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MACKINAWITE FROM SOUTH AFRICA

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Abstract

Mackinawite has been identified in mafic and ultramafic rocks of the Bushveld igneous complex and Insizwa and also in the carbonatite and pegmatoid of Loolekop, Phalaborwa complex in South Africa. The mineral occurs predominantly as somewhat irregular to oriented intergrowths in pentlandite in all these occurrences and less commonly as regular oriented lamellae in chalcopyrite and rarely in cubanite. The textural evidence suggests that mackinawite may represent an exsolution product of pentlandite, chalcopyrite and cubanite.

Introduction

The iron sulphide, mackinawite was recently named in a paper by Evans, *et al* (1964). Natural occurrences of this mineral from Finland were described by Kouvo *et al* (1963) and from the Muskox intrusion in Canada by Chamberlain and Delabio (1965).

During the present investigation mackinawite was distinguished from valleriite in the carbonatite and pegmatoid of Loolekop, Phalaborwa complex, in the Bushveld igneous complex, and from Insizwa, Cape Province. The mode of occurrence of the mackinawite in the carbonatite differs somewhat from that in the mafic rocks of Insizwa and the Bushveld complex.

Mineralogy

The physical and optical properties of mackinawite from the Bushveld complex, Insizwa and Loolekop are very similar and are in close agreement with the properties given for the same mineral from the Muskox intrusion by Chamberlain and Delabio (1965). The mineral takes a fairly good polish, particularly after buffing with a chromic oxide slurry. It has a marked cleavage in one direction and consequently tends to flake somewhat like graphite.

Both the anisotropism and bireflectance are very high. The bireflectance ranges from light pink to grey and the anisotropism from white to black when the nicols are completely crossed with the aid of a Nakamura plate.

The optic sign of mackinawite is negative and the sign of the phase difference is strongly positive. The rotation angle could not be determined by the normal Hallimond method (Cameron, 1961) because of the extremely high phase difference.

The white and black anisotropic colors of mackinawite serve to distinguish it from valleriite, the anisotropic colors of which vary from a very light bronze to grey bronze. It also has a higher reflectivity than valleriite.

The identification of mackinawite in pentlandite from the above-mentioned localities was confirmed by X-ray powder-diffraction patterns.

Chemical analyses of mackinawite from the Outokumpu mine (Kouvo *et al*, 1963) and from the Muskox intrusion (Chamberlain and Delabio, 1965) indicate that the mineral has a composition close to FeS, but that it does contain from 0.2 to 8.26 percent nickel.

Paragenesis

Pentlandite from the Bushveld complex and from Insizwa contains abundant mackinawite. In these occurrences the mackinawite takes up from 10 to 30 percent of the area of the pentlandite grains. The mackinawite is usually very regularly distributed in the host.

Four textural varieties of mackinawite can be distinguished in pentlandite from the Bushveld complex:

1. Feathery lamellae which range from about 2–30 micron in length (Fig. 1 and 2).
2. Unoriented as well as oriented networks of very fine lamellae (1–3 micron in length) parallel to (100) and (111) of pentlandite (Fig. 3).

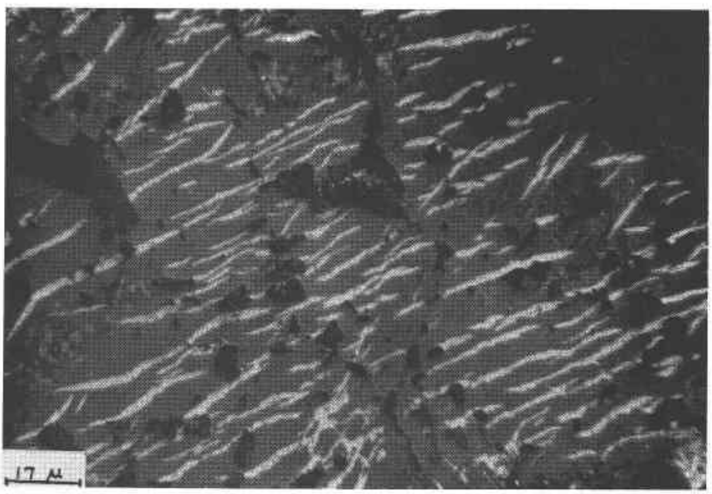


Fig. 1. Feathery lamellae of mackinawite (white) in pentlandite (gray) from Insizwa. Incident light, oil immersion, crossed nicols.

