains are analogous to those described by Soutendam (1967) from the desert sands of Algeria, which show fine uniform textures on the surface of the grains, where the chemical effects of desert dew were the cause of such features and later aeolian transport has destroyed parts of this texture.

However, not every grain examined exhibits such aeolian features. Others display surfaces with impact oriented V-shaped pits and triangular pits (Plate 2B́ and Ć). Similar crystallographically oriented chemical etch features were recognized by Biederman (1962) on quartz grains from the New jersey Coast, and he suggested a chemical solution origin (Compare Plate 2B́ with Biederman's Figure 2,1962, p.184). Soutendam (1967) has described similar V-shaped pits as characteristic features of the surface of river sand grains, (Compare his Fig. 3 with Plate 2B́). He (1967 p.286) stated that "the characteristic feature of the surface texture of the river sand grains were triangular pits.... and with a high magnification they really stand out". He further (p.287) noted that "the two textures (*i.e.* the triangular pits and the V-shaped patterns) are related to each other; most likely the triangular pits originate in rivers; this texture can probably survive the beach abrasion for some time, but it is eventually converted into V-shaped patterns", (Soutendam 1967, p.287). (Compare Plate 2B with the river sands in Fig. 3 of Soutendam 1967). Moreover, other grains with oriented pits resemble those on quartz grain surfaces described by Margolis (1968, Fig. 4 and Fig. 6) from beaches of different wave intensities along the Atlantic and Gulf coast of the United States. Margolis (1968) indicated that sand grains from beaches with low wave activity show oriented etch pits, attributed to the solution of quartz by sea water. He also claimed that these features are the surface reflection of defected internal crystal. Furthermore, sand grains from high-energy beaches predominantly show impact features. (Compare Plate 2Ć with Margolis Figures 4 and 6). Ingersoll (1974, Fig. 4a) has also published a photomicrograph of quartz sand grain, from Montara Beach, California, with V-shaped pits, which are similar to the pits on Plate 2B́, and Ingersoll suggested that such features are diagnostic of beach environments with high-energy conditions. However, Plate 2Ć shows a fine stippling of triangular etch pits and these are related to chemical-diagenetic patterns (Moshrif 1976) which are similar to those shown by Margolis (1968, Fig.6).

It appears probable that the oriented etch pits (*i.e.* the V-shaped and the triangular pits) observed on the surfaces of quartz sand grains from the Biyad-Wasia Sandstones, are a mixture of beach and river sands (Moshrif 1976).

Furthermore, the river oriented pits (Plate 2B́) may suggest highly turbulent conditions that closely resemble those present on a high-energy beach, which have produced similar oriented triangular etch pits (Plate 2Ć). These pits are formed as a result of chemical effects and are generally characteristic of aqueous abrasion.

Among those quartz grains examined from the borehole (PW_3) a few exhibit fresh conchoidal fractures, which are steplike with irregular oriented groove lines and sharp edges (Plates 3A, B,C,D). These freshly produced surface features are believed to have been produced by the mechanical coring processes, *i.e.* the breaking and crushing of the grains during the drilling operation (Moshrif 1976, p.205). It is worth noting that these newly created, surface textures, which have been imposed artificially, by machine could be misinterpreted as glacial features, such as those described by Margolis and Krinsley (1971), Krinsley and Doornkamp (1973) and Whalley and Krinsley (1974).

Conclusion

The quartz sand grain surface textures of the Biyad and Wasia Sandstones as revealed by scanning electron microscopy, included features characteristic of desert or aeolion, beach and river (*i.e.* fluvial) environment as compared with recent sands. However, a more precise assignment of the grains to their formative environment would require systematic and time-consuming statistical analysis of the different types of surface features. Such an analysis is beyond the scope of the present study.

