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CEMENTATION OF PLIOCENE-QUATERNARY FLUVIATILE CLASTIC DEPOSITS IN AND ALONG THE OMAN MOUNTAINS

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SUMMARY

Huge masses of coarse clastics were deposited and cemented during and shortly after the last uplift phases of the Oman Mountains; the environment was fluviatile and the climate was alternatively humid and semi-arid. The cement includes mainly calcite, high-magnesium calcite and dolomite; their genesis and relation to the area of water run off are discussed. The cement textures indicate both vadose and phreatic cementation. The absence of cement cathode-luminescence seems to be characteristic of this fresh-water environment of cementation.

I. INTRODUCTION AND GEOLOGICAL BACKGROUND

In order to gain insight into the cementation processes in fluviatile environment, the river deposits outcropping abundantly in and along the Oman Mountains, were investigated in the field and in de laboratory during 1972 and 1973.

The Oman Mountains consist of four major units (Fig. 1) (Glennie et al., 1973)

1. the basement and the autochthonous units with acid intrusives, metamorphics, clastics and carbonates;
2. the allochthonous Hawasina, mainly composed of carbonates;
3. the allochthonous Semail Nappe, an ophiolitic suite of peridotites, serpentinised periodites, gabbros, diabases, basalts and spilites;
4. the Maastrichtian-Tertiary transgressive carbonates.

The two allochtonous units were emplaced at the end of the Cretaceous; this event was followed by the deposition of Maastrichtian to Miocene shallow marine carbonates.

The main area of outcrop is occupied by the allochthonous units with their two contrasting lithologies. These two units also supplied the bulk of the components of the conglomerates and minor sandstones which were deposited shortly after or even during the last uplift phases of the Range.

These Pliocene-Quaternary coarse fluviatile clastics (Molasse?) directly overlie the Semail or Hawasina units in the Mountains (Fig. 2) and occur on top of mudstones associated with gypsum and rock-salt on the southern flank of the Range; in the Sur area (Fig. 1) the clastics form a system of terraces unconformably overlying slightly tilted Lower Middle Miocene shallow marine sandstones and conglomerates (Fig. 3).

II. RELATIONSHIP BETWEEN CEMENT AND SEDIMENTARY GEOMETRY

In most of the cases investigated breaks in the intensity of cementation (consolidation) closely followed surfaces of erosion within the clastic sequence itself. In some cases several surfaces of erosion truncating the pebbles were observed (Fig. 4). This suggests that the cementation is somehow bound to the successive depositional cycles and follows the deposition shortly afterwards.

Much more rarely, the degree of cementation correlated with depositional structures such as foresets. In these cases it is assumed that the primary permeability and capillary forces determined by the grain size were the controlling factors, which is a well-known fact.

III. CEMENT TEXTURES AND ENVIRONNMENT OF CEMENTATION

The textures of the carbonate cement recorded suggest both phreatic and vadose environments of cementation, in the sense of Land (1970).

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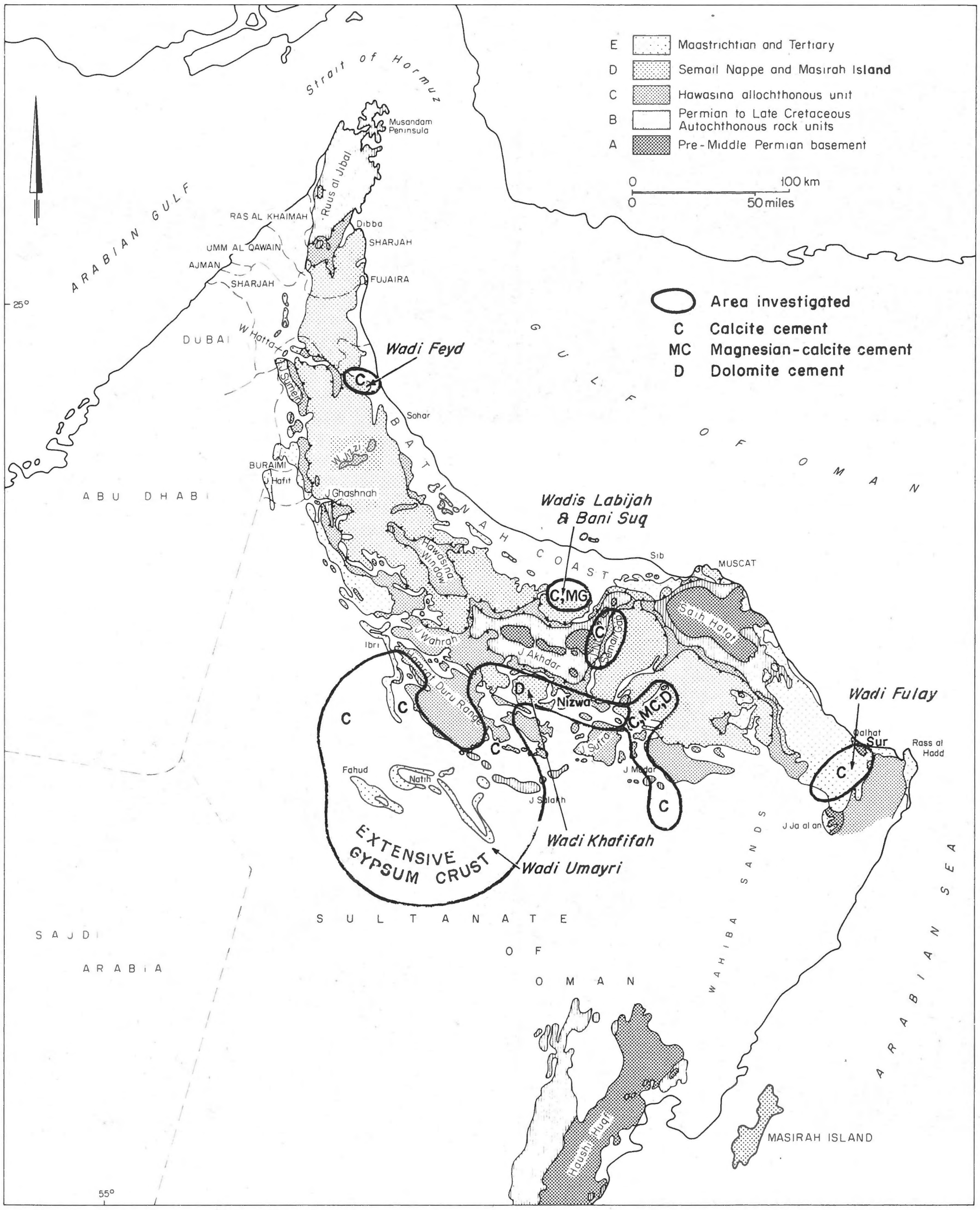