3. Mackinawite of patchy occurrence.
   a. Irregular patches (0.01–0.2 mm in diameter) mostly in the vicinity of cracks (Fig. 4).
   b. Irregular lenticular bodies (0.5×0.15 mm in diameter) with their long axes parallel to (111) of pentlandite (Fig. 5).
4. Very regular oriented lamellae parallel to (100) of pentlandite (Fig. 6).

Whereas the larger pentlandite grains contain abundant mackinawite of one or more of the above textural varieties, the smaller flames, rosettes

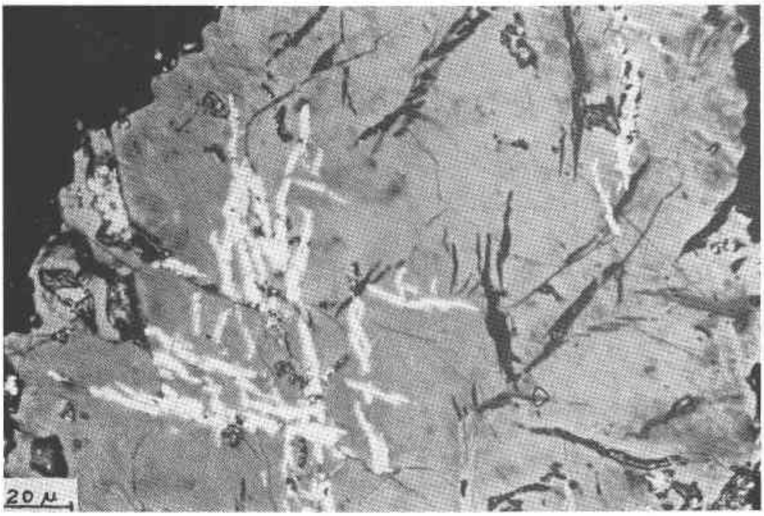


FIG. 2. Feathery lamellae of mackinawite (white and black) in various orientations in pentlandite (gray) from the Bushveld Complex. Incident light, oil immersion, nicols fully crossed.

and lamellae of pentlandite are almost invariably free of mackinawite.

In pentlandite from Insizwa the mackinawite lamellae are usually oriented in one direction and they all extinguish simultaneously (Fig. 1). Some of the mackinawite in the Bushveld Complex occurrences show a somewhat different behaviour. The lamellae are parallel to two more or less perpendicular directions and some of the lamellae of both orientations extinguish simultaneously, whereas other lamellae of the same orientations are illuminated in this position (Fig. 2).

Mackinawite is relatively rare in pentlandite from the Loolekop carbonatite. Some of the pentlandite grains contain irregular inclusions of mackinawite and others are free from inclusions.

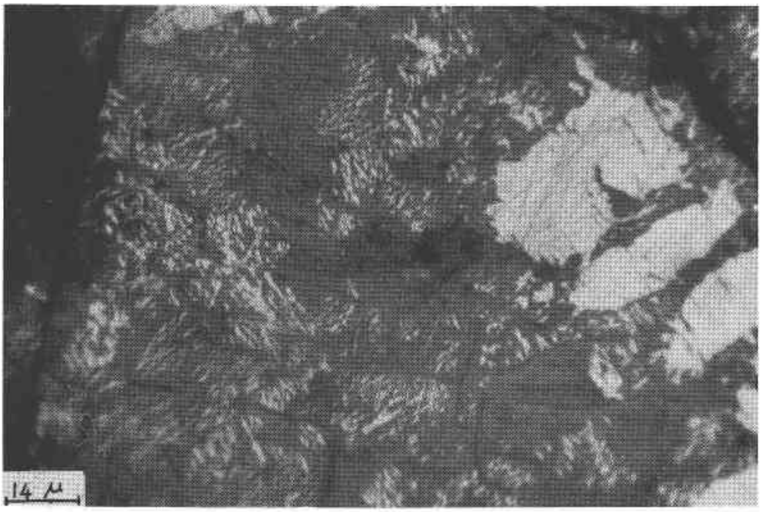


FIG. 3. Oriented network of very fine lamellae of mackinawite (white) in pentlandite. Incident light, oil immersion, nicols partially crossed.

