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Cementation, diagenesis and paragenetic sequence in the Biyadh–Wasï Sandstones (Lower-Middle Cretaceous) of central Saudi Arabia

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ABSTRACT

Although most of the Biyadh–Wasï Sandstones (Lower-Middle Cretaceous) are friable and poorly cemented, few specimens reveal some cementation principally by secondary silica (or quartz), carbonate or ferruginous material. The Biyadh–Wasï Sandstones have undergone several important diagenetic changes during their post-depositional history. The full paragenetic sequence commenced with primary partial silica cementation, which was followed by formation of iron in the remaining pore spaces. Both stages included quartz overgrowths, produced as a result of pressure solution. Later stages resulted in precipitation of Fe-rich clays and carbonate in new pore spaces created by partial replacement and corrosion of detrital quartz grains. The lack of quartz overgrowths in the later stages is believed to be due to inhibition of pressure solution. The final diagenetic stages include weathering, which has created new pore spaces, and precipitation of silica dust (probably of aeolian origin) in such pores which resulted in the formation of secondary silica overgrowths in the form of microcrystalline quartz. This process gives rise to the 'quartzitic' crusts typically developed on many elevated outcrops of the Biyadh and Wasï Sandstones.

INTRODUCTION

Dapples (1972) has stated that 'the term "cementation" involves mineral authigenesis, recrystallisation, and intergranular welding. In effect, cementation and lithification appear to be synonymous terms.' Pettijohn (1975) has indicated that a sand is transformed to lithified rock by a process of ageing. In part, the ageing processes are purely mechanical: grain fracturing, bending and deformation of detrital micas, and squashing of weaker pelitic grains. However, other processes are mainly chemical, involving solution, reprecipitation, decomposition, and intergranular reactions. Redistribution of materials such as quartz involving solution at one site and precipitation at another, leads to cementation and pore space reduction. Moreover, diagenesis is a term used to describe the mineralogical and textural changes which occur subsequent to deposition of the sediment and which are attributable to internal processes. Thus it appears from both views that cementation cannot be isolated from diagenesis, and in discussing cementation we are actually discussing the diagenetic processes that have led to cementation in a rock.

Although most of the Biyadh–Wasï Sandstones are friable and poorly cemented, some specimens reveal some cementation principally by secondary silica (quartz), carbonate, or ferruginous material. The purpose of this contribution, therefore, is to study the processes of cementation and diagenesis involved in the Biyadh and Wasi̇̈ Sandstones and to synthesise the paragenetic sequence in these sandstones.

GENERAL STRATIGRAPHY

The distribution of both the Biyadh and Wasi̇̈ Sandstones can be traced almost continuously northwards from Wadi As-Sabha to Wadi Al-Atk, a distance of nearly 250 km (Fig. 1). The Biyadh (Upper-Lower Cretaceous) Sandstone ranges in thickness

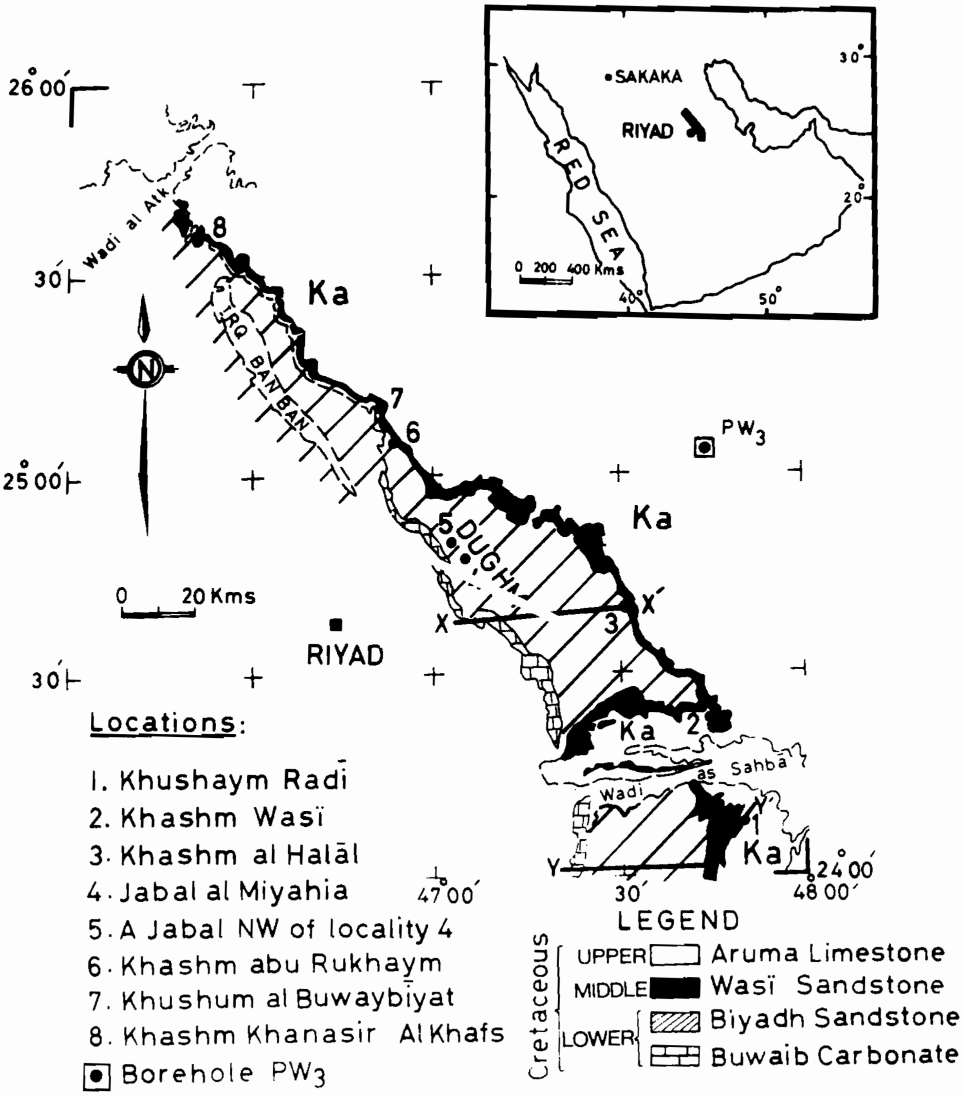

Fig. 1. Locality map showing general distribution of Cretaceous rocks in central Saudi Arabia. Inset (upper right) indicates location of study area in the Arabian Peninsula.