Simplified Geological map of the Oman mountains (from Glennie et al, 1973), location of the fluviatile deposits investigated and type of cement observed.

Depending on the level of the sample and on the fluctuations of the former water table, either vadose textures alone, or vadose cement followed by phreatic cement, can occur (Fig. 5).

In some cases there may even be a kind of rhythmic cementation, with several recurrences of vadose and phreatic textures.

The most typical and widely spread texture is that of stalactica-asymmetric cement ("dripstone"), as shown in Fig. 6.

Micritic sediment occurs occasionally and has a slight tendency to be more frequent close to the source of supply (i.e. in the mountains).

Fig. 2
Stratigrahic position of the cemented Pliocene-Quaternary river deposits (ORD) unconformably overlying a basement (BM) of Semail-Nappe Ophiolites. Note the recent, loose wadi deposits (RWD) cutting into the older deposits (ORD) and the basement. Wadi Labijah.

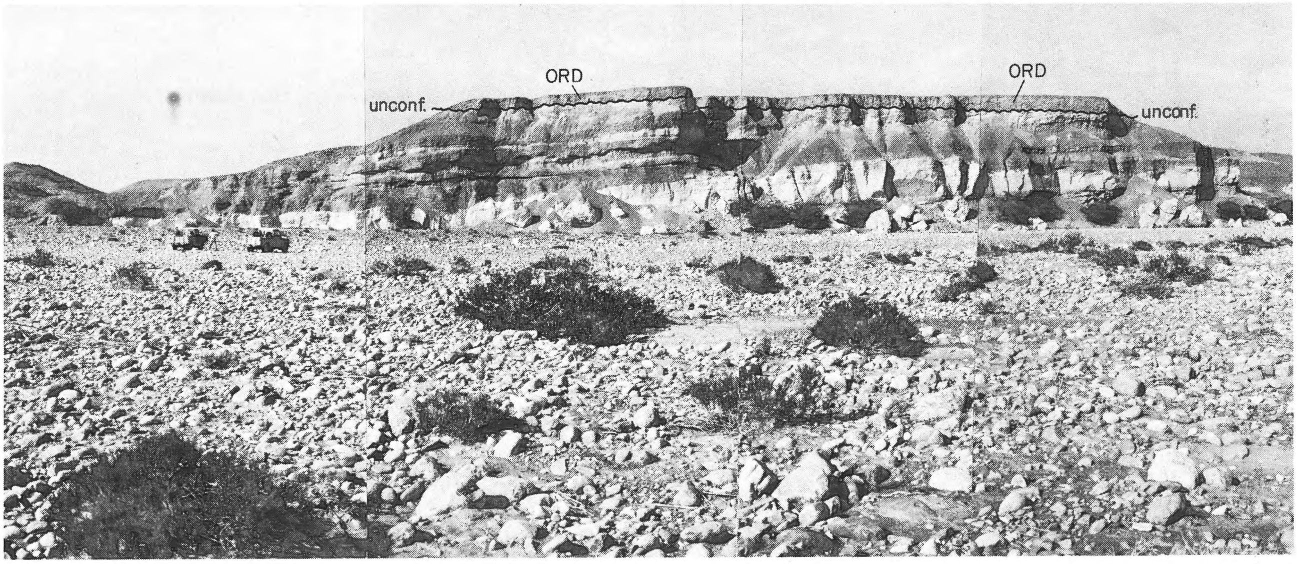

Fig. 3
Older river-deposits (ORD) unconformably overlying slightly tilted Lower-Middle-Miocene shallow marine calcite cement conglomerates and sandstones. Wadi Fulay, Sur area.