Mackinawite also occurs as oriented lamellae in chalcopyrite from Loolekop and from the Bushveld complex. The lamellae in chalcopyrite have regular boundaries and are more or less tabular in outline. Herringbone textures have also been observed (Fig. 7). The optical properties

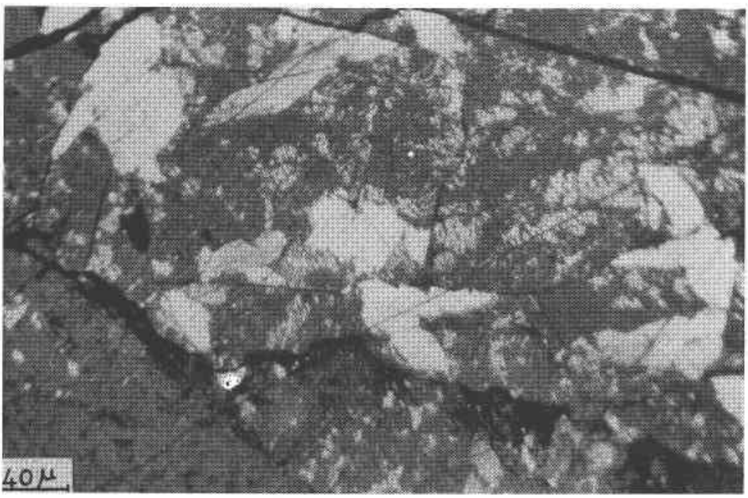


FIG. 4. Irregular patches of mackinawite (white) in pentlandite (gray). Incident light, oil immersion, nicols partially crossed.

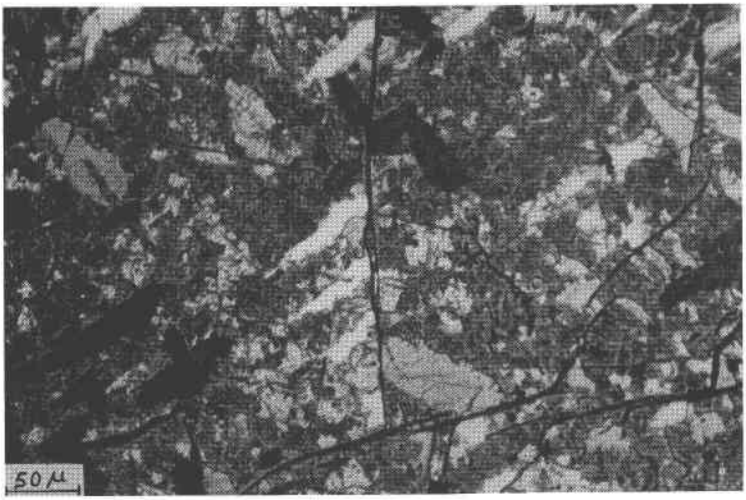


FIG. 5. Irregular lenticular bodies of mackinawite (white and black) parallel to (111) of pentlandite with fine intergrowths of mackinawite. Incident light, oil immersion, nicols partially crossed.

of the mackinawite in pentlandite and in chalcopyrite appear to be identical.

Mackinawite is rarely associated with cubanite in the Loolekop sulphides. Its mode of occurrence in cubanite is very similar to that in chalcopyrite.

The abundance of mackinawite in chalcopyrite and in cubanite is far less than in pentlandite and because the mackinawite lamellae rarely exceed 2 micron in width, the identification of mackinawite in chalcopyrite and cubanite could not be substantiated by X-ray diffraction. Its characteristic physical and optical properties do, however, permit positive identification.

DISTRIBUTION

Specimens from the whole succession of mafic rocks of the Bushveld complex, including material from various pipe-like bodies and the Merensky Reef, were studied by the second author during the present investigation. There does appear to be a depth control of the occurrence of mackinawite in both pentlandite and chalcopyrite, as is shown in Table 1.