from 360 to 625 m in central Arabia (Powers *et al.* 1966). Moshrif (1976) has estimated that within the area studied, the thickness of the Biyadh Sandstone ranges from 300 to 400 m (based on x–x′ and y–y′ traverse sections, the borehole PW_3 and other sections; see Fig. 1). Powers *et al.* (1966) indicated that in central Arabia the thickness of the overlying Wasï (Middle Cretaceous) Sandstone increases irregularly but persistently from south to north. They estimated a 40 m thickness at Wadi As-Sahba, 60 m near Khashm Khafs (near Wadi Al-Atk) and a maximum thickness of 285 m near Sakaka (in northwestern Arabia). Within the area of study, Moshrif (1976) has shown that the thickness of the Wasï varies between 12 and 20 m in outcrop sections and is nearly 185 m thick in borehole PW_3 to the east.

Although the Wasï is a much more ferruginous sandstone than the Biyadh, both sequences show very little variation in lithological composition and contain no fauna throughout. The sandstone beds generally display varied colours to purple, red, pale pink, grey to light yellow, and white to dull white. Both sequences include graded beds and are friable and poorly cemented. Some beds contain carbonaceous wood fragments and nearly all the beds are badly weathered. A few conglomerate units were recognised at the base of several observed fining-upward cycles within both formations (Moshrif 1976).

Most of the Biyadh and Wasï sandstone units show structures such as cross stratification (planar), cross lamination, horizontal lamination, parallel lamination, deformed cross stratification, a few symmetrical ripples and some biogenic disturbances (Moshrif 1976).

The conformable contact of the Biyadh with the underlying Buwaib Formation is marked by a conspicuous change in the character of the residual gravels on the surface, reflecting the major change in lithology from the friable dark brown ferruginous Biyadh Sandstones to the creamy to tan-white carbonate of the underlying Buwaib (Moshrif 1976). A more distinct and well-established disconformity between the Wasï Sandstone Formation and the overlying Aruma (Upper Cretaceous) Limestone Formation is recognised on the basis of the marked lithological and faunal contrasts between these two rock units.

DISCUSSION

Secondary silica (quartz)

Secondary silica (quartz) overgrowths surrounding detrital quartz grains have been observed in some thin sections of the Biyadh–Wasï Sandstones. They show an early stage of developing crystal faces, as indicated by grains rimmed with microcrystalline quartz, and in a thin but faint line of demarcation around each of the detrital quartz grains (Figs 2, 3 and 4) separating the primary quartz from the outer layer of secondary quartz. In a few of the thin sections examined, such rounded outlines of the detrital quartz grains are clearly marked by ferruginous dust inclusions (Fig. 5); others show few overgrowths when cemented by carbonate or ferruginous clay (Figs 6 and 7).

The general form of the overgrowths is determined by the character of the detrital grains involved. Thus it has been observed that the overgrowths on unstrained quartz grains are also composed of unstrained quartz, whereas strained quartz grains have overgrowths which reflect the extinction of the parent grains. Composite (polycrystal-

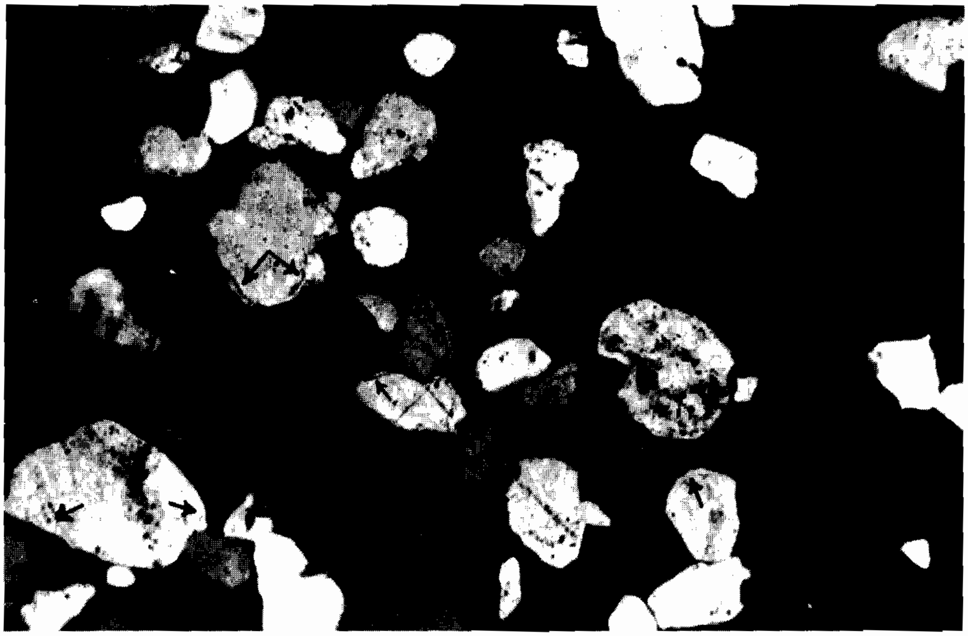

Fig. 2. Biyadh's quartzitic sample from Jabal Al-Miyahia, locality 4 (see Fig. 1) showing faint demarcation lines (arrows) between primary and secondary quartz overgrowths and grains rimmed with microcrystalline quartz (crossed nicols, × 10). Note the straight and concavo-convex contacts between grains.