IV. MINERALOGY OF THE CEMENT AND SOURCE OF SUPPLY

The bulk of the cement of these river clastics is carbonate; celestite, silica (Opal and chalcedony of length-slow optics) and iron hydroxides occur in very minor amounts. The carbonate, however, includes several phases (calcite, high-magnesium calcite and dolomite) which are thought to be related to the area of water run-off (generally the same ad for the clastic supply) on the basis of the following observations:

1. In the deposits deriving from carbonate sources (mainly Hawasina Formations) or from mixed carbonate-Semail ophiolite sources, the cement is calcite.

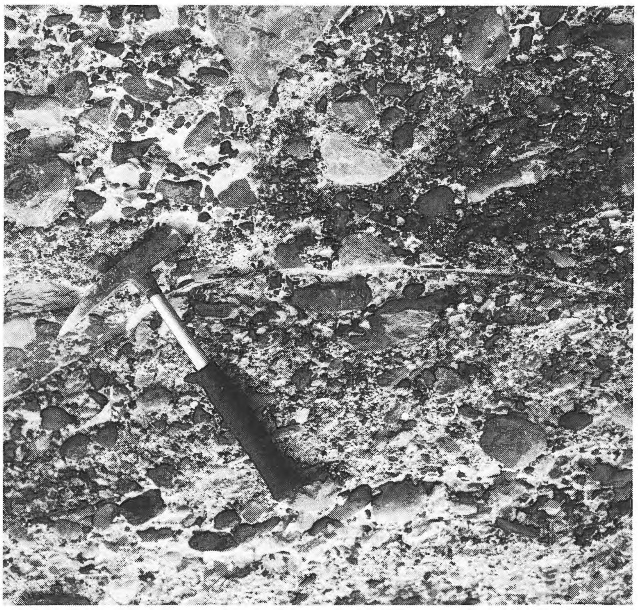

Fig. 4a
Repeated cycles of cementation and erosion in a sequence of older river deposits (ORD 1 – 3). Basement (BM). Wadi Labijah, N-flank of the Range.

Fig. 4b
Surface of erosion truncating pebbles, a direct indication that the calcite cementation is in this case bound to a discrete sedimentation phase. Wadi Labijah, N-flank of the Range.