Recently Subramanian (1975) has shown that individual quartz grains can display a wide range of surface features, and hence cannot be the best indicators of ancient sedimentary environments. His conclusion has been based upon optically clear quartz crystals which were etched in the laboratory, producing a wide variety of surface features which are very similar to those of naturally occurring quartz grains (see his Fig. 1 and 2). Thus it seems that quartz grain surfaces may undergo many changes through geological time, such as the V-pits described by Soutendam (1967) which were originally formed in beach deposits and were altered by abrasion to give an image of river or fluvial features deposits. The present writer tends to agree with the view of Subramanian (1975) that quartz grain surface features are not ideally reliable indicators of ancient sedimentary environments, for the following reasons:

(i) a great variety of surface features may be present on a simple quartz grain;

(ii) such features are not permanent and may change according to the possible alternation of mechanical and chemical processes which influence each quartz grain during and after deposition;

(iii) climatic changes, *i.e.* moisture, temperature, windy or stormy condition, all may play some part in further modifying surface features on each grain;

(iv) since surface textural features are sensitive and unstable they may be altered or modified to differing degrees, for example according to low or high beach energies or through the degree of current turbulence and the features preserved may be an accident of whether the final process prior to deposition was one of high or low energy;

(v) finally, diagenetic or weathering processes may profoundly affect grain surfaces, concealing or washing original features.

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PLATE 1

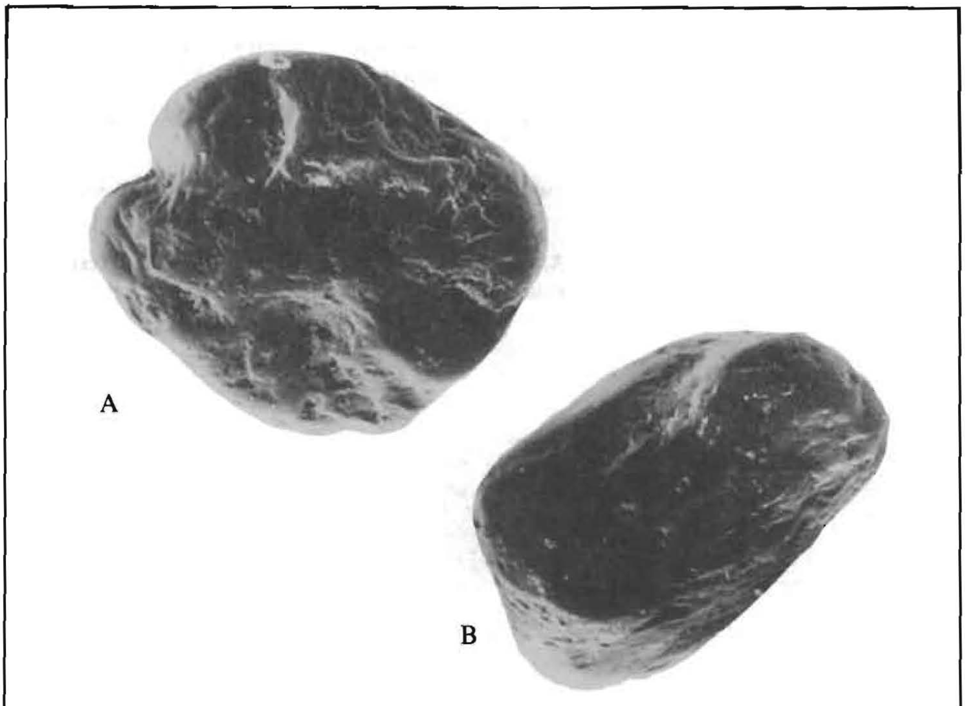

PLATE 1.

Scanning electron micrographs of quartz sand grains. Grain diameters vary between: (1.4mm and 0.5mm).

A. Sand grain from the Wasia Sandstone, borehole (PW_3).
Note : frosted appearance, moderately well rounded outline, with smooth surface and isolated small V–pits, scratches and low relief topography. X 100

B. Sand grain from the Biyad Sandstone, borehole (PW_3).
Note : as above, but with more scratches on the lower side, and more elongated outline. X 100

C. Sand grain from the Biyad Sandstone, outcrop, locality 3.
Note : as above but with more ditch-like deprestions and an irregular shape. X 120

