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Ophicarbonates: calichified serpentinites from Gebel Mohagara, Wadi Ghadir area, Eastern Desert, Egypt

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Abstract—An ophicalcite occurrence is recorded in the uppermost part of the Precambrian ophiolitic serpentinites at Gebel Mohagara (Wadi Ghadir area) in the Egyptian Eastern Desert. In this locality, the serpentinites and their ophicalcites are sometimes directly overlain by pelagic shales and calcareous sediments along thrust planes. Field relations suggest that these ophicalcites are present as serpentine-carbonate breccias that develop along conjugate shear planes and brecciation zones. Typical sedimentary features are common, such as the presence of micritic carbonate, colloform texture, geopetal-like structures and the presence of vugs. The latter are often filled by coarse calcite spars due to diagenesis and neomorphism. Another older type of less brecciated ophicarbonates (ophimagnesites) is also present and shows extensive replacement of serpentine minerals by magnesite. The ophicalcites are considered as sedimentary breccias formed in a weathered serpentinite lithology with fabrics of typical calichified rocks. It is believed that the calichified serpentinites represent a reworked oceanic calcite that have been formed after the obduction of the ophiolite nappe on the continent. The dissolution of the calcareous material in the pelagic cap furnished the needed carbonate influx to fill the brecciated serpentinite below. © *1997 Elsevier Science Limited.*

Résumé—Un affleurement d'ophicalcite s'observe dans la partie supérieure des serpentinites ophiolitiques précambriennes du Gebel Mohagara (région du Wadi Ghadir) dans le désert oriental égyptien. Dans cette localité, les serpentinites et leurs ophicalcites sont parfois recouvertes directement par des shales pélagiques et des sédiments calcaires le long de plans de chevauchement. Les relations sur le terrain suggèrent que les ophicalcites représentent des brèches de serpentine et de carbonates formées le long de plans de cisaillement conjugués et de zones de bréchification. Les structures sédimentaires typiques sont communes, comme la présence de carbonates micritiques, de textures collomorphes, de structures pétaloïdes et de géodes. Les géodes sont souvent remplies de cristaux grossiers de calcite à cause de la diagenèse et de la néomorphose. Un autre type, plus ancien, d'ophicarbonates moins bréchifiés (ophimagnésites) est également présent et montre le remplacement important des minéraux de serpentine par la magnésite. Les ophicalcites sont considérés comme des brèches sédimentaires formées aux dépens de serpentinite altérée avec des structures typiques de caliches. On pense que les serpentinites calichifiées représentent du matériel océanique calcitisé remobilisé après l'obduction de la nappe ophiolitique sur le continent. La dissolution du matériel calcaire de la couverture pélagique a fourni l'apport de carbonate nécessaire au colmatage de la serpentinite bréchique située en dessous. © *1997 Elsevier Science Limited.*

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INTRODUCTION

In many world-wide ophiolite occurrences, carbonates (sometimes termed ophicarbonates) are commonly associated with serpentinised ultramafics. In Egypt, carbonates in the uppermost part of the sequence are of limited distribution in the Precambrian Pan-African ophiolites of the Eastern Desert. Some workers recorded them in certain localities, e.g. Barramiya, Wadi Ghadir and Ras Shait area (El-Bayoumi, 1980; Shackleton *et al.*, 1980; Basta, 1983; this study). However, no detailed information on the mineralogy or petrogenesis of these Egyptian examples was presented. The present work documents the detailed geology of an ophicarbonate occurrence at Gebel Mohagara (Wadi Ghadir area, south Eastern Desert) in order to investigate its geotectonic significance and relationship to the host ophiolite slab. The term "ophicarbonate" for the present occurrence is totally descriptive, which means that it is not necessarily related to the genesis of the ophiolite itself.

The origin of ophicarbonates has been a matter of great controversy since the middle of the nineteenth century (Hunt, 1857, 1858). During the last three decades of the present century, the problem of ophicarbonates reappeared. Folk and McBride (1976) indicated that ophicarbonates (including serpentinite breccias) in the old literature were believed to be related to tectonism and submarine volcanism, carbonate magma and metasomatism. Peters (1963) stated that ophicarbonates result from contact metamorphism of the sediments by intrusive ultramafics. Trommsdorff and Evans (1977a, b) assigned a progressive metamorphic origin to the serpentinites and ophicarbonates that could be overprinted by contact effects of felsic intrusions. Trommsdorff *et al.* (1980) concluded that the precipitation of calcite in the ophicarbonates results from mixing of fluids from serpentinites with relatively more acidic fluids from felsic or mafic rocks.