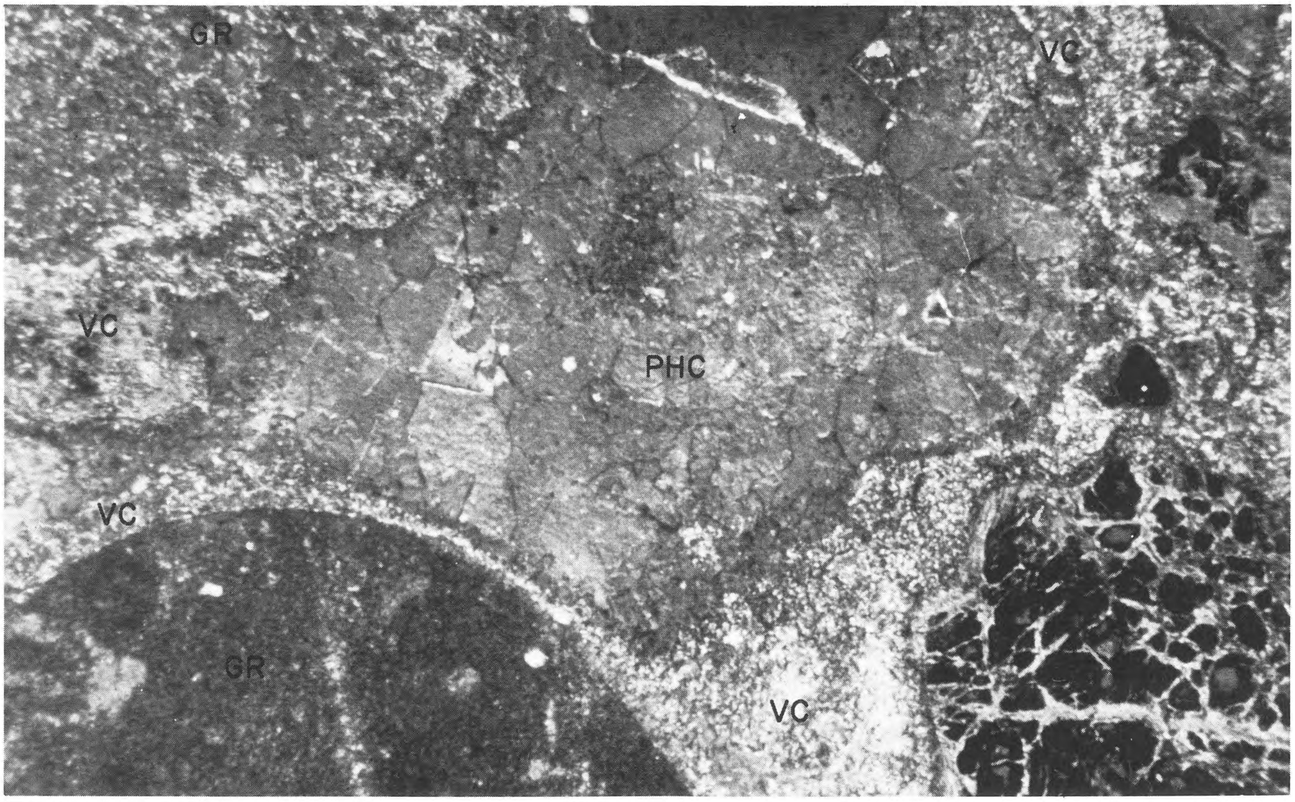

Fig. 5
Microcrystalline vadose calcite cement (VC) followed by phreatic blocky calcite (PHC). Clastic grain (GR) conglomerate, Wadi Umayri. X80.

Fig. 6
Typical "dripstone" cement indicative of vadose cementation. Clastic grain (GR). Conglomerate, Wadi Feyd. x 80.

2. In the deposits deriving from the Semail peridotite sources the deposits are cemented by calcite + high-magnesium calcite or by dolomite. These phases were identified both by staining and microprobe; they were not formed together and are zonally arranged (Fig. 7) and this suggests fluctuations of the chemical composition of the cementing fluids.

   A very interesting case occurs in Wadi Labijah on the northern flank of the Range; there the clastics are predominantly composed of carbonate lithoclasts, but the cement is the same as in the "peridotitic" deposits.

   This anomaly can be explained by the fact that the water-shed probably moved after the deposition of the clastics, which since this event supplied waters deriving solely from a peridotite run-off area.
3. In the deposits deriving from the bulk of the Semail Nappe and containing components of peridotite, gabbro, diabase and basalts the cement is calcite.

V. GENESIS OF THE CARBONATE CEMENT

1. *Mode of formation*

The calcite cement is thought to be a primary precipitation product, which is generally accepted. The mechanisms involved could be supersaturation by evaporation during dry periods[2] or CO_2-assimilation by organisms or a combination of the two. The fact that calcite is the only cement phase, with exclusion of the exceptions mentioned above, also suggests a sedimentary mode of formation.

The high-magnesium calcite is also thought to be a direct precipitation product, because it usually occurs in zones which closely follow the outlines of the clastic components (Fig. 8). Such a relationship with the clastic grains suggests that the high-magnesium calcite (up to 30% mol $MgCO_3$) is not a diagenetic product, because it is highly improbable that "dolomitising" solutions would follow the grain outlines so closely.

The general association of dolomite cement with a high intercrystalline porosity (Weyl, 1960), a high degree of leaching of Mg-Fe-mineral grains and subsequent iron-hydroxide cement formation, suggests that the dolomite is a replacement product and not a primary cement (Fig. 9).

For the formation of calcite or high-magnesium calcite, the Mg/Ca ratio is thought to be determinant, as was shown by Kubler (1958), Skinner (1963) and Müller et al. (1972). It will be explained in the following section that such fluctuations in the Mg/Ca ratio can reasonably be postulated in the present case.

2. *Origin of Ca and Mg*

In the case of carbonate source-areas, the origin of the Ca^{+2} is obvious; for cement deriving from gabbro and basalt-sources the Ca^{+2} occurs in large quantities within plagioclases and pyroxenes. For the peridotite source areas Ca^{+2} would be available from pyroxenes and from subordinate amounts of plagioclases. In the case the Mg/Ca ratio would be rather high.

The Mg^{+2} necessary for the precipitation of high-magnesium calcite and for dolomitisation occurs abundantly in the olivine and pyroxenes of the peridotitic members of the Semail Nappe.

The liberation of the calcium and magnesium from the silicates very likely took place anough hydrolysis processes (Krauskopf, 1967) which were possible during the cementation period (see below). Such a chemical weathering would also have provided a basic environment for the

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[2] The presence of length-slow chalcedony would corroborate this hypothesis, since this particular optics is thought to indicate the existence of a former evaporitic environment (Folk & Pittman, 1971; Siedlecka, 1972).

