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DEFORMATION HISTORIES AS RECORDED BY SERPENTINITES. III. FRACTURE PATTERNS DEVELOPED PRIOR TO SERPENTINIZATION

FREDERICK J. WICKS

Department of Mineralogy and Geology, Royal Ontario Museum, Toronto, Ontario M5S 2C6

ABSTRACT

The fractures in olivine grains and the fractures and cleavage planes in pyroxene and amphibole grains have long been recognized as the sites from which serpentinization progresses during the pseudomorphic replacement of these host minerals. The pseudomorphs preserve not only the shape of the host-mineral grains, but also the site of the fractures and cleavage planes that existed in the host. In pseudomorphs after olivine, the fractures are commonly the site of secondary magnetite. The preservation of the olivine fracture-pattern by serpentine mesh-textures is not always recognized in the literature. A curtain-like or banded-growth texture after olivine has commonly been interpreted as a feature of the recrystallization of an orthogonal mesh-texture. This interpretation fails to recognize that such a texture is the expression of an unusual fracture-pattern in the original grains of olivine and, therefore, not a recrystallization phenomenon. This texture thus has important implications for the interpretation of the sequence of events that have affected an ultramafic rock.

Keywords: fracture patterns, olivine, pyroxene, lizardite, serpentinization, banded growth texture, curtain-like growth texture, mesh texture, bastite.

SOMMAIRE

On sait depuis longtemps que les fractures des grains d'olivine et les fractures et plans de clivage des grains de pyroxène et d'amphibole sont le site de l'amorce de la serpentinisation lors du remplacement pseudomorphique de ces minéraux hôtes. Les pseudomorphoses préservent non seulement la forme du grain originel, mais aussi le site de ses fractures et plans de clivage. Dans les pseudomorphoses de l'olivine, les fractures sont, dans la plupart des cas, le site de magnétite secondaire. La préservation du réseau de fractures de l'olivine dans les textures réticulées de la serpentine n'est pas toujours bien interprétée dans la littérature. Les textures en rideaux ou en croissance rubanée des pseudomorphoses d'olivine ont généralement été considérées comme produits de recristallisation d'une texture réticulée orthogonale. Cette interprétation ne tient nullement compte du fait que de telles textures sont l'expression d'un réseau de fractures inhabituel dans les grains originels d'olivine, fait qui exclut l'hypothèse d'une recristallisation. Cette texture joue donc un rôle important dans l'interprétation de la suite des événements qui ont affecté une roche ultramafique.

(Traduit par la Rédaction)

Mots-clés: réseau de fractures, olivine, pyroxène, lizardite, serpentinisation, texture de croissance rubanée, texture de croissance en rideaux, texture réticulée, bastite.

INTRODUCTION

The morphology of serpentine pseudomorphs after olivine, pyroxene and amphibole and the nature of the pseudomorphic processes have been the subjects of papers by Wicks *et al.* (1977) and Wicks & Whittaker (1977). The preservation of the original grain-boundaries, the grain-to-grain relationships and the primary textures by the pseudomorphs has been established. The preservation of some internal features of the original grains, such as kink bands in pyroxene, has been discussed in part I of this series (Wicks 1984a). Although the fact that the pseudomorphs preserve the sites of the original fractures in the host grains was discussed in these papers, its significance has not been fully appreciated. It is the purpose of this paper to draw attention to this phenomenon and to emphasize its potential use in geological interpretations.

FRACTURES AND THE PSEUDOMORPHIC PROCESS

Observations on slightly, partly and completely serpentinized olivine, pyroxene and amphibole grains illustrate that serpentinization begins along fractures, grain boundaries and cleavages, if present, and proceeds away from these initial sites out into the host grain, until ultimately the host is consumed. The form of the resulting pseudomorphs has been described in detail for olivine by Wicks *et al.* (1977) and Wicks & Whittaker (1977), and for pyroxene and amphibole by Wicks & Whittaker (1977). In the case of olivine, the fracture pattern and the shape of the host grain are the controlling factors that determine the form of the resulting pseudomorph. In the cases of pyroxene and amphibole, the crystal structure, as well as the fracture pattern, cleavage pattern and grain shape, is also important. This is clearly indicated in the pseudomorphs after enstatite. In the partially developed bastite studied in detail (Wicks 1969), it was found that the replacement was in part topotactic, with the general relationship $x_{liz} \parallel z_{opx}$,