In the basal and critical zones of the complex mackinawite is relatively abundant in pentlandite and it becomes less common higher up in the succession. Mackinawite is far less abundant in chalcopyrite in which its

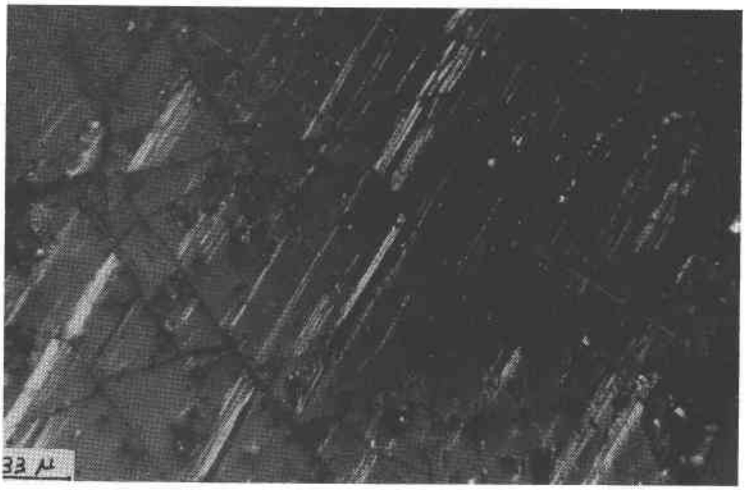


FIG. 6. Very regular oriented lamellae of mackinawite parallel to (100) of pentlandite. Incident light, oil immersion, nicols partially crossed.

occurrence is restricted to the upper part of the Basal zone, the Critical zone, the Main zone and the lower part of the Upper zone.

The distribution of mackinawite at Insizwa was not studied. Most specimens of pentlandite do, however, appear to have associated mackinawite.

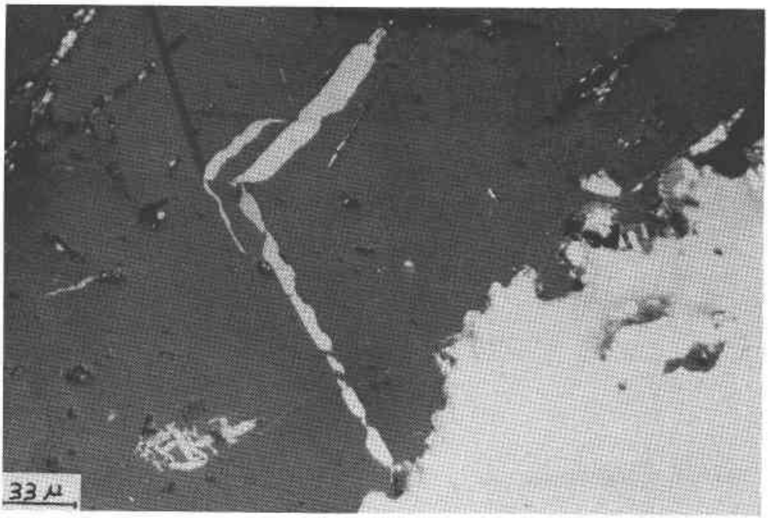
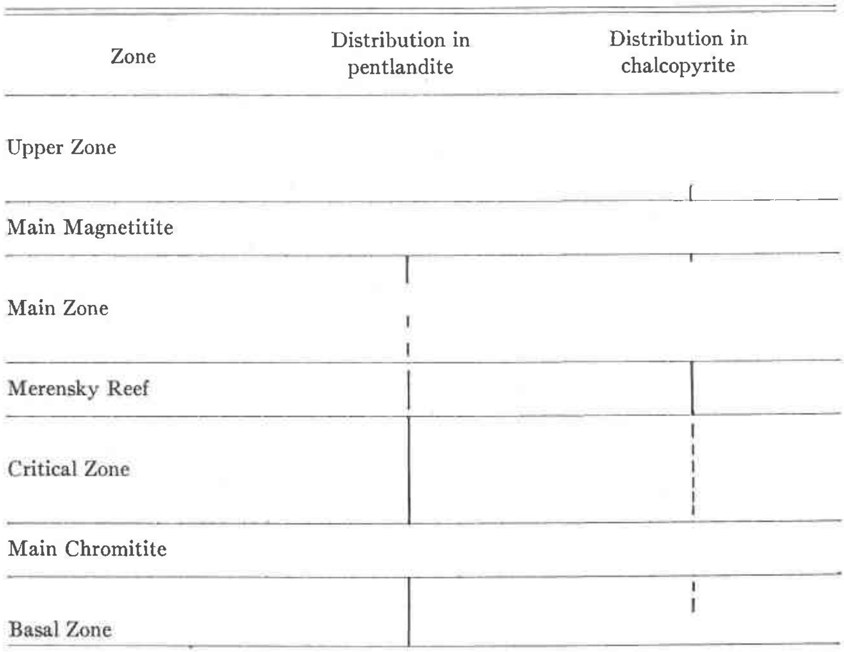


FIG. 7. Lamellae of mackinawite (white) in chalcopyrite (gray). Incident light, oil immersion, nicols fully crossed.