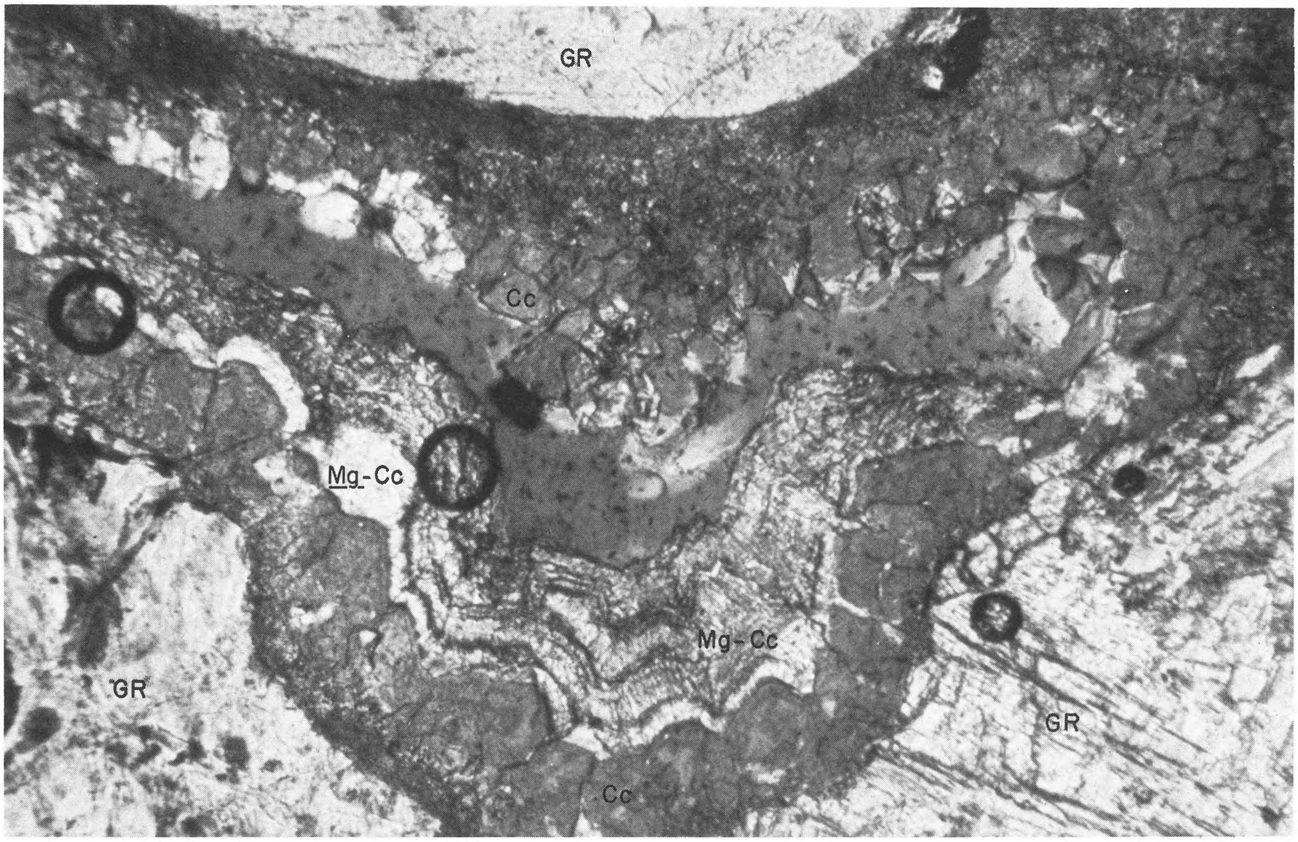


Fig. 7
Changes in cement mineralogy as indicated by staining: (Cc) calcite, (*MG* – Cc) high-magnesium calcite, (MG – Cc) calcite of intermediate $MgCO_3$-content. Note the zonal arrangement of the different carbonates suggesting a *primary sedimentary crystallisation*. Clastic grain (GR). Conglomerate, Wadi Khafifah. x 185.

solutions with resulting higher stability of CO_{3-} with respect to HCO_3^-. This would be in good agreement with the mode of origin of dolomite derived by Lippmann (1973).

VI. LUMINESCENE CHARACTERISTICS OF THE CARBONATE CEMENT

Cathode-luminescence properties of the carbonate cement were investigated in order to detect hidden textures or other characteristic features (Sippel & Glover, 1965).

It was found that the carbonate cement is generally non-luminescent (Fig. 10), except for the carbonate cements deriving from peridotite sources which showed an orange-reddish luminescence due to the presence of Mn^{+2} in the carbonate lattice (Sommer, 1972). In the latter case the luminescence occurs in zones and displays a mechanism of regular growth of the carbonate minerals.

It has been observed that the finer grained cement shows a tendency to be slightly more luminescent than the coarser cements, which is perhaps related to the easier incorporation of trace-elements during faster crystallisation.

VII. TIMING OF THE CEMENTATION AND CLIMATIC CONDITIONS

1. *Timing of the cementation*

From the stratigraphic data of the Sur area (see above) it can be concluded that the deposition of the fluviatile deposits and therefore their cementation took place after the Miocene.