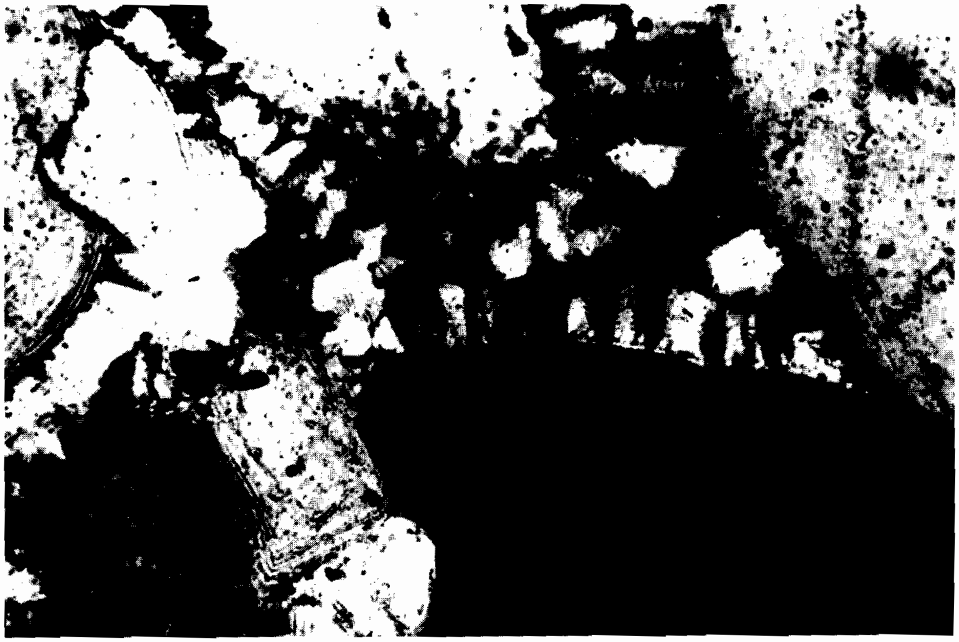

Fig. 3. Demarcation lines between primary and secondary quartz overgrowths. Note the microcrystalline quartz (crossed nicols, × 40). Selected Biyadh's sand sample from traverse y–y′ (see Fig. 1).

Fig. 4. Quartz overgrowths indicated by demarcated lines, showing euhedral crystalline quartz overgrowths (crossed nicols, × 40). Selected Biyadh's sand sample from traverse y–y′ (see Fig. 1).

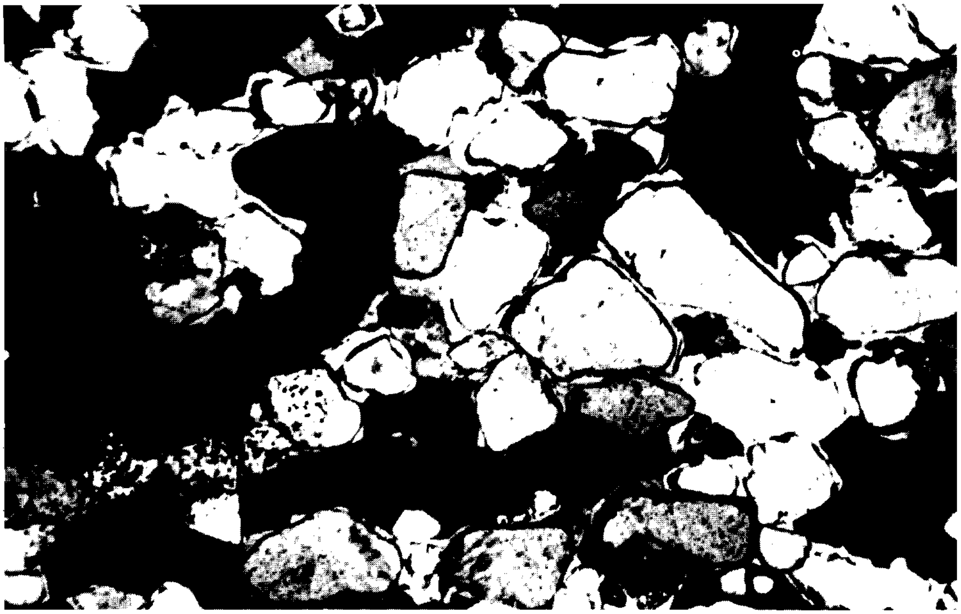

Fig. 5. Quartz grains with distinct ferruginous dust rings, indicating syntaxial secondary quartz overgrowths (crossed nicols, × 10). Selected Biyadh's sand sample from traverse y–y′ (see Fig. 1).