A sedimentary origin (deep-sea sedimentation) for ophicalcite breccias was favoured by many authors (e.g. Decandia and Elter, 1972; Barbieri *et al.*, 1979; Bertrand *et al.*, 1980; Cortesogno *et al.*, 1981 Barrett, 1982; Bernoulli and Weissert, 1985; Frisch *et al.*, 1994). Most of these authors concentrated their work on the Alps of France, Switzerland, Austria and Italy. According to this hypothesis, the ophicalcites are always stratigraphically overlain by thick sequence of open marine arenaceous sediments (e.g. Cortesogno *et al.*, 1981) or shales and limestones (e.g. Bernoulli and Weissert, 1985; Frisch *et al.*, 1994). Actually, the cap above the ophicalcite in many cases is also constituted of massive and pillow basalts (Bertrand *et al.*, 1980; Frisch *et al.*, 1994). According to these authors, brecciation results from the upward propagation of movements from master faults into a network of smaller ones at the surface (i.e. fracture flextures).

On the other hand, a pedogenic origin is suggested for the ophicalcites (e.g. Folk and McBride, 1976). In this hypothesis, it is thought that the ophicalcites are calichified serpentinites located at the uppermost part of ophiolite sections. The occurrence of this ophicalcite in the structural highs (horst blocks) in addition to the presence of the altered serpentinite bedrock as a quasi-horizontal blankets led these authors to think about formation through vadose processes. They also supported their conclusions by the presence of circumgranular cracking in the serpentinite clasts, jasper beds with soil-like microfabrics, low length calcedony, which are all expected in the semi-arid soils. Bogoch (1987) presented different classifications and genitic models for the ophicarbonate rocks and discussed both of the above hypotheses.

FIELD OBSERVATIONS AND MEGAFABRICS

The Wadi Ghadir area is a well known example of ophiolite occurrence in the south Eastern Desert of Egypt (Fig. 1), which was first identified by El-Sharkawi and El-Bayoumi (1979). El-Bayoumi (1980) and Basta (1983) studied the Ghadir ophiolite and associated mélange rocks in detail. They both agreed that the Ghadir ophiolite represents a dismembered ophiolitic sequence. In their conclusions, they mentioned the presence of pelagic sediments (with fragments of radiolarian chert) at the top of the sequence. El-Bayoumi (1980) agreed with Shackleton *et al.* (1980) that this ophiolitic occurrence represents an olistostrome and he subdivided the mélange into proximal and distal facies with repsect to the presence or absence of blocks. At Gebel Mohagara (Fig. 1), Takla *et al.* (1982) gave a petrographic study of the ophiolitic assemblage. They considered serpentinites rich in carbonates as carbonate serpentinites without refering to the problem of the origin of the ophicarbonates. Takla *et al.* (1992) noted that the whole ophiolitic slab in Wadi Ghadir area is thrust over old continental gneisses and migmatites.

