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Chrysotile and polygonal serpentine from the Balangero serpentinite

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ABSTRACT. Transmission electron microscopy shows that normal chrysotile and polygonal serpentine occur together and in parallel association with balangeroite, within the slip-veins of the Balangero serpentinite. Chrysotile substitutes for balangeroite and it is later replaced by the polygonal serpentine.

The chrysotile fibres are packed together according to a rod close-packing scheme, with defects. Lattice images of the polygonal serpentine confirm the structure model proposed by Middleton and Whittaker (1976), consisting of polygonally arranged flat layers. This structural type is probably common for serpentine minerals and constitutes a fourth main type of layer configuration in 1:1 layer silicates.

KEYWORDS: chrysotile, serpentine, balangeroite, electron microscopy, Balangero, Italy.

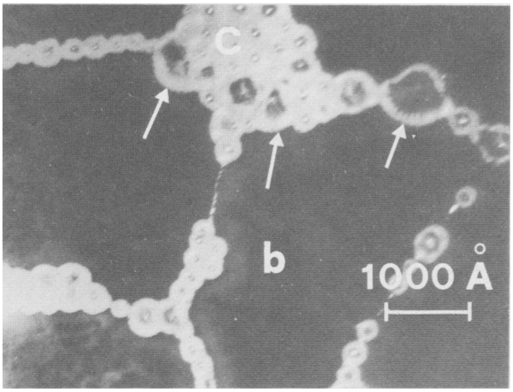
THE classification of the serpentine minerals is based on the different sorts of tetrahedral-octahedral composite layers (Whittaker and Zussman, 1956). Flat layers occur in lizardite, curled layers in chrysotile and corrugated layers in antigorite (Wicks and Whittaker, 1975). Further complexity occurs, mostly due to the occurrence of different polytypes for chrysotile and lizardite (Wicks and Whittaker, 1975; Mellini, 1982), and to the occurrence of different superlattice periodicities for antigorite (Zussman *et al.*, 1957; Kunze, 1961).

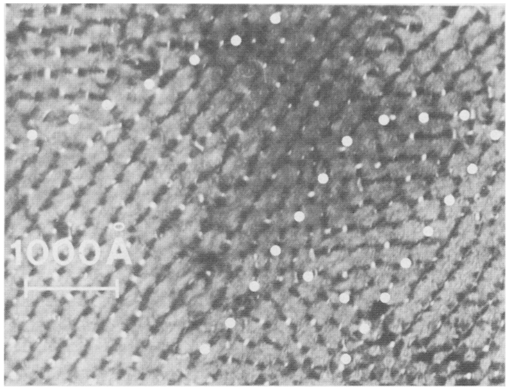
Krstanović and Pavlović (1964, 1967) described a splintery serpentine, named Povlen-type serpentine, that did not entirely fit into this scheme as it produced anomalous fibre diffraction patterns. These patterns resembled normal chrysotile, but were distinct from it, as additional sharp spots were present in odd-number layer-lines. This serpentine appeared to be intermediate between rolled chrysotile and flat-layer lizardite. Middleton and Whittaker (1976) discovered several specimens with similar features and were able to propose a very interesting structural model for the Povlen-type serpentine. According to them, the Povlen-serpentine consists of polygonally arranged flat layers, possibly around a core of normal, curled chrysotile. As Cressey and Zussman (1976) and Cressey (1979) actually observed polygonal cross-sections by amplitude-contrast transmission electron microscopy, the Middleton and Whittaker model seemed to be highly realistic. The name polygonal serpentine was proposed (Cressey and Zussman, 1976) and this proposal will be adopted throughout this paper.

In this report, the results of investigation by transmission electron microscopy on the parallel association between polygonal serpentine and normal chrysotile are reported. The results parallel the previous observations by Cressey and Zussman (1976), Cressey (1979), and Veblen and Buseck (1979), who similarly found submicrometric co-existence among the different serpentine polymorphs. Furthermore, the acquisition of lattice images of the polygonal serpentine allows the direct observation of the structure predicted by Middleton and Whittaker (1976) and recently imaged also by Jiang and Liu (1984). This polygonal structure should be accepted as a fourth main type of layer configuration in 1:1 layer silicates.

Experimental. The specimens described occur in the Balangero serpentinite, Western Alps, Italy. The rock is a serpentinized lherzolite-harzburgite, belonging to the Lanzo Massif, and it forms the most important asbestos deposit in Western Europe (Compagnoni *et al.*, 1980). The specimens studied occur in veins showing parallel association between long-fibre slip serpentine and balangeroite, the latter being another asbestiform silicate with composition $(Mg,Fe,Mn)_{42}Si_{16}O_{54}(OH)_{40}$ (Compagnoni *et al.*, 1983; Ferraris *et al.*, 1985).