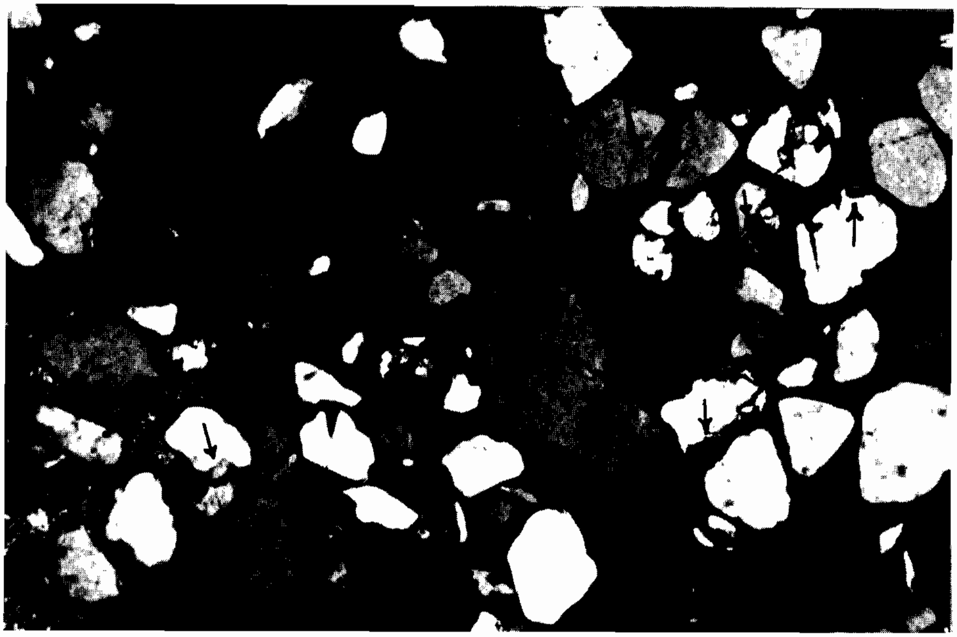

Fig. 6. Quartz grains in crystalline calcite cement, inhibiting quartz overgrowths and partially replacing quartz grains as indicated by some corroded and invaded grains (arrows) (crossed nicols, × 10). Biyadh caliche 'ball' sample from Jabal Al-Miyahia, locality 4 (see Fig. 1).

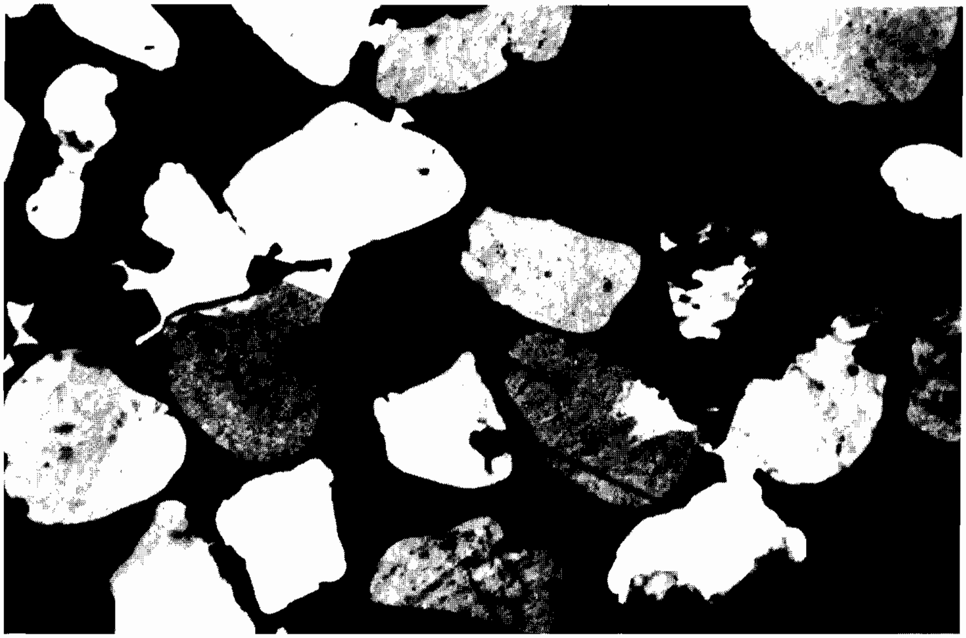

Fig. 7. Quartz grains in ferruginous clay matrix, inhibiting quartz overgrowths. Note marked marginal corrosion of several quartz grains (crossed nicols, × 10). Selected sand sample from traverse y–y′ (see Fig. 1).

line) grain overgrowths also have been observed in a few sections, their development being controlled by the sub-units within the grain (see Moshrif 1976).

Source of secondary silica

Many theories have been suggested to account for the source or origin of secondary silica in sediments, but no unified theory has yet been devised. The factors involved have been discussed by Ireland (1959) and include: biochemical origin, pH, environment, weathering and diagenesis of silicates and clays, precipitation from circulating meteoric ground waters (Van Hise 1904), pressure solution effects (Waldschmidt 1941) and solution and precipitation of silica dust in arid aeolian environments (Biederman 1962; Waugh 1970). Moreover, Towe (1962) has postulated that the post-deposition transformation of montmorillonite and/or mixed-layer illite–montmorillonite of shales to illite, may act as a possible source of silica cement in sedimentary rocks. Such a transformation is promoted by depth of burial. Taylor (1950) has also indicated that there is a direct correlation between depth and pressure solution. A more plausible source of silica is from solution at points of grain contact, and by intrastratal solution along stylolite seams (Heald 1955, 1956). This intrastratal pressure solution origin was also recognised by Waldschmidt (1941). In an investigation of sandstone cementation, he concluded that intrastratal, that is intergranular, pressure solution acted as a secondary source of silica. Furthermore, Heald (1956) suggested that clay minerals promote pressure solution, whilst Carozzi (1960) claimed that clay minerals appeared to minimise or inhibit the effects of pressure solution in feldspathic sandstones. Similarly, Whisonant (1970) has indicated that abundance of clay matrix may reduce the number of grain-to-grain contacts, and thus restrict the pressure solution of the quartz, i.e. retard the development of secondary silica as overgrowths and cement. Heald & Larese (1974) have further concluded that coatings of some clay minerals, hematite, chert or carbonate on quartz grains may inhibit quartz cementation and although such coatings do not always prevent quartz overgrowths, they commonly cause the growths to form with unique features. Moreover, an experimental study by Heald & Renton (1966) also indicated that chert tended to retard quartz growths. Pressure solution has also been produced in laboratory experiments (Ernst & Blatt 1964; Renton *et al.* 1969) and occurs when grains are in contact under pressure in the presence of solutions.