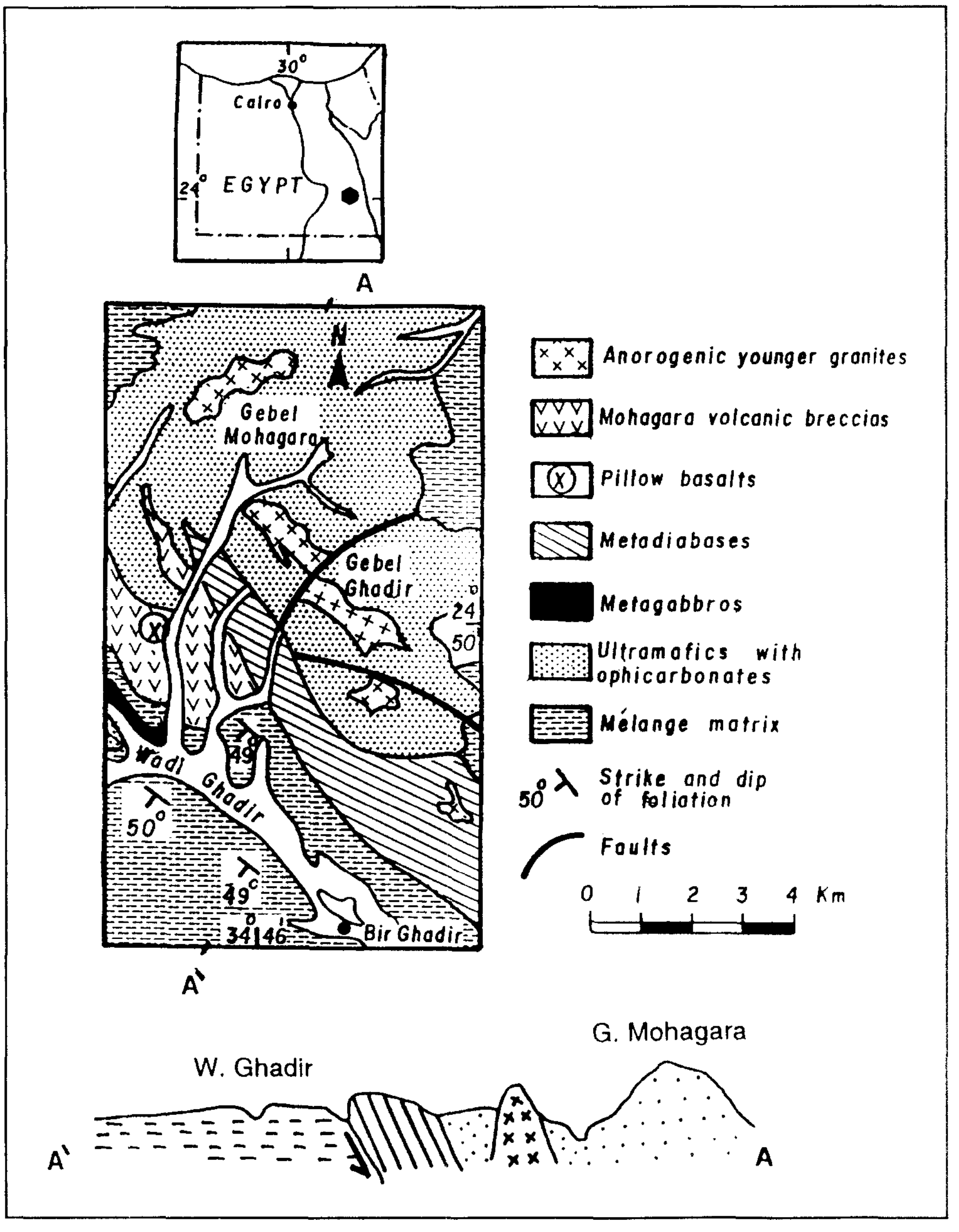

Figure 1. *Geological map of the area around Gebel Mohagara (after Basta, 1983).*

Field observations of the authors at Gebel Mohagara indicate that the ophicarbonates and the host serpentinites occur as low lying moderately elevated peaks. The serpentinites are sometimes overlain by pelitic and calcareous pelagic sediments varying in thickness from 15 cm up to 1.2 m. The contact between the ophicarbonate-serpentinites and the sediments is usually structural along low angle thrust planes (Fig. 2). These sediments show typical sedimentary stratification. The shales are commonly pinkish, fine-grained rocks and the limestones are greyish white, thin-laminated rocks. In some other instances, the sediments rest directly with normal stratigraphical contacts on pillow basalts, representing the top of the dismembered ophiolite sequence.

Below the contact between the pelagic sediments and the serpentinite carbonate breccias at the top of the ophiolite complex, white carbonate in veins and irregular patches are very common, filling the fractures of the brecciated serpentinised ultramafics. Some light reddish staining of the carbonates is observed. Figure 2 shows that the whole ophiolitic serpentinite mass is highly fractured and brecciated, but that the calcite veins are restricted to the uppermost part of the ultramafic