PLATE 2

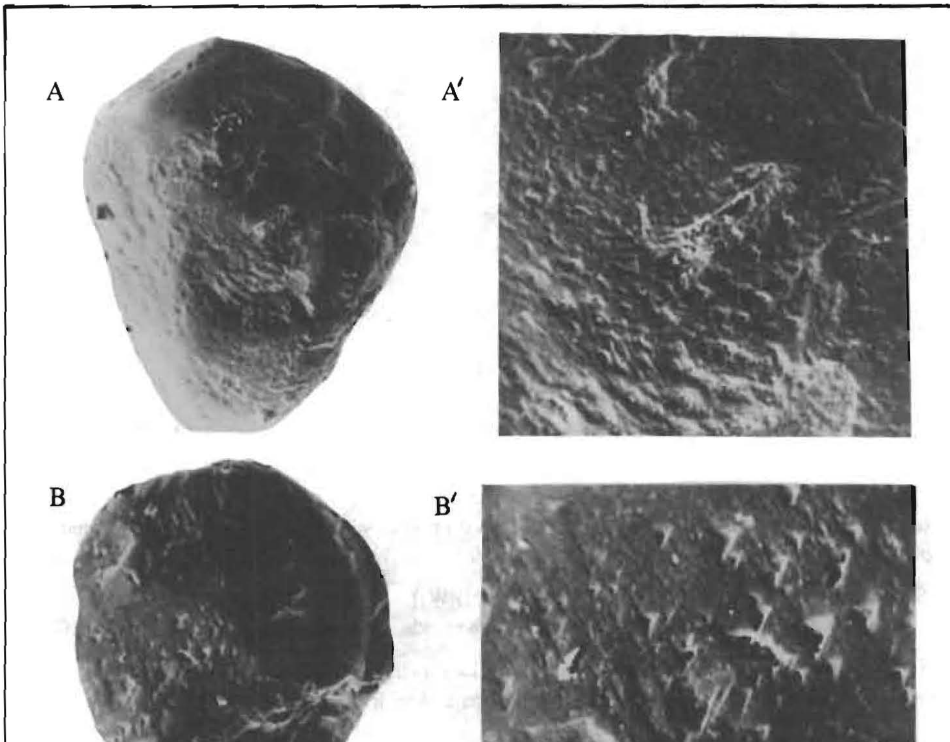

PLATE 2.

Scanning electron micrographs of quartz sand grains.

A. Frosted grain from the Biyad sands, borehole (PW_3).
Note : nearly spherical in shape, low relief topography, very small and numerous V–pits and prograding solution pits. See enlargement in next A′. X 100

A′. Enlargement area from near the centre of the grain in A.
Note : Prograding silica solution pits due to chemical diagensis. and forming a fine uniform texture, indicating desert or aeolian environment, similar to those described by Soutendam (1967, Fig. 2) X 1000

B. Sand grain from the Biyad Sandstone, outcrop, locality 3.
Note : frosted appearance, oriented V–shaped pits, smoother surface in some parts. with numerous solution pits and surface scratches at the upper part. X 100

B′ Enlargement area from the top centre of the grain in B.
Note : oriented V-pattern indicating water-deposit (*i.e.* beach or river) similar to those described by Biederman (1962, Fig. 2) and Soutendam (1967, Fig. 3). X 225

C. Sand grain from the Biyad Sandstone, outcrop, locality 3.
Note : irregular shape, high relief topography, smoother surface in places, fractured and eroded edges, scratches, deep ditches and oriented V–shaped pits. X 100

C′. Enlargment of the area on the middle right of the grain in C.
Note : oriented triangular each pits, with their fine stipple appearance, attributed to chemical diagenetic effects, similar to those described by Margolis (1968, Fig. 4 and 6). X 2000