Several other evidences suggest that the cementation took place during the last uplift phases of the Oman Mountains:

(i) pseudoschistous boulder beds were observed on the northern flank of the Range (Wadi Bani Suq). In these

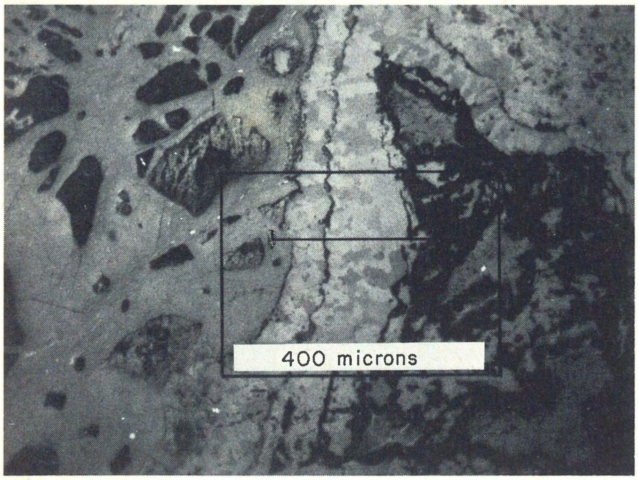
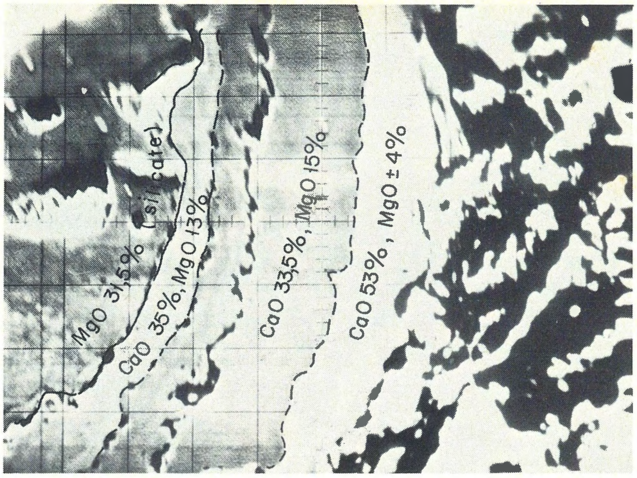
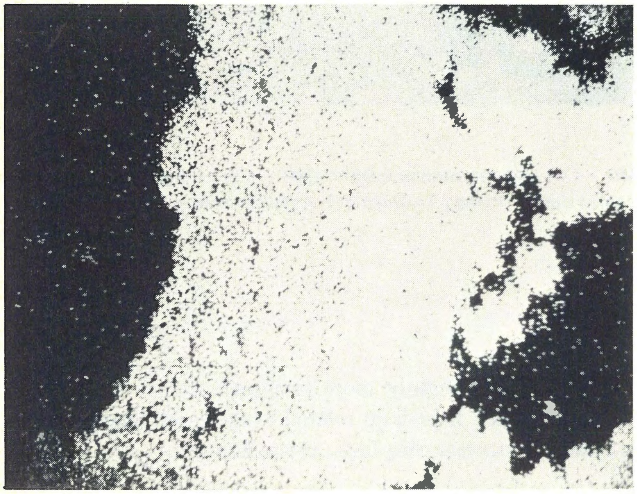


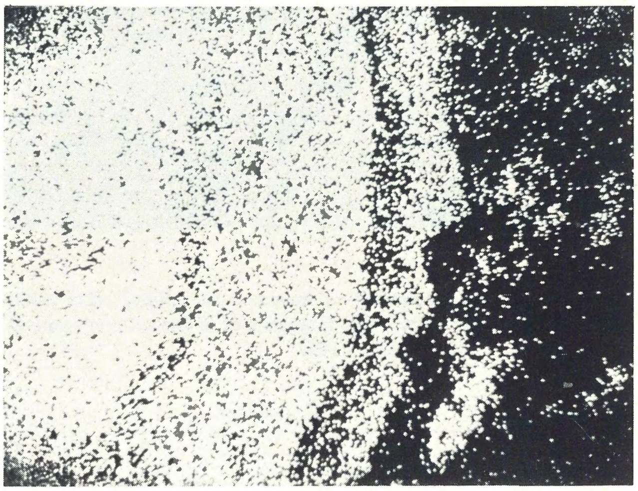
Fig. 8a 8b 8c 8d
Example of microprobe pictures showing the relationship between cement fabrics and composition. The different cement zones closely follow the contours of the detrital grains which indicates primary precipitation. Note the sharp compositional break crossing the crystals. Conglomerate, Wadi Khafifah.



Sample-current picture. The darker the colour, the richer in Mg is the carbonate.



x-Ray fluorescence picture showing the distribution of the magnesium atoms.



x-Ray fluorescence picture showing the distribution of the calcium atoms.

boulder beds a subhorizontal set of fissures crosses boulders and cement (Fig. 11). This suggests the existence of some tectonic (?) forces after the boulders were already cemented;

(ii) the shifting of the water-shed mentioned above could also be related to tectonism;

(iii) the existence of such huge masses of coarse clastics so widely spread all around the Oman Range must be related to uplift of the Range.