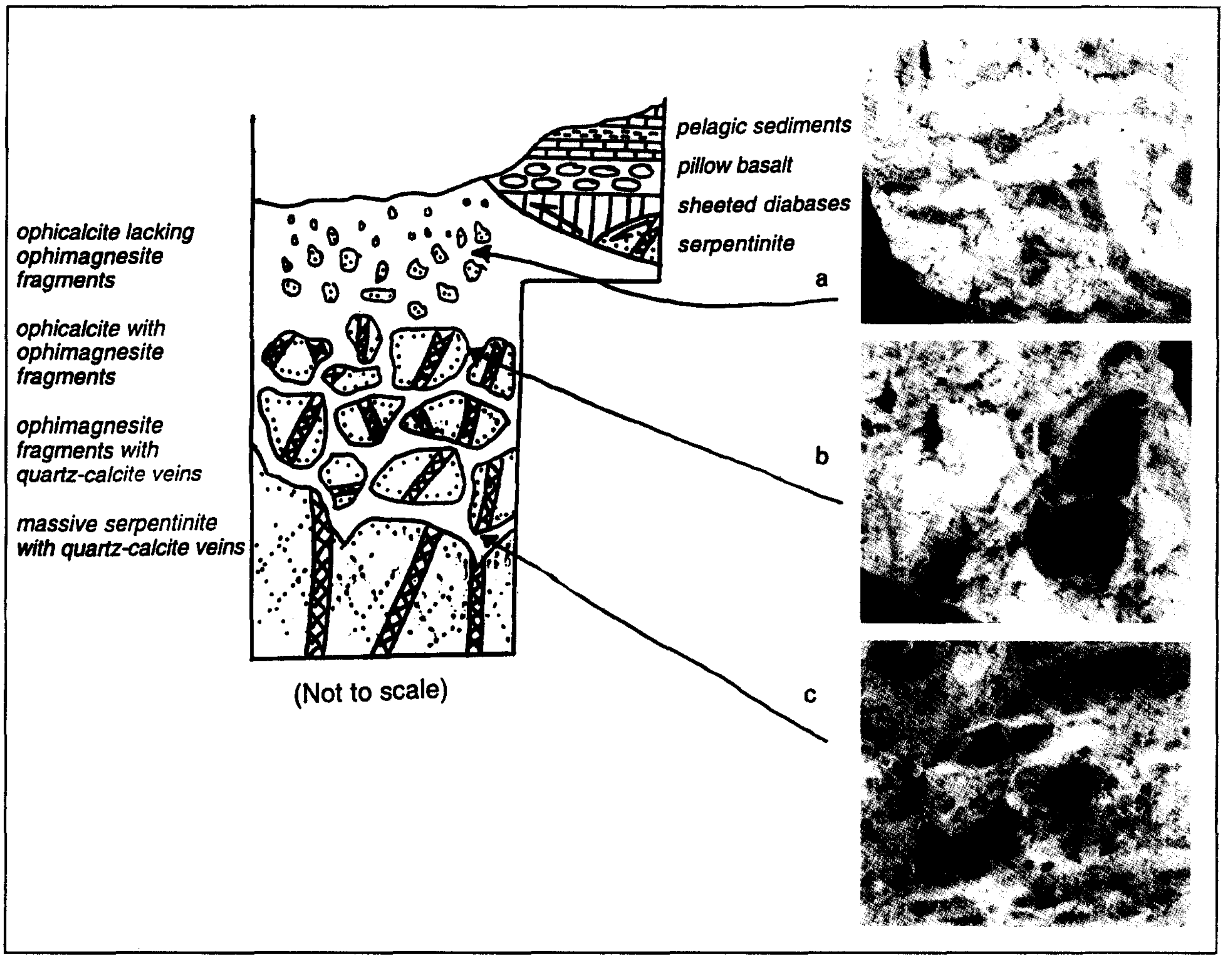

Figure 2. An idealised section showing the occurrence of ophicarbonates. (a) ophicarbonate with little serpentine. (b) matrix dominated breccia. (c) breccia with closely-fitting fabrics. Dimensions of all field photos are 15 cm x 20 cm.

domain. This observation suggests that the calcite precipitated downwards to cement the sheared and brecciated serpentinite clasts. Megastructurally, the calcite thus fills "neptunian"-like dykes and veins with increasing width upwards. Similar dykes are recorded for example by Bernoulli and Weissert (1985) in the ophicalcite occurrences of the Arosa zone, Switzerland, and by Folk and McBride (1976) in the Ligurian ophiolite of Italy. The breccia adjacent to the more resistant serpentinites is characterised by closely-fitting, angular to sub-angular clasts, suggesting that the serpentinites were brecciated along a conjugate fracture system. At highly brecciated spots, especially upwards, the rock is either a clast supported breccia or a matrix dominated breccia. Generally, open space structures are common, as will be discussed in the section on petrography and microfabrics. Most of the serpentinite clasts are green in color, but some brownish or reddish ones are recorded. The latter could represent some imprints of aerial or subaerial oxidation, most possibly contemporaneous with the deposition of the calcite cement.

In the Wadi Ghadir area, ophimagnesites, as another type of ophicarbonate, is also present. In contrast to the younger ophicalcites, the former show no clear sedimentary characteristics. They are simply fractured and show no evidence of either development of angular clasts or open space structures. Most importantly, the carbonates (magnesite in this case) are not in the form of matrix cement, but appear replacing the serpentine minerals, leaving behind fisk-like remnants of serpentinites. These ophimagnesites are considered as products of CO_2 metasomatism either by descending and/or ascending solutions, which still need some isotopic analysis. Hydrothermal quartz-calcite veins and dykes are common below the Ghadir serpentinites either with or without ophicarbonates.

A schematic column (Fig. 2) illustrates that quartz-calcite veins and the ophimagnesite clasts