Evidence in favour of several of the theories outlined above concerning the source of silica have found application in specific cases in the Biyadh–Wasi' Sandstones. Thus, pressure solution is applicable only to those specimens of the massive quartzitic beds which cap most of the Biyadh hills, such as Jabal Al-Miyahia, locality 4 (see Moshrif 1976). The thin sections of this material show interstitial material and a close packing of grains which have slightly inhibited the formation of large secondary quartz overgrowths (Fig. 2). Thus the presence of small amounts of finer material (clay) may have minimised the compactional effects and reduced the degree of solution movements (Whisonant 1970). In a study of sandstone fabrics, Adams (1964) has proposed a terminology for degrees of pressure solution based on grain-to-grain contacts as observed in thin section. According to the classification of Adams (1964), two grain contact fabrics are observed in the Biyadh quartzitic thin sections, namely concavo-convex and long (straight) or tangential contacts (Fig. 2 and compare it with Fig. 5B, D of Adams 1964). On the other hand, strongly sutured contacts are not seen in the

Biyadh–Wasi̇ thin sections, implying the absence of a high degree of pressure solution. Concavo-convex and long or tangential contacts are taken to indicate moderate to minor degrees of pressure solution respectively (Adams, 1964). The effect in sandstones is the solution of quartz grains at interpenetration points and precipitation of silica cement in voids generally outside the influence of high pressure (Heald 1956; Thomson 1959; Adams 1964).

The study of other Biyadh–Wasi̇ quartz grain surfaces under the electron microscope (Moshrif 1978) has revealed that many of the sand grains display features which are characteristic of wind-blown sand, i.e. an aeolian origin. On the basis of a scanning electron microscope examination of recent aeolian sands, Biederman (1962) has postulated that in a desert environment, a speck of silica dust is dislodged by impact-abrasion from each pit on the quartz grain surface, furnishing a possible source of secondary silica. Moreover, Krynine (1941) also indicated that past periods, during which desert conditions prevailed, are often characterised by the presence of well-cemented orthoquartzites which may be attributable to the production of fine aeolian quartz dust, which forms a starting point for the solution and reprecipitation of silica cement. Laboratory experiments reveal that siliceous dusts have a highly soluble surface layer which passes into a non-soluble core (Demster & Ritchie 1952). Various solvents are able to remove this surface layer and produce colloidal flakes of silica and through further abrasion the soluble surface layer can be restored. In the Penrith Sandstone of England, Waugh (1970) has suggested that siliceous dusts formed during aeolian abrasion of the detrital quartz have provided the source of the abundant secondary quartz. He added that alkaline desert groundwaters are considered responsible for taking the siliceous dust into solution which, upon evaporation, precipitated the silica and formed the quartz overgrowths around the detrital quartz grains.

Many of the features recorded by Waugh (1970) are noted in the Biyadh–Wasi̇ Sandstones, and it is therefore suggested that much of the secondary silica in these rocks may have been produced by the solution and subsequent reprecipitation of silica dust which probably took place during periods of aeolian reworking of the fluvial sands of the Biyadh–Wasi̇ Formations (Moshrif 1976).

Carbonate cement

No dolomite cement is present, but calcite cement has been encountered in a few Biyadh–Wasi̇ thin sections. This occurs as a patchy cement and often appears to have replaced former areas of detrital matrix. Occasional specimens are very rich in carbonate (calcite) with detrital quartz grains in a coarsely crystalline calcite cement (Fig. 6). This crystalline calcite matches the form of lustre-mottling described by Pettijohn (1975). Corrosion and encroachment upon the detrital quartz grains are conspicuous as indicated by the inhibition of secondary quartz overgrowths, irregular and embayed contacts between the grains and the cement, and partial replacement of many detrital quartz grains by calcite (Fig. 6). In those specimens which contain a high proportion of calcite, it is very likely that the crystallisation of carbonate and corrosion of the detrital grains have together produced the floating texture of the quartz grains, since the force of crystallisation of the calcite could have retarded and hindered cementation by secondary silica, and thus minimised the effects of pressure solution.

The occasional concentration of calcite cement in near-surface exposures of the sandstones, in the form of 'cannon balls and cylinder' shapes (Fig. 8), has been

Fig. 8. Concretionary type, caliche 'cannon balls and cylinder' shapes, located in Middle Biyadh Sandstone at Jabal Al-Miyahia, in the Dughm area (see Fig. 1).

interpreted as a type of caliche precipitation, resembling the examples described by Nagtegall (1969) in his study of Late Palaeozoic and Triassic Sandstones of the Pyrenees, in Spain.

Several theories concerned with the origin of carbonate cement in sandstones are discussed in Pettijohn *et al.* (1972). A late secondary origin is suggested for the calcite cement in the Biyadh–Wasi Sandstones from the evidence of its corrosive and replacive effects on the detrital quartz overgrowths (Figs 6 and 7).

Although there is no clear evidence for the ultimate source of the cementing carbonate, there appear to be two possibilities: (i) the carbonate is derived from adjacent carbonate formations (i.e. the Yamama and Buwaib or Aruma), by leaching and circulating groundwaters. Although thin section study has shown that there is no obvious vertical trend in carbonate cementation of the Biyadh–Wasi sediments, it is very probable that large amounts of carbonate solution percolated down through the large-scale cavernous hollows in basal Aruma (Fig. 9). (ii) The carbonate cement is also produced from solution of carbonate shell material which perhaps was trapped within the sediment. The dissolved carbonates are redistributed, initially as pore fillings, and in some places concentrated to such a degree that marginal replacement of adjacent detrital grains is ensured. Thus in the case of the Biyadh–Wasi Sandstones, it appears that a minute proportion of carbonate cement was produced by the probably very few shells in these fluvial sediments. However, the absence of carbonate cement at the outcrop is frequently due to weathering and leaching processes.

Fig. 9. Close-up view of the cavernous dolomitic limestone surface of the Lower Aruma Formation at Khushaym Radi, locality 1 (see Fig. 1).