PLATE 3

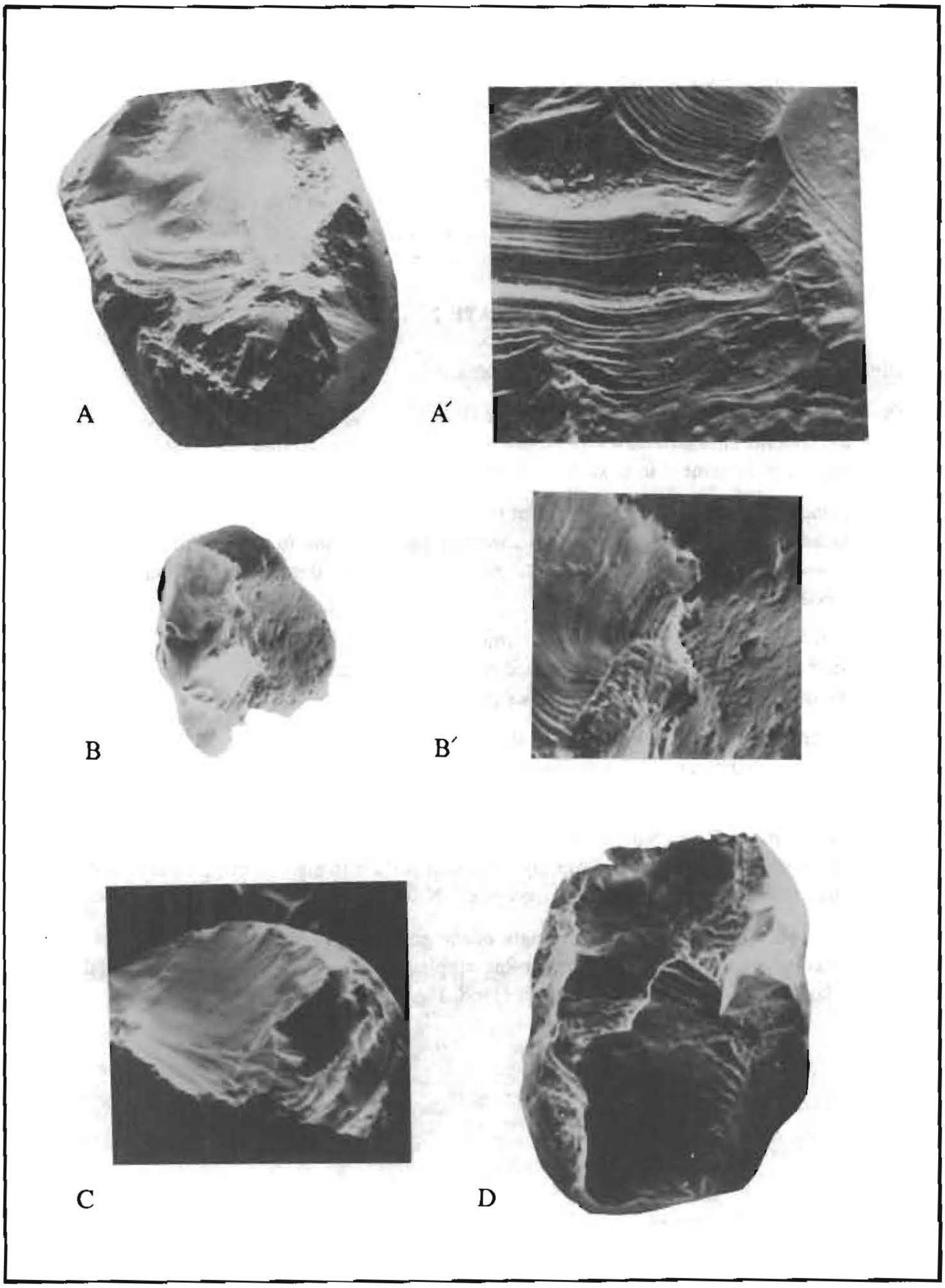

PLATE 3.

Scanning electron micrographs of quartz sand grain, from Biyad and Wasia Sandstones, Borehole (PW_3). Misleading surface features which might be interpreted as characteristics of a glacial environment. (See discussion in text).

A. Sand grain from the Biyad Sandstone.
Note : Freshly broken parts, sharp edges, conchoidal fractures, smoother surface on the surrounding sides. X 105

A′. Enlargment of area near the left centre of the grain in A.
Note: irregularly oriented grove and curved lines. These lines are believed to result from coring processes. X 750

B. As above.
Note : conchoidal fracture at the bottom of the grain, arcuate fresh lines to the top left and smoother but pitted surface on the gight half of the grain. X 60

B′. Enlargement of the area at the top left of the grain in B.
Note : original surface textures on the right side of the microphotograph. The fine texture and solution pits reflect chemical diagenetic effects. Compare with Plate 2A′. X 200

C. As above.
Note: Conchoidal fracture, fresh grooves and very sharp edges, caused by drilling abrasion. X 80

D. Sand grain from Wasia Sandstone, borehole (PW_3).
Note : Step-like fractures and sharp edges also caused by coring processes. X 100