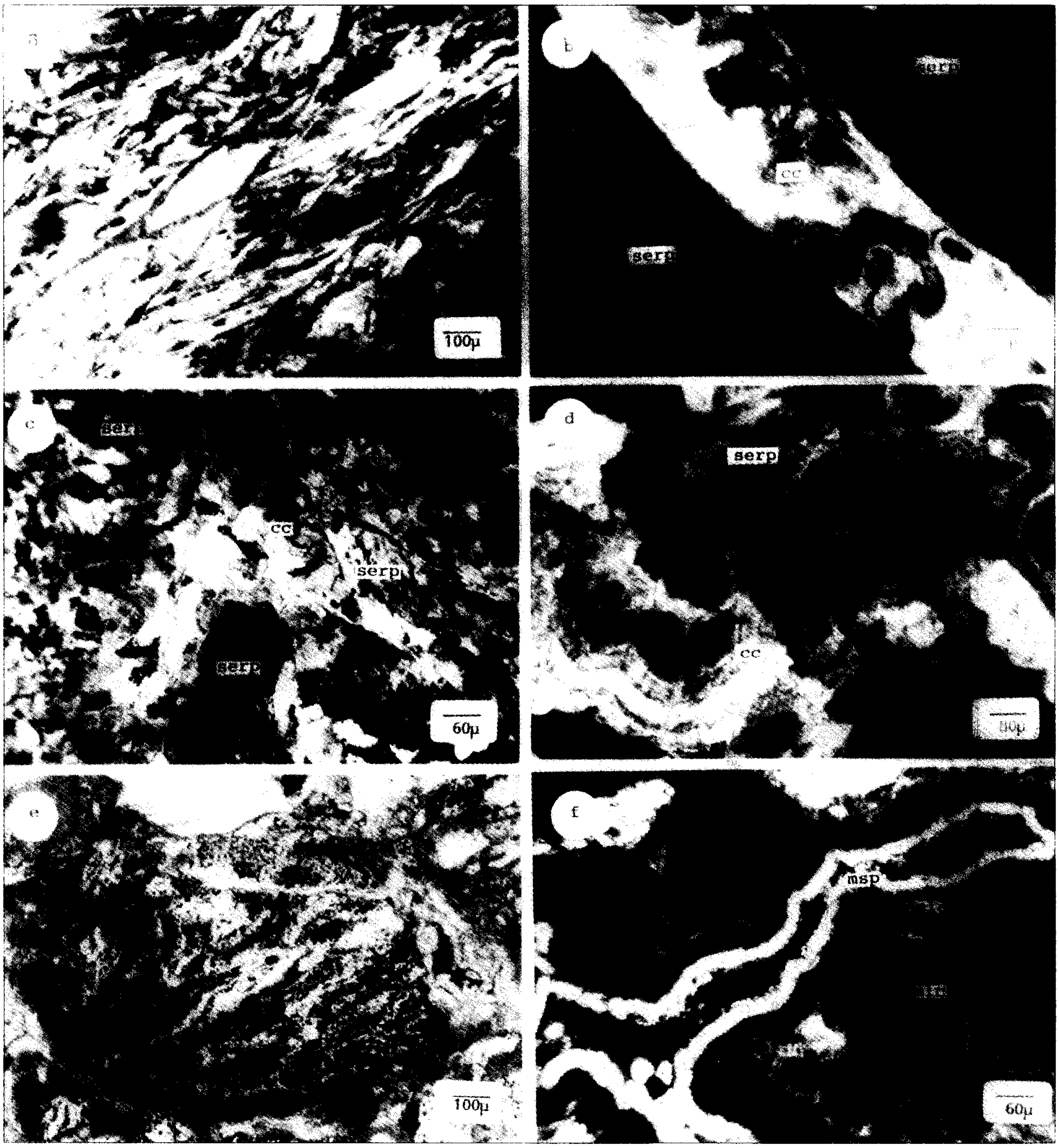

Figure 3. Photomicrographs of the ophicalcites. (a) Fine calcite veinlets along the conjugate fractures of the least brecciated serpentinites, cross-nicols. (b) Details of colloform calcite (cc) in veinlets cutting serpentinite (serp), cross-nicols. (c) Angular serpentinite clasts (serp) cemented by colloform calcite (cc), cross-nicols. (d) Colloform calcite (cc) with staining in some layers around the serpentinite clast (serp) cross-nicols. (e) Subrounded serpentinite clast with fine opaques encrusted by colloform calcite, plane-polarised light. (f) Mineralogical variation profile from micritic calcite (mic) to diagenetic micrite (dmic) to calcite microspars (msp) towards the vug, cross-nicols.

with fish-like serpentinites are older than the ophicalcite. The latter lacks ophimagnesite fragments (clasts) upwards. According to this field relation, the sequence of formation of the carbonate bearing rocks is as follows: quartz-calcite veins (oldest), ophimagnesites and finally ophicalcites (youngest).

MICROFABRICS AND TEXTURES

The three carbonate bearing rock varieties in the serpentinites of the Wadi Ghadir area, and at Gebel Mohagara in particular, were identified in the field and studied microscopically in order to investigate their diagnostic microfabrics, which could help to elucidate their petrogenesis.

The microscopic description of these rocks is summarised as follows:

Sedimentary ophicalcites

Sedimentary textures are predominant in all the studied samples of ophicalcite breccias. In some samples (breccia with closely-fitting clasts), fragmentation of the parent serpentinite seems to develop along a "conjugate" or "diamond-shaped" fracture system (Fig. 3a). In this case, calcite matrix precipitates in nearly regular planes, outlining the rhomb-shaped serpentinite clasts. Detailed features of calcite in the vein fractures indicate a very characteristic colloform nature (Fig. 3b). Another type of breccia is a clast supported breccia (Fig. 3c), in which stained calcite is also of colloform texture. It appears that fine drusy calcite crystals first start to crystallise on the irregular surface of the angular serpentinite clasts. The next calcite crust to crystallise in the colloform layers is highly stained, and finally the calcite cement crystallising furthest from the clast is completely clear calcite microspars (Fig. 3d, e). In some other cases, the calcite mud as a cementing material is followed by a stained diagenetic calcite and ended with calcite microspars towards the void vugs (Fig. 3f). When the vugs are filled, pure calcite spars are recognised.

Microscopic sketches (Fig. 4) show the common examples of the observed microfabrics in the studied sedimentary ophicalcite breccias. The regular rhomb-shaped serpentinite clasts appear as "floating" fragments in the carbonate cement or the micritic mud (Fig. 4a). The open space structures are characterised by the geopetal-like carbonate filling (Fig. 4b). Similar structures are very common in sedimentary ophicalcites from Italy and Switzerland (e.g. Folk and McBride, 1976; Bernoulli and Weissert, 1985). The latest calcite cement phase, filling the voids between the colloform layers, is either elongate calcite spars (Fig. 4c), or polygonal ones (Fig. 4b).