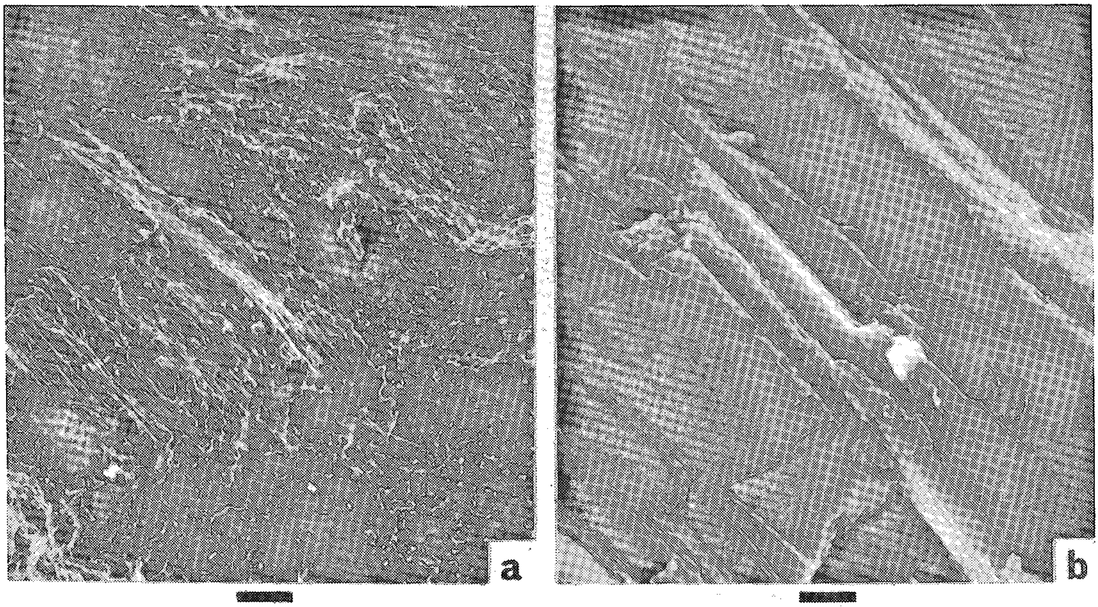

FIG. 1. SEM micrographs of a lizardite-1*T* bastite after enstatite. Sample 18510, The Lizard, Cornwall. (a) Overview of the bastite. Bar represents 100 μm. (b) Detail showing stepped cleavage-planes of the lizardite. Bar represents 2 μm.

$y_{liz} \parallel y_{opx}$ and $z_{liz} \parallel x_{opx}$. The orientation of x_{liz} about the z_{opx} position is fairly rigorous but the orientation about the other two axes is much less so (Wicks & Zussman 1975). Lizardite also occurs in other orientations (Wicks & Zussman 1975), in association with semicircular sections of polygonal serpentine and minor chrysotile (Cressey 1979). In spite of these variations from the ideal orientation, there is enough lizardite in parallel orientation with the host enstatite to give the relationship noted above. One of the results of this relationship is that the sites of some of the cleavage planes of the host enstatite are preserved by the lizardite-bastite (Figs. 1a, b). Thus, although the enstatite is now absent, some of its cleavage planes remain. This is also true of other pyroxenes and amphiboles.

In the pseudomorphic replacement of olivine by lizardite, the fracture pattern of the olivine is preserved as the central parting of the lizardite mesh-rims (Wicks *et al.* 1977, Fig. 1a), or as the parting that defines the cells of the hourglass texture (Fig. 2d). The central parting may be empty (Wicks & Whittaker 1977, Fig. 1a), occupied by secondary magnetite (Wicks & Plant 1979, Fig. 9f), isotropic serpentine (Wicks & Plant 1979, Fig. 5d), nonfibrous chrysotile (Wicks & Plant 1979, Fig. 11a), cross-fibre chrysotile-asbestos veins (Wicks & Whittaker 1977, Fig. 6b), or it may be the site of failure during stress (Wicks 1984, Fig. 2e). However, whether the site of the fracture is filled or empty, the important point is that the individual fracture-sites and the overall fracture-patterns of the original grains of olivine are clearly preserved by the pseudomorph. They are, therefore, available for observation and interpretation in spite of the absence of the olivine.