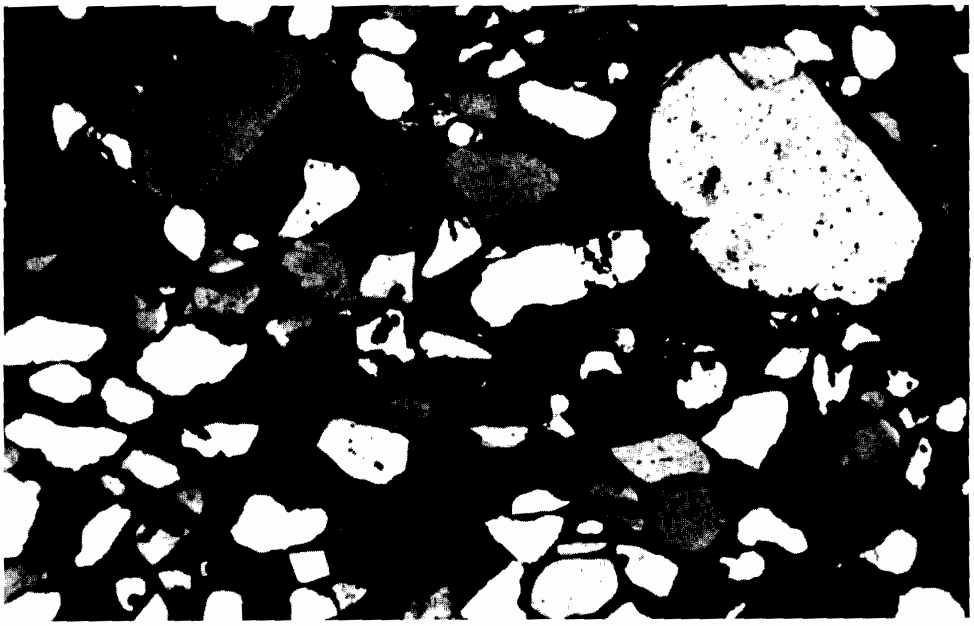

Fig. 10. Quartz grains in a ferruginous clay matrix, inhibiting quartz overgrowths as in Fig. 7. Note minor embayments and marginal corrosion (crossed nicols, × 10). Wasī's sand sample from Jabal Al-Halal, locality 3 (see Fig. 1).

Ferruginous cement

Many thin sections of the Biyadh–Wasï Sandstones contain ferruginous material in the form of a cement. This is more abundant in most of the Wasï rocks. The detrital quartz grains may appear to float in the ferruginous, clay-like matrix and exhibit no points of grain contact (Figs 7 and 10), similar to features seen in the carbonate cement (Fig. 6). A few hand specimens from Middle Biyadh contain iron-coated quartz grains, indicated by scattered dark spots in a fresh white, friable sandy bed (also observed in a few massive quartzitic blocks similar to the ones capping several Biyadh hills) and giving a 'salt and pepper' appearance (see Fig. 11).

Numerous tube or rod-like ball or hollow-box structures (Fig. 12), are observed at the outcrop of various horizons in the Biyadh–Wasï Sandstones. These types of concretions possess a hard crust (1–3 cm thick), of ferruginous material, forming a cast or shield around non-ferruginous friable quartz grains (see Fig. 12). Jackson (1971) has suggested that such structures are formed as a result of subaerial weathering. They are developed by the oxidation of iron to limonite at the margins of clay–ironstone concretions. As leaching and oxidation proceed, the iron migrates in solution to the surface of the body and is precipitated as limonite, forming a hard cement for the surrounding sand. The original iron cement or concretion is often completely leached out, leaving unconsolidated sand inside the ferruginous cemented structure. A similar origin appears likely for the Biyadh concretions since the friable core sands maintain a yellowish coating as a result of the limonitic dust-like material still remaining unoxidized (see Fig. 12 and compare it with Fig. 3.46 of Jackson (1971)).

The origin of the ferruginous cements encountered in sandstones remains obscured and controversial. Van Houten (1968) has summarised several studies on the origin of iron oxides in sediments, and has indicated briefly the diagenetic processes involved,

Fig. 11. Dark ferruginous spots are iron-coated quartz grains, at the base of Middle Biyadh Sandstone, locality 5 (see Fig. 1), giving a 'salt and pepper' appearance.

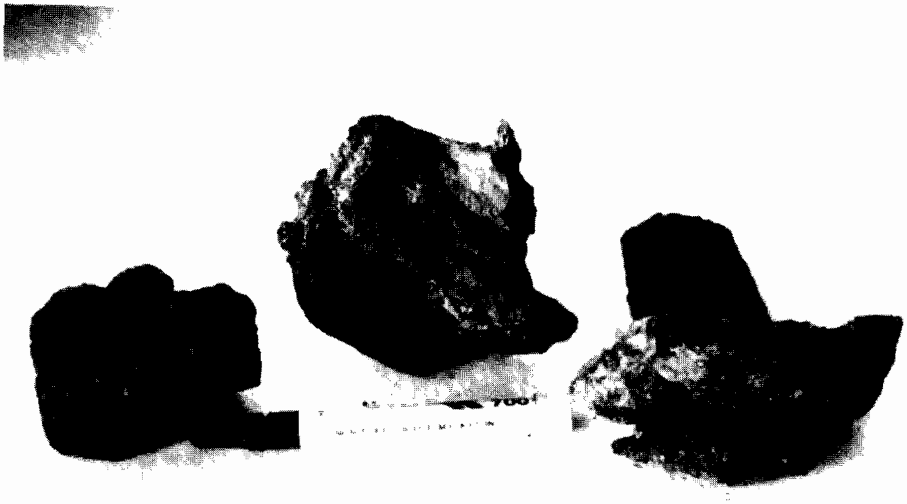

Fig. 12. Ferruginous Biyadh–Wasi's sand samples from traverse y–y′ (see Fig. 1), showing ferruginous crust or shield-like cement enclosing friable liminotic sands.