Ion-thinned specimens were prepared starting from petrographic thin-sections that had been cut across the fibre axis. Electron optical observations were obtained by a Philips 400T transmission electron microscope. The optimum imaging conditions was severely hindered by the serious beam damage effects (Veblen and Buseck, 1983). Both chrysotile (Yada, 1967) and polygonal serpentine become completely amorphous within a few seconds of exposure under high resolution conditions.



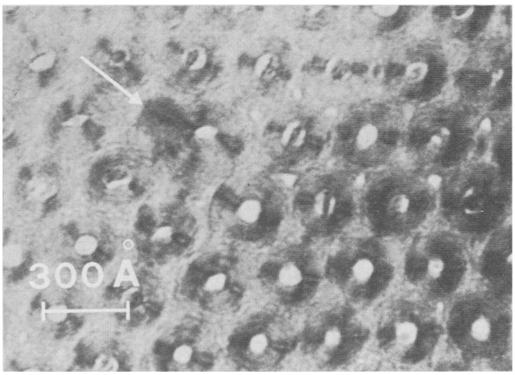


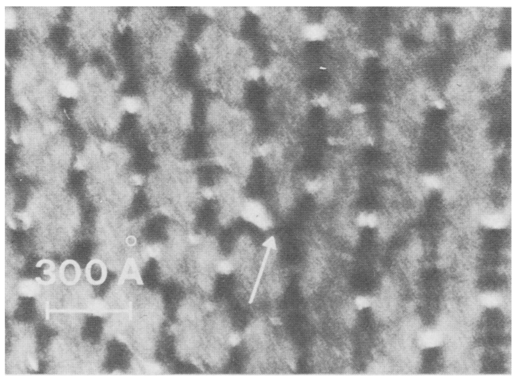
FIGS. 1 and 2. FIG. 1 (*left*). Parallel association between balangeroite (b) and chrysotile fibres (c). The arrows indicate large chrysotile fibres, with approximately 800 Å diameter. FIG. 2 (*right*). The chrysotile fibre texture: chrysotile fibres approximately 280 Å in diameter are packed according to a close-packed scheme. The orientations of the radial extinction contours define a pseudo grain boundary structure, as marked by the dotted white lines.

Furthermore, only the average orientation of the fibre bundle can be obtained, with individual fibres in different alignment. Such a misalignment commonly occurs in asbestiform material along the fibre axis, as previously observed for carlosturanite (Mellini *et al.*, 1985).

Results. Under transmission electron microscopy the balangeroite-serpentine veins reveal a complex, graded intergrowth. The simplest texture consists of balangeroite fibres only, but becoming progressively modified to an intergrowth of balangeroite and chrysotile. For instance, fig. 1 shows an intermediate state, with advanced substitution of chrysotile for balangeroite. In this figure the chrysotile and balangeroite fibre axes lie parallel to the observation direction, and chrysotile has nucleated around the rims of the balangeroite fibres. Two different sorts of chrysotile fibre occur. The first are more abundant and have smaller diameters, of approximately 280 Å; the second, giant fibres, have outer diameters up to 800 Å and grow directly at the contact with balangeroite. Since the balangeroite, and the balangeroite-chrysotile association is described in detail by Ferraris *et al.* (1985), attention here will be paid to the serpentine minerals only.

A second main fibre-texture of the veins consists of chrysotile only (fig. 2), individual fibres showing quite uniform cross-sections, with approximate average diameters of 280 Å. Rare giant chrysotile fibres, up to 800 Å in diameter, also occur (fig. 3). Such a distribution of fibre sizes is quite common in





FIGS. 3 and 4. FIG. 3 (*left*). A giant chrysotile fibre, marked by the arrow, substitutes for three smaller fibres. Slight bending of the close-packing planes occurs on the two sides. FIG. 4 (*right*). The radial extinction contours of the chrysotile fibres stress the occurrence of an 'edge dislocation', and its core is indicated by the arrow.

chrysotile and the most frequently observed value, 280 Å, fits quite well with that reported by Yada (1967, 1971, 1979), and predicted by Whittaker (1957). On the other hand, anomalously large fibres have been extensively reported by Cressey and Zussman (1976). As a result of the quite constant value in outer diameter, a 'quasi-crystalline' rod close-packing is present, with every chrysotile fibre surrounded by six similar fibres. The analogy between the chrysotile fibre texture and the rod close-packing can be further extended with the observation of several kinds of 'crystal defects'. A first possible example for these 'defects' is the substitution of a larger fibre for three normal 280 Å fibres (fig. 3); the local disturbance in the rod close-packing leads also to deformation on the two sides of the 'defect', and slightly bent close-packed planes occur. Another example (fig. 4) shows an 'edge dislocation'. Moreover, when the orientations of the radial extinction contours are taken into account, more features such as 'grain boundaries' (fig. 2) are observed.