Francis (1956) used the term *curtain-like* or *banded growth* to describe a distinctive variety of lizardite mesh-textures in which one set of mesh rims has been very well developed but in which the perpendicular set of mesh rims and mesh centres has been poorly developed or is absent (Fig. 2a). Other researchers (*e.g.*, Klinkhammer 1962, Hochstetter 1965, Tröger 1969) have also used the term or the German equivalent, *Bänder-Serpentinit*, to describe the same features. Wicks *et al.* (1977) described banded growth in terms of an idealized mesh-texture based on a model made up of identical cubes. Limited amounts of the banded-growth texture are produced by the cube model (Wicks *et al.* 1977, Fig. 5C), but elongate orthorhombic units rather than cubes would produce a better-developed banded growth. Maltman (1978) has described the same feature but has used the term *ribbon texture*. Although banded growth is a minor textural feature, it does have, as the references above suggest, a wide occurrence in a variety of geological settings. In the present author's experience, banded growth has been observed in serpentinites at Pipe Lake, Setting Lake and Island Lake, Manitoba, at the Lizard, Cornwall, and at Kaponigbach, Austria, as well as in the layered intrusive complex at

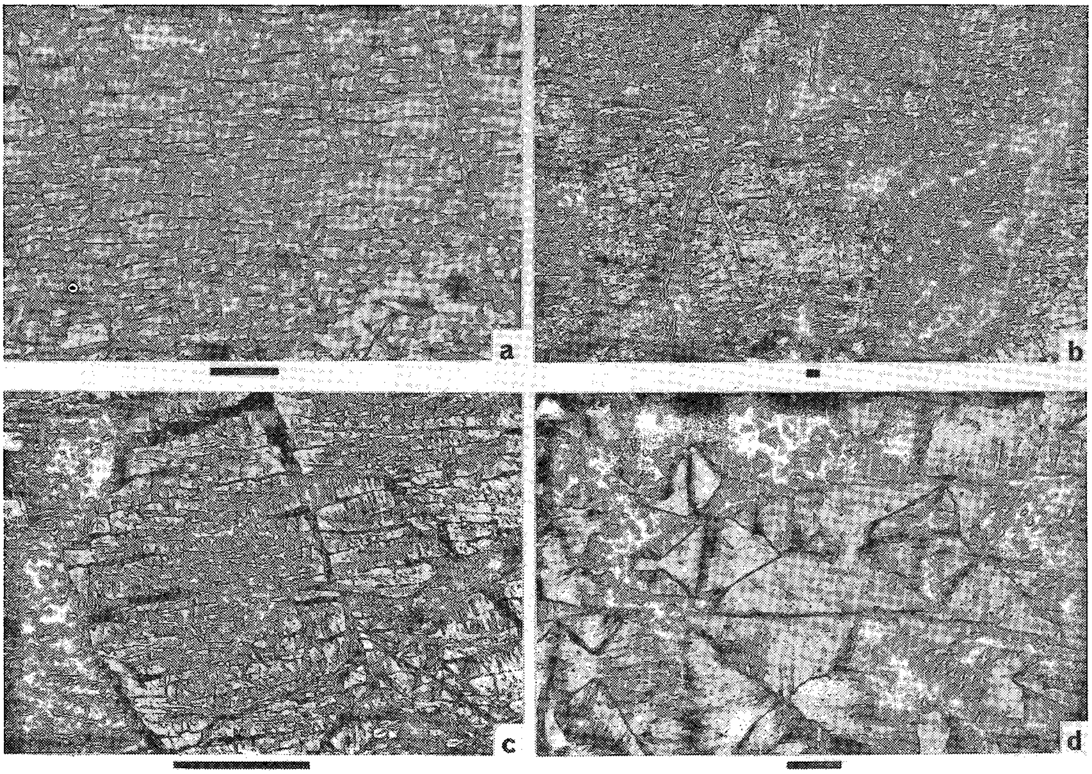

FIG. 2. (a) Details of lizardite-1*T* banded growth showing the closely spaced fractures (horizontal) responsible for the banded growth and the more widely spaced fractures (vertical) normal to the first set. Sample W66–72, Glen Urquhart, Scotland. (b) Lizardite-1*T* banded growth after coarse tabular grains of olivine. Sample W66–72, Glen Urquhart, Scotland. (c) Lizardite-1*T* banded growth after coarse grains of olivine. Some of the closely spaced fracture-sites from the olivine contain magnetite and some pass through one olivine pseudomorph into the adjacent pseudomorph. Sample 18506, Setting Lake, Manitoba. (d) Lizardite-1*T* hourglass texture illustrating the preservation of the fracture pattern from the olivine as the partings that bound the hourglass cells. Sample 18540, Jeffrey mine, Quebec. All under crossed nicols. Bar represents 0.2 mm.