which comprise: the ageing of brown amorphous ferric oxide to geothite and haematite, the alteration by dehydration of goethite to haematite (since crystalline haematite is more stable under reducing conditions than amorphous ferric oxide), and finally both a warm climate and increased temperature of burial promote the alteration of brown ferric oxide (limonite) to red haematite pigment in sandstones. Van Houten claimed that there is no reliable technique by which one can determine whether the haematite pigment in red beds is (a) inherited from red soil, (b) is an alteration product of limonite in the source area or in transit, by post-depositional conversion of brown oxides to red haematite, or (c) is formed by intrastratal alteration of iron-bearing silicates (Van Houten 1968). However, Walker & Ribble (1967) and Walker (1966) have suggested that most diagenetic haematite in sandstones has been formed *in situ* after deposition by intrastratal alteration of iron-bearing detrital grains (iron-rich minerals such as hornblende and biotite) in hot arid or semi-arid climates or in desert basins. On the other hand, Pettijohn (1975) has proposed that most of ferruginous or iron oxide-cemented sandstones may originally have been sideritic sandstones. 'Siderite is not so rare, perhaps, as is commonly believed, it is seldom seen in outcrop materials, simply because it is very unstable in the presence of the atmosphere' (Pettijohn 1975). He also added that examination of several iron-spotted sandstones has revealed that each spot, an area cemented by limonite, is formed by oxidation of siderite.

The absence of iron-rich minerals from the Biyadh–Wasi Sandstones, as revealed by heavy mineral separation and analysis, and the presence of limonitic material in the form of orange-yellow powder as observed in the field and examined in many specimens certainly suggest that siderite might provide a source for the ferruginous material

Fig. 13. Deformed and rope-like structures in the ferruginous crust on Wasï material at Khushaym Radi, locality 1 (see Fig. 1).

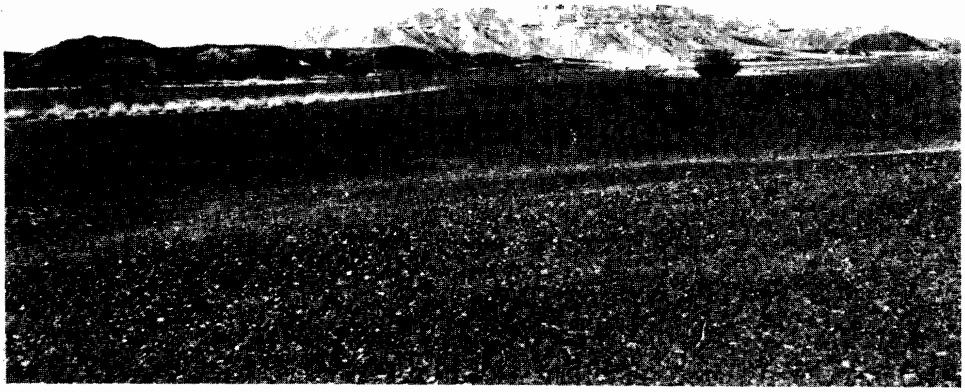

Fig. 14. Distant view of Khashm Wasï, locality 2 (see Fig. 1), showing ferruginous Wasï Formation (dark coloured, in foreground), and limestones of Aruma Formation (light coloured, in background).

in the rocks concerned. Alteration of the ubiquitous yellow or brown limonite to red haematite under the existing warm climate (>45°C) is considered probable since nearly all the dark iron oxides encrusting the sandy beds are exposed at the ground surface whilst neither Wasi̇̈ nor Biyadh Sandstone samples obtained from the borehole PW_3 exhibit such dark iron oxide or ferruginous coatings. Thus it appears that the prevalent high temperatures and the contemporary weathering processes together have produced vital effects upon the occurrence of the ferruginous cements and encrustations of many of the Biyadh and most of the Wasï rocks. The abundance of haematite in the Wasï sediments may be due to an original enrichment in siderite.

It seems likely that iron was derived in solution from igneous and metamorphic provenance and deposited as the carbonate (siderite) in the Biyadh–Wasï sediments. Oxidation under climatic conditions similar to those now prevailing promoted the conversion of siderite into limonite and additional oxidation altered the limonite to haematite pigments now seen either as red-coloured bands as in some of the Lower and Middle Biyadh (Moshrif 1976) or as the dark iron-oxide coatings of many Upper Biyadh and Wasï beds (Moshrif 1976).

Paragenetic sequences in the Biyadh–Wasï Sandstones

The great majority of these sandstones are now and probably were originally very porous and therefore form chemically open systems which may be subject to many complex post-depositional changes. However, careful study of the mutual relationships of the various cementing mineral phases indicate a general order of development which is indicated below and summarised in Table 1.

Following burial of the sands, the first event appears to have been the precipitation of quartz overgrowths which probably originated from the dissolution of detrital quartz under the effects of pressure (i.e. due to compaction of the quartz grains), producing a partial silica cementation in the form of localised overgrowths (Fig. 2). The pressure involved was moderate, as indicated by the two main contact types observed, i.e. straight and concavo-convex (Fig. 2).

Evidence from the 'quartzite caps' clearly demonstrates an early stage of both silica cementation, as well as some ferruginous coatings. The next diagenetic stage was precipitation of Fe in the remaining pores, clearly marked by the ferruginous dust rings and accompanied by additional syntaxial quartz overgrowths (Fig. 5). The third stage involves pore enlargement through marginal corrosion of detrital quartz grains with concomitant precipitation of Fe-rich clays, resulting in the 'floating' texture observed in certain sandstones (Fig. 7). Subsequently, there has been inhibition of contact pressure effects upon the quartz grains, and thus there is an absence of silica overgrowths, but marginal corrosion by the clay of a few quartz grains is observed (Fig. 7).