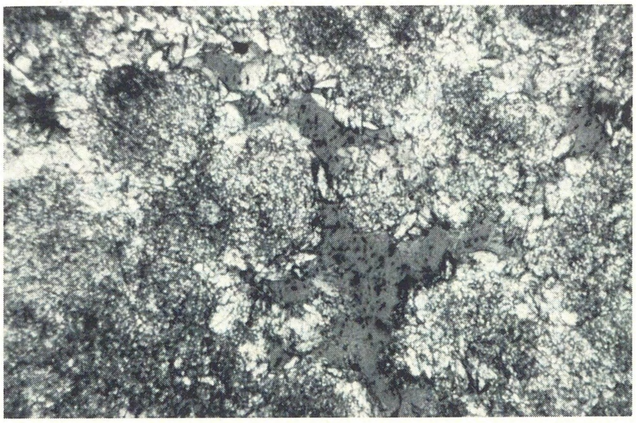


Fig. 9
Example of *intercrystalline* porosity in the dolomite cement of a peridotite breccia/conglomerate. Bahla area.

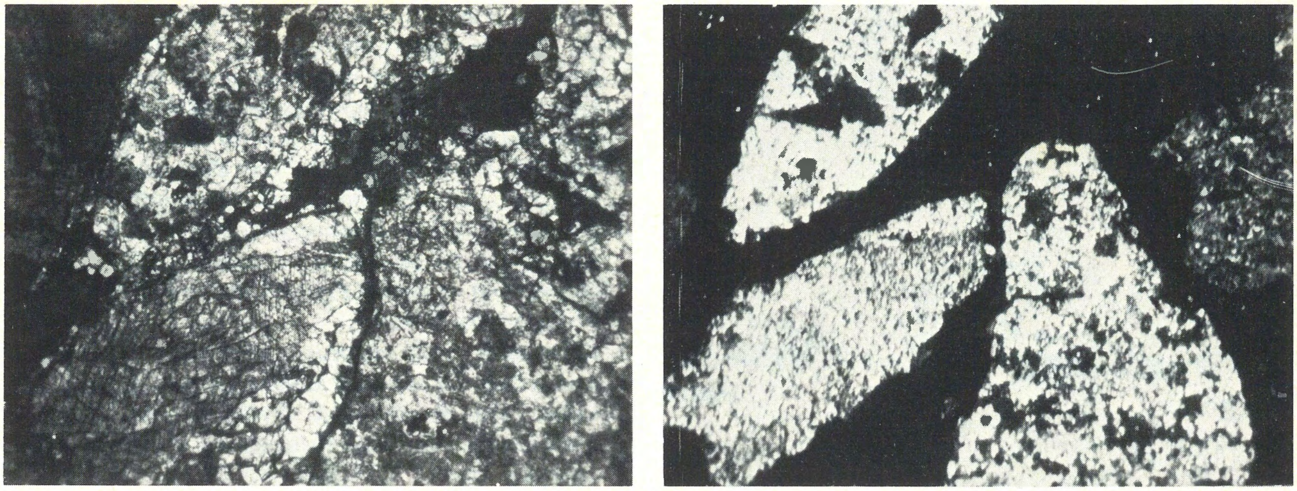


Fig. 10
Typical case of marine carbonate lithoclasts that are strongly luminescent; the fresh water calcite cement is non-luminescent. (A) normal microscope picture, (B) cathode-luminescence picture, Both pictures x 50. Conglomerate, Wadi Fulay, Sur area.

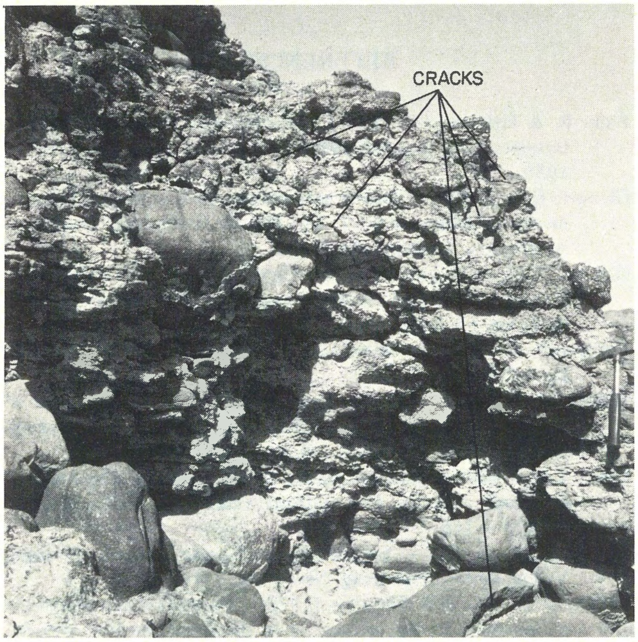


Fig. 11a
Outcrop of 'pseudoschistous' boulder bed where a subparallel set of cracks, later filled by calcite, crosses the boulders. This indicates early cementation and existence of some tectonic (?) forces. Wadi Bani Suq.