Ophimagnesites

Some brecciation or cataclastic textures are recognised in this type of ophicarbonates. Nevertheless, cracks are common along which the solution circulated. Texturally, it is obvious that the magnesite extensively replaces the serpentine minerals, leaving behind some lensoidal or fish-like relics (Fig. 5a). It is also evident that prismatic and flaky lizardite is less susceptible to replacement by magnesite than chrysotile-antigorite (Fig. 5a, b). Collapse of the serpentine structure resulted in the appearance of amorphous Fe-hydroxides and hematite in the form of reddish brown materials. Chlorites, when present, are clinochlores occurring as fine streaks replacing the serpentine minerals.

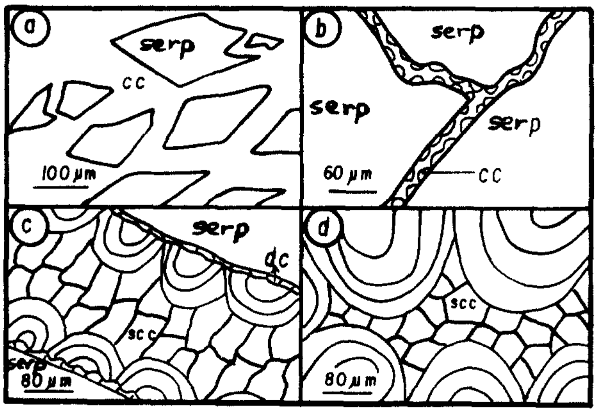

Figure 4. Sketches of some ophicalcite microfabrics. (a) Rhomb-shaped clasts of serpentinite (serp) with calcite filling (cc). (b) Geopetal filling of colloform calcite (cc) in serpentinites (serp). (c) Details of carbonates in a veinlet cutting the serpentinite (serp) with drusy calcite (dc) grains at the vein-walls, followed by colloform calcite and ending with long coarse calcite spars (scc). (d) Polygonal calcite spars (scc) and earlier colloform calcite.

Quartz-calcite veins

This type of vein is very common in many Pan-African ophiolitic ultramafic masses in the Eastern Desert. In the area of study, the hydrothermal nature of quartz is evident. Quartz grows as idiomorphic crystals on the fracture walls with pyramidal terminations (Fig. 5c). Growth zoning in some quartz crystals is also observed. Well-crystallised calcite appears to follow the quartz crystals in the paragenetic sequence, since it invades and "cements" the latter (Fig. 5c).

EVOLUTION OF THE OPHICARBONATES

From the foregoing review of the mega- and microfabrics of the sedimentary ophicalcite breccias of Gebel Mohagara, the present authors tend to consider that the breccia is clearly a tectonic breccia, as suggested by the cataclastic textures, that are in some cases followed by mylonitisation and slickensides (i.e. consequent phases of brittle and ductile deformation). These all suggest a brecciation event during the tectonic emplacement of the ophiolitic ultramafics under oceanic conditions, before or contemporaneously to the process of serpentinisation via sea-floor metamorphism. Bonatti *et al.* (1974) suggested two other origins