It was indicated earlier that detrital siderite was probably common in the original sediments and provided a source for much of the ferruginous material in the Biyadh–Wasï sands. The oxidation and alteration of this iron is suggested by the limonitic and haematitic materials observed. However, later weathering and leaching of the oxidised iron has created more pore spaces and thus produced the weak cementation and friability characteristic of most of these sands, as observed in a few ferruginous but friable Biyadh–Wasï units. On the other hand, as leaching and oxidation proceeded, iron migrated in solution to the surface of a few rock units and was precipitated as limonite, forming a hard cement or crust, as observed in the form of concretions (Fig. 12) and also mantling several Wasï units (Figs 13 and 14).

Table 1. Synthesis of the paragenetic sequence in the Biyadh–Wasi' Sandstones

Stage	Post-sedimentation changes		
1	Burial of sand, primary partial silica cementation (quartz overgrowths)	← Pressure solution →	← Degradation ¦ Aggradation →
2	Precipitation of iron in remaining pores, plus additional quartz overgrowth		
3	Precipitation of Fe-rich clays, partial corrosion of detrital quartz grains, absence of quartz overgrowths	← Inhibition of pressure solution →	
4	Precipitation of carbonate in pore spaces, partial replacement and corrosion of quartz grains and no overgrowths		
5	Weathering, intrastratal solution by circulating waters, oxidation of iron and leaching of both oxidised Fe and carbonate producing present friability of sands		
6	Precipitation of silica dust in remaining pores, secondary silica overgrowths (mainly in microcrystalline form)		

The formation of the carbonate which forms poorly developed patches in some Biyadh and Wasi' Sandstones, cannot be dated directly on textural grounds with respect to the main stage of ferruginous cementation. However, the carbonate does appear to post-date the early-stage silica cementation, and has the same replacive and corrosive relationship to detrital quartz grains as the iron-rich clays. Thus the carbonate appears to have been formed at approximately the same diagenetic stage as the ferruginous clays and may, indeed, represent the residuum remaining after mobilisation of iron out of the original siderite. However, at least some of this carbonate may have been derived in solution from overlying (or underlying) limestones to be precipitated first as pore fillings, then subsequently expanded by marginal replacement of adjacent detrital quartz grains (Fig. 6). Thus, although almost contemporaneous with the precipitation of the iron-rich clays, the formation of cementing carbonate is assigned to a slightly younger diagenetic stage (Stage 4 in Table 1).

The last two stages in the post-depositional history of these sandstones are concerned primarily with the present conditions of weathering, and involve intrastratal solution of the more soluble cementing materials, together with some additional oxidation and leaching of iron and carbonates, the effect of which is to produce the general friability of the sands (Stage 5). However, in certain near-surface cores, the prevailing arid conditions have produced appreciable amounts of aeolian silica dust which may be trapped in crevices and pore spaces, and subsequently mobilised by 'desert dew' and other aqueous media to be precipitated as pore fillings and secondary overgrowths in the form of microcrystalline quartz (Fig. 2). Where well developed, such nearly euhedral microcrystalline overgrowths confer the indurated character observed in the 'quartzite caps' (Fig. 4) and represent the last diagenetic event (Stage 6, Table 1).

CONCLUSION

In spite of the friability and poor cementation of the Biyadh and Wasï Sandstones, a few beds show some cementation principally by secondary silica, carbonate or ferruginous cements. These sandstone sequences have been subjected to several important diagenetic changes since their depositional history. Their paragenetic sequences begin with primary partial silica cementation, which was followed by formation of iron in the remaining pores. Both these stages involved quartz overgrowths, produced as a result of pressure solution. Later stages proceeded by precipitation of Fe-rich clays and carbonate in new pore spaces created by partial replacement and corrosion of detrital quartz grains. The lack of quartz overgrowths is believed to be due to inhibition of pressure solution in these stages. The final diagenetic stages include weathering, which has produced new pore spaces, and precipitation of silica dust (probably of aeolian origin) in such pores which resulted in the formation of secondary silica overgrowths in the form of microcrystalline quartz. This process gives rise to the superficial quartzitic blocks typically mantling many elevated outcrops of the Biyadh and Wasï Sandstones.

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اللحام والتغيرات المتأخرة وتتابع تكونها في حجر رمل البياض ـ الوسيع في وسط المملكة العربية السعودية

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خلاصة

بالرغم من أن أحجار رمل البياض ـ الوسيع بطبيعتها سريعة التفتت وضعيفة الالتحام ، إلا أن بعض العينات يلاحظ فيها بعض اللحام وبشكل رئيسي من السيليكا الثانوية (المرو) ، أو الكربونات أو المواد الحديدية . وقد مرت أحجار رمل البياض ـ الوسيع بعد ترسبها بعدة مراحل مهمة من التغيرات المتأخرة .

ويبدأ التتابع الكامل لهذه التغيرات باللحام الجزئي بالسيليكا ويتبع ذلك ترسب المحاليل الحديدية في الفراغات المتبقية . وكلتا المرحلتين تشتمل على نمو للمرو يتم كنتيجة للتضاغط السائلي الحادث . وتنتج المراحل التالية بترسب محاليل الطين والكربونات الغنية بالحديد في فراغات جديدة أحدثت بواسطة الاحلال الجزئي وتآكل حبيبات المرو الفتاتية .

ويعتقد أن عدم حدوث النمو الثانوي للمرو مرده إلى عدم وجود التضاغط السائلي . وتتضمن المراحل النهائية للتغيرات المتأخرة التجوية التي أحدثت فراغات جديدة وترسبات من غبار السيليكا في تلك الفراغات مما نتج عنه نمو ثانوي للسيليكا على هيئة مرو دقيق التبلور . وتؤدى هذه المرحلة إلى تكون الغطاء « الكوارتزي » الذي يوجد عادة على العديد من المنكشفات المرتفعة من حجر رمل البياض ـ الوسيع .