Chrysotile commonly produces electron optical images with radial extinction contours, and they have already been observed by Cressey and Zussman (1976) and Spinnler (1984, private communication). According to Cressey and Zussman (1976), fibres with zones of high symmetry exactly parallel to the beam would show many radial extinction contours, whereas the occurrence of only one or two pairs would indicate misalignment. From fibre to fibre, these radial extinction contours show a preferred orientation effect and common directions occur over a number of neighbouring fibres (figs. 2, 3, and 4). This observation indicates strong parallelism within that group of adjacent fibres, whereas fibres are inclined in slightly different directions in adjacent groups.

The third most important kind of texture is due to the appearance of larger polygonal fibres together with normal chrysotile. These fibres correspond to the polygonal serpentine described by Cressey and Zussman (1976) and Cressey (1979). They have diameters up to 1 μm, and exhibit definite polygonal contours as a result of evident sector zoning. Either incomplete, fan-shaped fibres or more completely formed polygonal fibres (fig. 5) occur. Chrysotile may be more or less abundant, but is always present, at least as a single, rolled fibre just in the core of the polygonal serpentine. As stressed by Cressey and Zussman (1976) and Middleton and Whittaker (1976), the polygonal contour is a strong indication that favours the Middleton and Whittaker model. However, a still more conclusive indication can be found in images such as fig. 6*a*, where the fundamental 7 Å interplanar spacing of 1:1 layer silicates is resolved

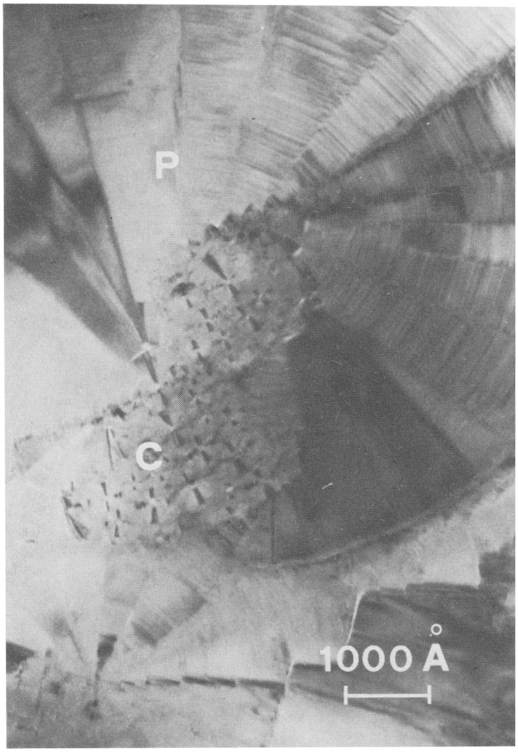
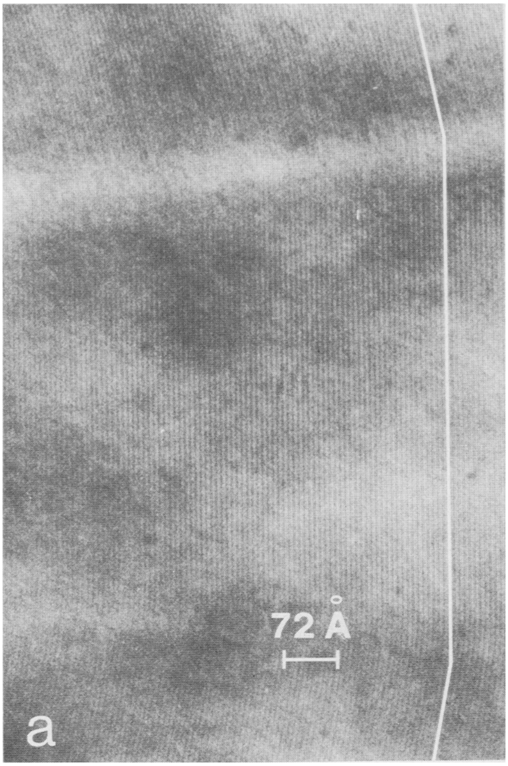


FIG. 5. Almost complete polygonal serpentine fibre (p), with chrysotile (c) core.