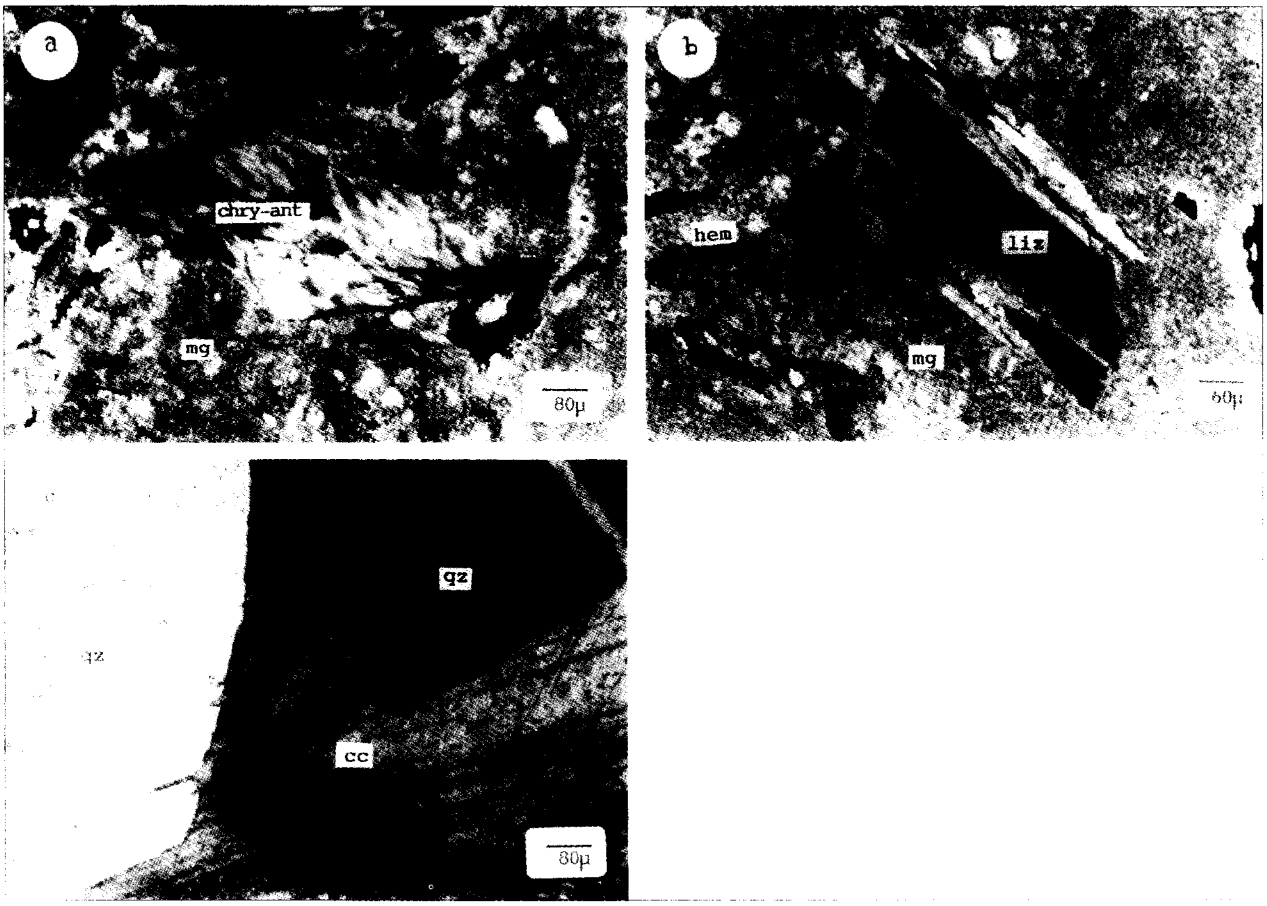

Figure 5. Photomicrographs of ophimagnesites and quartz carbonate dykes. (a) Lensoidal remnant of chrysotile-antigorite (chry-ant) replaced by magnesite (mg), cross-nicols. (b) Resistant lizardite (liz) with some replacement by magnesite (mg). Notice the presence of hematite (hem), cross-nicols. (c) Idiomorphic quartz (qz) and coarse calcite in a quartz carbonate dyke, cross-nicols.

of ophicalcite breccias dredged from the Mid-Atlantic ridge at the equatorial zone. One could be the product of submarine alteration and the other is a talus breccia. The Gebel Mohagara samples show no textural or mineralogical evidence in support of such origins. If the serpentinite breccia is to be considered as a talus breccia, then other ophiolitic fragments must also be encountered. In this respect, the present authors agree with Folk and McBride (1976) that such breccia is "monogenic" because the serpentinite is the only clast component. This, together with other evidence, suggests a pedogenic overprint on the already deposited marine ophicalcite. On the other hand, some other world-wide ophicarbonate occurrences show the presence of oceanic ophicalcite that have been deposited in open marine conditions. This latter calcite shows no evidence of pedogenesis in terms of carbonate recrystallisation and late precipitation (i.e. without any aerial weathering effects).

Bonatti *et al.* (1974) argued that the trace element and isotopic composition of the carbonates at active oceanic ridges are produced from CO_2-rich mantle-derived fluid, as suggested by Bostrom (1973). For the proper primary oceanic ophicalcite, it is believed that the oceanic waters in contact with the ultramafics became alkaline due to the hydrolysis reactions of serpentinisation.

A completely different genetic model for the Gebel Mohagara ophicalcite is suggested. Field relations and microfabrics indicate that the serpentine-calcite breccias are calichified serpentinite rubble. The pelagic carbonates were thrust along low angle faults over the brecciated ultramafics, and they may represent one of the sources of calcitic carbonates. However, the field relations and microfabrics suggest that the calichified rubble has been reworked, post-dating the calcite formed in fractures in open marine conditions. Aerial to subaerial weathering of the pelagic cap resulted in the dissolution of these

Table 1. Representative electron microprobe analyses of calcite and magnesite from ophicarbonates

Mineral	Calcite				Magnesite		
Sample No.*	Moh3	Moh7	Moh8	Moh9	Moh3	Moh3	Moh7
FeO	0.10	0.05	0.00	0.09	0.02	0.02	0.01
MgO	0.00	0.00	0.00	0.00	45.64	46.98	46.61
CaO	63.23	62.01	63.03	62.74	4.71	2.99	2.78
TiO_2	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Cr_2O_3**	0.00	0.01	0.00	0.01	0.01	0.00	0.00
NiO	0.03	0.00	0.00	0.02	0.03	0.04	0.00
Total	63.36	62.07	63.03	62.86	50.41	50.04	49.41

*: Samples Moh3 and Moh7 are dominated by magnesite (collected from the lowest parts of the calichified profile).

Samples Moh8 and Moh9 represent the mostly calichified serpentinites at the top, with little magnesite.

