Mackinawite from the Lizard, Cornwall

In the few years since its characterization by Kouvo *et al.*, 1963, and Evans *et al.*, 1964, mackinawite, $(Fe, Ni, Co)_{1+x}S$, has been identified in a wide range of rocks and ore deposits, particularly in nickel-rich environments. This mineral occurs in minor amounts in the pre-Devonian serpentinized peridotite of the Lizard, Cornwall (Green, 1964), and has been recognized in polished sections of specimens collected from surface exposures in the vicinity of The Rill, Kynance Cliff (Nat. Grid ref. 674136). In this area Green's 'recrystallized anhydrous assemblage' is the predominant modification of the peridotite. The olivine–enstatite–clinopyroxene–plagioclase–spinel rocks show marked foliation, with occasional spinel porphyroblasts up to 6 mm in diameter. Serpentinization is generally only partial, but has been almost complete in restricted zones, and has resulted in the formation of chrysotile, tremolite, chlorite, talc, magnesite, and magnetite. As described by Green, the primary chrome spinel of the peridotite suffered replacement by magnetite during the serpentinization, and the clusters of small magnetite subhedra, frequently haloed by flakes of (probably chromian) chlorite, observed in these rocks are indicative of the former presence of spinel grains.

In the specimens examined, the mackinawite forms minute flakes, averaging 20–30 μ in diameter, which are entirely concentrated within such magnetite–chlorite patches. The sulphide flakes constitute a reticulate network between the clustered magnetite grains, and are finely intergrown with chlorite laths. The optical properties of the pinkish-grey mackinawite are diagnostic (e.g. Kouvo *et al.*, 1963; Chamberlain and Delabio, 1965), and are characterized by strong bireflectance, from pink to grey, and very marked anisotropism, from bluish-white to dark grey. Reflectivity and hardness, not measured, are in the same range as those of pyrrhotine.

Quantitative electron-microprobe analysis of the mackinawite has not been carried out, but preliminary, semi-quantitative microprobe studies (in co-operation with Mr. A. M. Clark[1]) have confirmed the identification. The sulphide phase is an iron sulphide containing appreciable nickel and minor cobalt and chromium. The integrated counts for Fe-$K\alpha$, Ni-$K\alpha$, and S-$K\alpha$ were found to be of the same order as those obtained for mackinawite (8–8·5 wt. % Ni) from the Outokumpu deposit, Finland (Kouvo *et al.*, 1963), and, on this basis, it is tentatively estimated that the Lizard mackinawite contains about 7 to 9 wt. %

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nickel. Both cobalt and chromium are consistently present in concentrations of approximately 1000–8000 ppm. Despite the small size of the sulphide grains, it is considered that the chromium is present in solid solution in the mackinawite, and is not contributed by the enclosing silicates and oxides. Chromium has not previously been recorded as a constituent of mackinawite, even in that from the chromium-rich Outokumpu ores (Kouvo *et al.*, 1963).

It is proposed that the mackinawite formed during the late-stage serpentinization of the Lizard peridotite, and was nucleated by nickel released in the breakdown of the primary spinel. Green (1964) has shown that the olive chrome spinel of the intrusion contains about 1 % nickel, and, although the magnetite structure can accept at least this concentration of nickel in solid solution (Deer *et al.*, 1962), this element could not be detected by microprobe analysis of the magnetite associated with the mackinawite (limit of detection, about 1000 ppm). The formation of the latter phase implies some mobility of sulphur during the serpentinization stage, which in other areas of the intrusion saw the development of minor valleriite (in preparation), pyrite, marcasite, and pyrrhotine (monoclinic and hexagonal low-temperature polymorphs). It is evident that much of the nickel that was released in the conversion of spinel to magnetite was incorporated in chlorite and serpentine, and mackinawite formed sporadically only in sulphur-rich zones. Chamberlain and Delabio (1965) have suggested that mackinawite is unstable in near-surface, aqueous environments, but this sulphide is unaffected by supergene oxidation in the specimens examined.

The available data on the thermal behaviour of analysed natural mackinawites (Kouvo *et al.*, 1963; Takeno, 1965; Clark, 1966*a*) may be interpreted as indicating that the upper stability limit of this mineral is directly influenced by the degree of substitution of iron by other cations (chiefly nickel), the breakdown temperature rising from about $135 \pm 5°$ C for $Fe_{1+x}S$ to about 200–250° C for mackinawite with 8–9 wt. % Ni+Co (Clark, 1966*b*). The mackinawite in the Lizard peridotite, therefore, probably crystallized below about 250° C. Similar relationships have been described for the Muskox ultramafic pluton by Chamberlain and Delabio (1965); in this intrusion nickel-bearing mackinawite formed, largely through the replacement of pentlandite, during the intermediate stages of serpentinization.

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Stellate wollastonite from calc silicate skarns of Jothwad Hill, Panchmahal District, Gujrat, India

In his classic account of the manganese ore deposits of India, Fermor (1909) has described in detail the geology of Jothwad Hill. The hill lies about 3½ Km north of Jambughoda, a pre-merger state capital, about 16 Km north of Bodeli junction on the Pratapgunj–Chote-Udepur branch line of the Western Railway. Here intricately folded gonditic gneiss and crystalline limestones have been invaded by a porphyritic biotite granite and its differentiates, with the result that a variety of interesting manganese and calc silicate minerals have been produced.

Stellate wollastonite occurs in the outer margin of the wollastonite zone of the calc silicate rocks, slightly away from the granite–limestone contact. A recent study by Sadashivaiah (1963) of the calc silicate skarns of the hill, with special reference to wollastonite paragenesis, fails to mention the stellate mode of occurrence of wollastonite reported here. As far as known to the authors, stellate wollastonite is not previously reported from India.

The stellate wollastonite aggregates are set in a matrix of calcite and other calc silicates, and are circular to ovoid in shape, ranging from 5 to 4 cm in diameter, and consisting of well-defined radiating needles of wollastonite. In general they exhibit a tendency for crowding, although scattered ones are not uncommon. In closely packed condition, they form rounded polygons, apparently due to mutual interference at the time of crystalloblastic growth. Actual merging is also common. Many of the large stellate bodies have grown around quartz granules while the smaller, more closely packed ones lack such nuclei.