within three adjacent sectors. Similar results have recently been reported by Jiang and Liu (1984). Flat layers, resembling those found in lizardite, occur within the given sectors, and they are coherent across sector boundaries with abrupt angular changes of approximately 15°. Whereas such a sharply defined boundary between sectors is the usual feature of the outer fibre, more gradual connections can be found in the inner regions of the fibre, where adjacent sectors are connected by sheets which are bent with a high radius of curvature (fig. 6*b*). Another common difference between the inner and outer regions of the polygonal fibres is due to their different degrees of crystal order. In fact, apart from the obvious sector zoning, the outer regions commonly display highly ordered arrangements. In contrast to this, more complex arrangements occur only in the cores of the polygonal fibres, where completely flat layers coexist both with partially curled and completely rolled layers (fig. 7). Also, deformations and parting surfaces are characteristic features of the core and at least one chrysotile fibre occurs here. On the whole, the



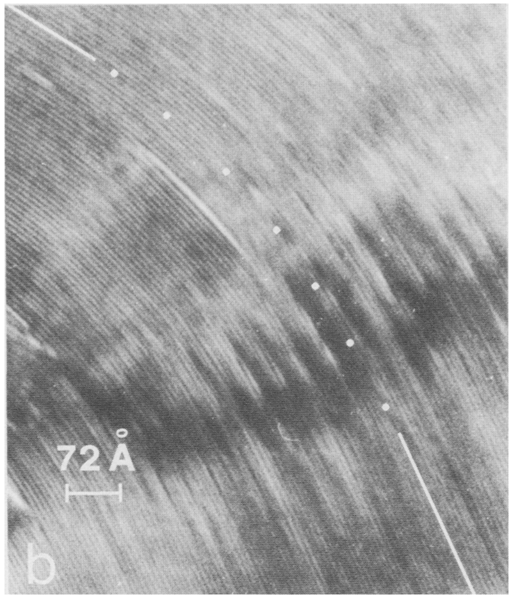


FIG. 6. (*a*) Flat layers in three adjacent sectors of the polygonal serpentine. The 7 Å interplanar spacing is resolved. (*b*) Adjacent flat-layer sectors of the core region of the polygonal serpentine are connected through layers with high curvature radius.

structural and textural arrangement within the polygonal fibres seems to be consistent with a transformation process. Small chrysotile fibres transform to large polygonal serpentine, according to a growth pattern from the core to the rim. The chrysotile fibres in the core would act as nucleation centres for polygonal structures that would substantially grow through a two-dimensional growth process, by subsequent deposition of complete tetrahedral–octahedral layers. The possible role of the larger, 800 Å chrysotile fibres as nucleation centres for the polygonal serpentine is still to be proved.

Discussion and conclusions. As previously reported, the veins of the Balangero serpentinite reveal a complex balangeroite–chrysotile–polygonal-serpentine fibre texture when examined by transmission electron microscopy. Such a texture has been interpreted in terms of a progressive substitution mechanism; chrysotile would substitute for balangeroite (Ferraris *et al.*, 1985) but it would be later replaced by polygonal serpentine.

As regards this last mineral, its crystal structure clearly corresponds to the idealized model proposed by Middleton and Whittaker (1976). Furthermore, it is worthwhile to stress that such an arrangement does not seem to be uncommon for serpentine. For instance, Krstanović and Pavlović (1964) report sixteen 'Povlen-type' specimens over a group of approximately thirty 'clinochrysotile' specimens, and state 'all of the clinochrysotiles which we have

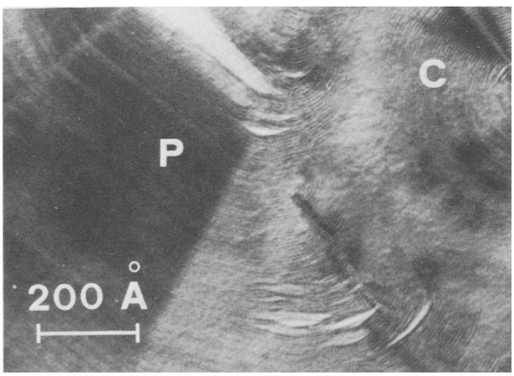


FIG. 7. Chrysotile fibres (c) and curled layers in the core of the polygonal serpentine (p).

examined so far by taking fiber diagrams and which appear massive or platy in hand specimens, belong to the Povlen-type'. Several findings of similar material are reported by Cressey and Zussman (1976), Middleton and Whittaker (1976), Cressey (1979), and Morandi and Felice (1979). Therefore, polygonal structures are quite important in serpentine mineralogy, not only because they appear to be quite common but because they reveal a fourth main type of layer configuration. Most probably, their identification was sometimes overlooked, owing to the difficulties in identification of serpentine minerals (Wicks and Zussman, 1975). For instance, crushing the specimen for powder diffractometry will destroy the polygonal structure of this serpentine (see Cressey and Zussman, 1976, for similar comments on the electron microscopy of serpentine minerals). More information on the nature of polygonal serpentine may be expected through the full use of the microdiffraction and microanalysis capabilities of the analytical electron microscope.

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