**: Cr_2O_3 in serpentine and clinochlore averages 0.12 and 0.15 wt%, respectively.

Oxides are in wt%.

carbonates during wet periods after emergence (semi-arid conditions). Fluctuating pH during subsequent aridity on the continent is responsible for redeposition of the carbonates. This is common in many caliche profiles, which is evident in the present case by the microfabrics which are characterised by colloform textures and vugs that give the rock its cottage cheese-like appearance. Colloform textures always result from gel or supersaturated solutions. Similar colloform textures were also recorded in other ophicarbonates (e.g. in the Himalayas; Sinha and Mishra, 1995). The role of any biogenic effect in the studied samples is not yet clear.

Table 1 gives some representative microprobe analyses of calcite from the sedimentary ophicalcites and of magnesite from the ophimagnesites. The Fe content is generally low in the calcites, but its concentration varies from nil in the clear coarse calcite spars to 0.10 wt% in the stained micritic material and fine microspars, respectively. The calcite is Mg free, corresponding to the common occurrence of low Mg calcite in weathered rocks such as caliches (Dixon and Weed, 1977). The magnesite shows appreciable CaO content, ranging from 2.78 to 4.71 wt%. No distinct differences are evident in the trace element contents (Ni, Cr and Ti) of both calcite and magnesite. The trace element composition is further evidence for a non-metasomatic origin for the Gebel Mohagara ophicalcite. Cr_2O_3 in the magnesite is nearly absent, whereas it amounts to 0.12 wt% and 0.15 wt% in the serpentine and clinochlore assemblages, respectively. This is explained by the replacement of the serpentine minerals by the magnesite. The released Cr^{3+} then enters the crystal lattices of other associating minerals (e.g. clinochlore). The present trace element composition of marine calcite (in deeper horizon), which are less effected by later calichification, is similar to that of other ophicalcites (e.g. Treves *et al.*, 1995; Sinha and Mishra, 1995).

CONCLUSIONS

Collective field observations, microfabrics and available mineral chemistry of carbonates and metamorphic silicates suggest a tectono-sedimentary origin for the ophicalcite breccia at Gebel Mohagara prior to calichification. More specifically, the Mohagara ophicarbonates are products of mixed tectonic-sedimentary processes related to the tectonic evolution of the ultramafics and the subsequent weathering on the continent. The following concluding remarks are presented:

i) The Gebel Mohagara ophicalcite breccias are typical examples of carbonate reworking in weathered caliche profiles of arid to semi-arid regions. It is believed that calcite infill in the serpentinites originally took place after serpentinisation in open marine conditions. The reworked calcite (caliche) contains intraclasts of radiolaria in some thin-sections.

ii) Brecciation of the serpentinites is probably of tectonic origin and occured during obduction (Bernoulli and Weissert, 1985 and others). Similar ophicalcite occurrences are known in the Alps of Italy, Switzerland, Austria and France. There is also evidence of brecciation in present day oceans during the formation of ophiolites (Bonatti *et al.*, 1974).

iii) The formation of ophicalcite is only restricted to the top of the brecciated serpentinites and occured after the allochthonous lateral movement and obduction as nappe(s) on the older basement, i.e. during a phase of emergence and weathering.

iv) The colloidal nature of the carbonate supersaturated fluid is attributed to the increase of alkalinity in the weathering (vadose) zone.

v) The variation of ophicalcite microfabrics from reworked micritic mud, derived mostly from seawater infiltration (Bogoch, 1987) and may also be driven from the dissolved pelagic carbonate cap, to fine and coarse calcite spars implies diagenetic effects and neomorphism. Rao (1985) and Retallack (1990) described similar neomorphic calcite spars from calichified rocks.

vi) A pedogenic origin for the Mohagara ophicalcite is suggested as most of the caliche characteristics (e.g. meteoric cementation, geopetal structures, carbonate lamination, colloform textures and formation of hematite and its hydration products) are present. This goes in complete harmony with the data cited in Folk and McBride (1976) and Goudie (1983).

vii) The horizons of the soil profile which developed above the weathered ultramafic rocks at Gebel Mohagara are not all recognised. It is clear that the obvious well-developed one is characterised by matrix dominated breccias equivalent to the 'B' horizon in many known calichified rocks. According to Guthrie and Witty (1982), such horizons include material from the underlying (C) horizon of the country bedrock and the overlying horizon.

viii) The ophimagnesite, on the other hand, could represent a variety resulting from mixed waters (meteoric and hydrothermal).

ix) The quartz-calcite veins are exclusively of hydrothermal origin and older in age than both the metasomatic ophimagnesite and the calichified serpentinites. Reworked ophicarbonate might have been filled by carbonate derived from the older hydrothermal veins.

x) Chronologically, the sequence of carbonate bearing rocks at Gebel Mohagara is: hydrothermal quartz-calcite veins cutting the ultramafics prior to brecciation and the formation of the ophicarbonates. Ophimagnesite is then formed by Mg metasomatism of serpentine minerals. This is followed by marine calcite sedimentation, and finally reworking of this calcite through weathering (calichification) after emergence.

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