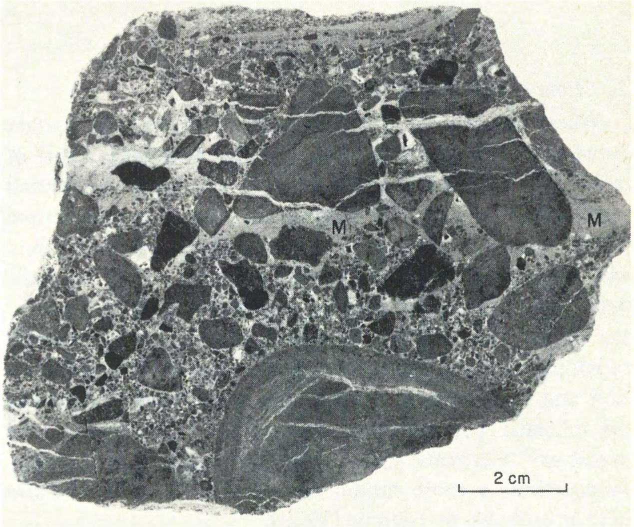


Fig. 11b
Polished slab of conglomerate as in fig. 11a. Note the subparallel cracks through the pebbles, later filled by calcite. Micritic sediment (M). About natural scale.

However, it was shown that the cementation of these clastics was bound to discrete episodes of deposition, because several polished erosion surfaces could occur within the same section of clastics. Therefore, the cementation also took place during the uplift of the Range.

(iv) the fact that angular unconformities within the Pliocene-Quaternary clastic sequence are more frequent very close to or within the Mountains indicates also that the cementation occured during the axial uplift of the Mountains.

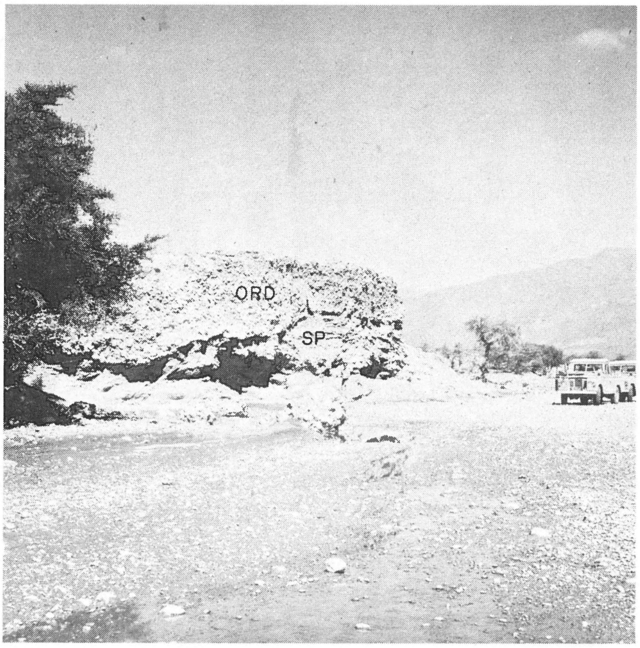


Fig. 12
Older river deposits (ORD), non-conformably overlying deeply weathered spilites (Sp) with caliche-like encrusting, close to Nizwa.

2. *Climatic conditions*

Where the erosion is deep enough to display the contact between the fluviatile deposits and the basement, a sort of lateritic soil or caliche-like crust is overlying the Semail ophiolites (Fig. 12). This suggests that the climate exhibited both humid and semi-arid conditions. Such a climate could well have persisted during the cementation of the fluviatile deposits and have promoted the chemical weathering, causing the hydrolysis of the silicate minerals, and therefore providing the necessary chemical environment for cementation and formation of Mg-carbonates. Alternate humid and dry climatic periods could respectively have supplied the nescessary elements and caused supersaturation through evaporation: a more humid climate than nowadays is also held as probable by Glennie (1970).

VIII. CONCLUSIONS

The present study has shown that:

1. direct precipitation of high-magnesium calcite is possible in fluviatile environment, provided the Mg/Ca ratio is high enough (in this case due to the high Mg content of the peridotite source areas);
2. dolomitisation of carbonate cement is possible in a fluviatile environment, in the present case due to the hydrolysis of Mg- and Mg-Ca-silicates; this process may produce high intercrystalline porosity;
3. the cementation of the fluviatile coarse clastics in and along the Oman Mountains that took place while the Range was still rising was a rather fast process bound to the discrete depositional episodes. The climate at that time was probably of subtropical nature (rather hot and humid). In practical terms this means that the presence of cemented river deposits such as occur massively within the beds of actual wadis does not absolutely prove the existence of an important present-day aquifer;
4. cathode-luminescence petrography could well be a useful tool in the reconnaissance of ancient environments of cementation, as already foreseen. Such a conclusion needs further testing, however;
5. the textures of the carbonate cement formed in fluviatile environment are the same as those generally referred to as vadose and phreatic and display a large variety of combinations, the most characteristic texture being the dripstone cement. The existence of micritic sediment mixed with the finer clastic fraction suggests that the formation of carbonate was relatively easy and fast (Pettijohn et al. 1972).

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