Stillwater County, Montana and Fox River, Manitoba (Wicks 1969).

A re-examination of the lizardite-1*T* ± brucite banded-growth textures and fracture patterns in the Glen Urquhart thin sections was carried out in conjunction with the study of the pseudomorphs of deformation textures (Wicks 1984a). The outlines of the original grains of olivine are still clearly visible; these indicate that the grains had been coarse, up to 6 mm across, and either equant or slightly tabular (Fig. 2b). The fracture pattern of the original grains of olivine, as recorded in the banded-growth texture, is composed of one set of closely spaced ($\simeq$ 0.02 mm apart), roughly parallel fractures, with a second, more widely spaced ($\simeq$ 0.2 mm apart) set roughly at right angles to the first (Fig. 2a). The closely spaced set of fractures commonly passes through a grain and into an adjacent one (Fig. 2c). These features, observed in the Glen Urquhart dunites, are common to examples of banded-growth textures from the other localities listed above.

INTERPRETATION OF BANDED-GROWTH TEXTURES

Francis (1956) attributed the banded-growth textures to the effect of local shearing on regular mesh-textures, which recrystallized one set of mesh rims at the expense of the mesh centres and the mesh rims at right angles to the recrystallized set of mesh rims. Maltman (1978) attributed the banded-growth (ribbon) textures in Anglesey to recrystallization under a regional shear-stress. In both cases, the closely spaced partings and the long dimension of the dominant mesh-rim of the banded growth were interpreted as being parallel to the local (Francis 1956) or regional (Maltman 1978) shear-stress.

The observations and discussion on the response of serpentine to stress presented in the foregoing paper (Wicks 1984b) indicate that serpentine minerals do not respond to stress in the manner suggested by Francis (1956) and Maltman (1978). Under stress at high confining pressures, deformation will take the form of plastic flow and recrystallization that will obliterate any recognizable pseudomorphic textures. Under stress at low confining pressures, deformation will occur as brittle fractures lined with elongate chrysotile apparent fibres or blades parallel to the fracture. The serpentine textures adjacent to the fracture will be unaffected by deformation. At slightly higher confining pressures, the serpentine texture adjacent to the fractures may be affected, but again in this case, plastic flow and recrystallization will obliterate any earlier pseudomorphic textures. An examination of all the available examples of banded-growth textures reveals none of the features characteristic of deformed serpentines (compare Figs. 2a to c to those in Wicks 1984b).

The only recognized recrystallization of serpentine that is in part similar to Francis's and Maltman's proposed recrystallization is the development of lizardite-1T $\pm$ brucite hourglass-textures (Fig. 2d). Wicks & Plant (1979) noted that such textures occur in an assemblage that is produced by mild prograde metamorphism. They suggested that the lizardite-1T $\pm$ brucite hourglass developed as a result of this prograde event either through the recrystallization of an earlier lizardite-1T $\pm$ brucite mesh-texture or through the direct serpentinization of olivine. The first case of recrystallization of a preexisting texture has similarities to Francis's and Maltman's proposed mechanism, but it is produced by static and not dynamic metamorphism. However, even in this recrystallization, the fracture sites from the original olivine are still clearly preserved as partings between the hourglass cells (Fig. 2d).

Lizardite-1T banded-growth texture is a pseudomorphic feature formed by a distinctive fracture-pattern in the host olivine. It is a special case of mesh textures, as was pointed out by Wicks *et al.* (1977), and is not a deformation-related feature. Any stress involved in the formation of banded growth is slight and restricted to a force holding the more widely spaced set of fractures closed to inhibit serpentinization while allowing the closely spaced set of fractures to open providing access for the water that produces the lizardite banded growth. Textures that are intermediate between fully developed banded-growth texture and fully developed mesh-texture are the result of the geometry of the fracture pattern in the olivine and of minor stress during serpentinization that controls the access of water to the different sets of fractures.

The recognition of the banded-growth texture as a pseudomorphic feature and, in particular, the recognition of the preservation of the fracture pattern in olivine by banded growth are of critical importance in the interpretation of geological histories. This is also true of the host-mineral fracture patterns preserved in mesh- and hourglass-texture pseudomorphs after olivine and in bastite after pyroxene and amphibole. Thus Maltman's (1978) correlation of the development of lizardite-1T banded-growth and mesh textures in Anglesey with the regional D_1 event may not be correct. It is the fracturing of the olivine that should be correlated with the regional D_1 event. Serpentinization must have occurred later, along the fractures produced by the earlier deformational event.

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