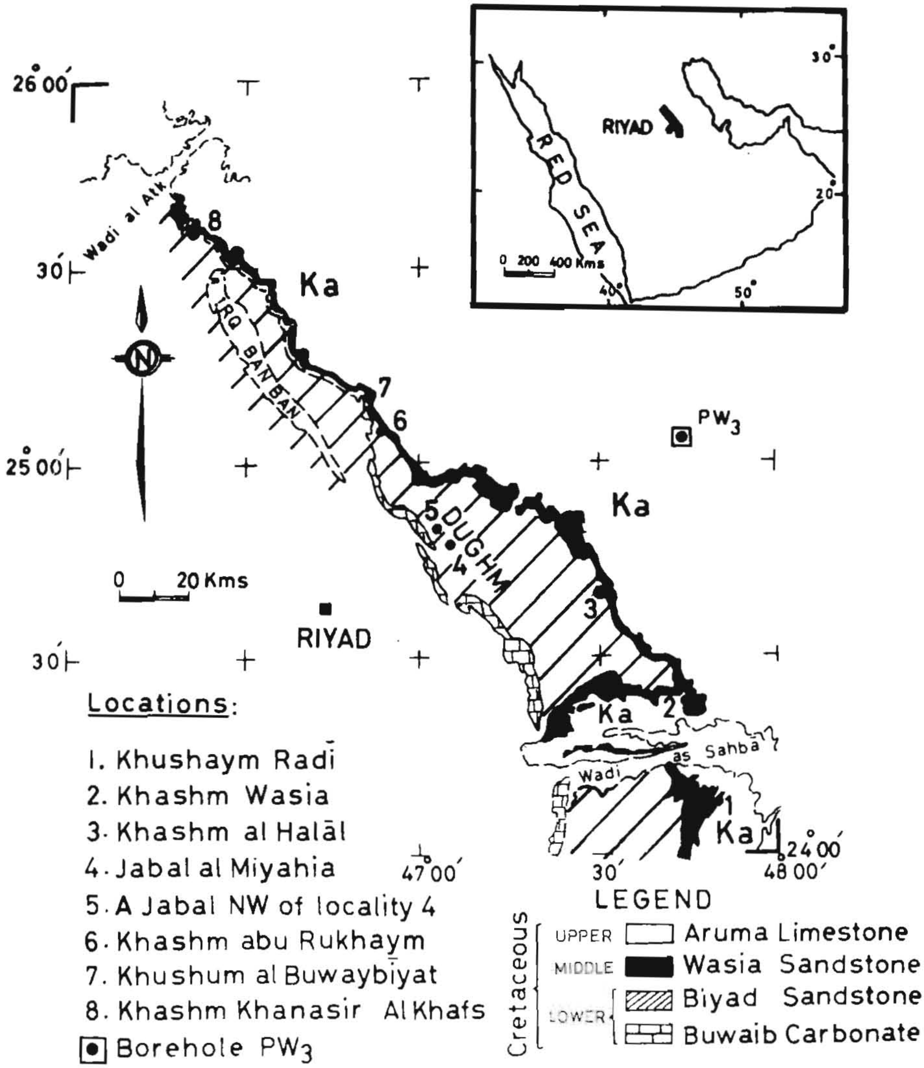

Fig. 1. Locality map of the studied area

تفسيرات بيئية للأنسجة السطحية من حبيبات رمل متكون البياض والوسيع الظاهر في وسط المملكة العربية السعودية

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لقد درست الأنسجة السطحية لحبيبات الكوارتز المأخوذة من الطبقات الظاهرة وتحت السطحية لكل من متكون البياض والوسيع الرملي في وسط المملكة العربية السعودية . ومع أن الأنسجة السطحية لهذه الحبيبات ـ كما ظهرت تحت المجهر الالكتروني ـ تشتمل على أجسام تدل على خصائص بيئات صحراوية أو ريحية ، شاطئية ونهرية إلا أنه عندما قورنت بحبيبات رمل حديثة تبين أن الأجسام السطحية لحبيبات الكوارتز لا يعتمد عليها بشكل نهائي أو نموذجي للاستدلال عن بيئاتها القديمة .