TABLE 1.—DISTRIBUTION OF MACKINAWITE IN THE BUSHVELD COMPLEX



At Loolekop the study of a large number of polished surfaces by the first author indicates that the mineral is irregularly distributed throughout the deposit, with a somewhat higher concentration in the pentlandite and chalcopyrite associated with the youngest carbonatite.

ORIGIN

The mackinawite from Insizwa was originally described by Scholtz (1936) as valleriite. According to him ". . . The microscopic study of the Insizwa and other ores clearly indicates that there is no evidence to support the contention that valleriite is to be regarded as an exsolution product of pentlandite . . ." Ramdohr (1960) also refers to the valleriite (now regarded as mackinawite) from Insizwa and from the Bushveld complex. Regarding the origin, however, he states that ". . . Im Pentlandit von Insizwa und anderswo findet sich sehr schön und regelmässig Valleriit als Entmischungsprodukt . . ."

Chamberlain and Delabio (1965) favour the replacement of pentlandite, or another sulphide such as cubanite, as the probable mode of formation of mackinawite. They interpret the formation of mackinawite as a result of the serpentinization of olivine and state that mackinawite occurs as irregular grains and never as oriented intergrowths in pentlandite.

Mackinawite from Loolekop, Insizwa and the Bushveld igneous complex occurs partly in rocks which are free from serpentine. Moreover, the oriented nature of the mackinawite in pentlandite is clear from Figures 1, 2 and 3.

Pauly (1958) postulates the existence of a high-temperature mineral "chalcopentlandite" in order to explain the presence of oriented intergrowths of chalcopyrite in pentlandite. The oriented lamellae of mackinawite in pentlandite point to exsolution from a complex nickel-iron sulfide as a possible mode of origin of the mackinawite. In this case, the existence of a high-temperature mineral "mackinaw-pentlandite" could be postulated.

Brett (1964) has pointed out that noncoherent exsolution can form textures which may resemble replacement textures. The regular distribution of the mackinawite along the crystallographic directions in pentlandite (Fig. 1, 2 and 3) also points to exsolution rather than replacement as the mode of origin of the mackinawite. It is therefore possible that the difference between the regular oriented nature of the mackinawite from Insizwa and the Bushveld complex and the more irregular nature of the material from Loolekop and from the Muskox intrusion (Chamberlain and Delabio, 1965) is due to variations in the mechanics of exsolution rather than to more selective replacement in the case of the former.

Recent work by Kullerud (1963) on the system Fe-Ni-S clearly shows that pentlandite does not exist above 610°C. At this temperature it forms by reaction between pyrrhotite and the nonquenchable $(Fe, Ni)_3 \pm xS_2$ phase. Kullerud suggests that pentlandite forms a limited solid solution with Fe-S at 610°C but that this solid solution increases at lower temperatures and reaches a maximum at 580°C. Below this temperature pyrrhotite exsolves from pentlandite.

It is suggested that mackinawite instead of pyrrhotite may exsolve from pentlandite at some temperature below 580°C. We contemplate experimental work to obtain more information on these aspects.

Conclusions

A final answer to the origin of mackinawite in pentlandite will have to await further evidence on its phase relationships in the system Fe-Ni-S. The textural relationships of mackinawite and its distribution in pentlandite do, however, indicate that the mineral formed by exsolution from pentlandite.

The regular oriented nature of the mackinawite lamellae in chalcopyrite from the Bushveld complex and Loolekop also point to exsolution as the probable mode of origin of mackinawite. Evidence on the phase relationships of mackinawite in the system Cu-Fe-S will, however, also have to be awaited before a definite conclusion regarding its origin can be reached.

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Figure 2 is taken from van Rensburg's unpublished M.Sc. dissertation at the University of Pretoria, South Africa.

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