ON THE USE OF ORE MINERALS IN THE INTERPRETATION OF THE STAGE OF METAMORPHISM WITHIN THE AMPHIBOLITE AND SAUSSURITE FACIES

BY

VLADI MARMO

(Geological Survey of Finland, Helsinki).

CONTENTS.

A b s t r a c t. In the present paper the author draws attention to the possibility of using ore minerals, especially the ex-solutions observable in sulphides, in the interpretation of the metamorphic facies of the host rock. In the present paper he considers most common ex-solutions characteristic of the range of temperature corresponding to the amphibolite and to the saussurite facies, and applies microscopic observations in explaining two not very common mineral assiocations of the rocks.

Introduction.

Normal diaphtoretic metamorphism is always accompanied by the incorporation of water. Hence in the metamorphic facies corresponding to lower PT-conditions, the characteristic minerals contain more water (OH) than those belonging to the higher facies. On going from the pyroxene-hornfels facies with the mineral association diopside — hypersthene towards the amphibolite facies with hornblende, water must be added, and the transition temperature between these two facies is, according to ROSENQVIST (1952), that of the expulsion of the water from hornblende — about 750° C at atmospheric pressure.

If water is not available, the change of facies does not occur, or results in assemblages not definitely interpretable. Rosenqvist (1952) called this kind of metamorphism "dispsenic". In such cases the determination of the stage of metamorphism is not always easy, and sometimes it is impossible.

In such cases, when the rock also contains ore minerals, the origin (or introduction into rock) of these is controlled by definite conditions, often by a determinable range of temperature under special tectonic circumstances. Usually the first factor determines the possibility of movement of the corresponding ore minerals, the second factor the place where they will be deposited.

The conditions governing the deposition of an ore apply to the silicate minerals of the host rock also; hence the stage of metamorphism during the deposition of the ore will also correspond to the same conditions. Consequently it seems to be possible to find some trends, from the manner of occurrence of ores, which can be used in determining the range of metamorphism in the host rock. Examples of such trends are many kinds of ex-solutions, often observed in the ore minerals. The unmixing of a solid solution takes place by diffusion through the lattice of the solvent substance, and this diffusion through such minerals as oxides and sulphides is so slow that certain textures arising from arrested diffusion persist throughout geological time. (EDWARDS, 1947, p. 56). If there occur in the ore minerals such unmixing phenomena, then they can be used to determine the PT conditions governing the metamorphism of the rock during the deposition of the ore. If ex-solutions do not occur, in many cases assemblages of ore minerals, replacements, alterations, etc. can also be used for determining the PT conditions.

In the present investigation only the amphibolite and saussurite facies will be discussed.

The Amphibolite Facies.

The amphibolite facies of the rocks corresponds to the range of temperature between 400 and 750° C (or the corresponding "high gneiss facies'' of ROSENQVIST (1952) between 400 and 700° C). Among the commonest sulphides occurring in the Finnish ores the following ex-solutions have been studied experimentally; all within the temperature range of the amphibolite facies:

TABLE I.

Host mineral	Ex-soluted mineral	Temperature below which unmixing occurs ° C	Authority
Pyrrhotite	chalcopyrite	600	Hewitt-Schwartz (1937)
Chalcopyrite	sphalerite	550	Buerger (1934)
Chalcopyrite	stannite	500	Ahlfeld (1934)
Pyrrhotite	pentlandite	425—450	Newhouse (1927) Hewitt (1938)
Bornite	chalcopyrite	475	Schwartz (1931)
Chalcopyrite	cubanite	450	Schwartz (1927)

(This table is taken from EDWARDS, 1947, p. 72).

At Puumala, in Southeast Finland, there is a basic cluster embedded in mica schist and characterized by a high content of sulphide minerals together with ilmenite and magnetite as accessories. The main sulphide is pyrrhotite, but pentlandite is also abundant. In addition chalcopyrite occurs. The basic cluster consists in its marginal parts of hornblende, (diopside), plagioclase, and quartz, but the inner part mainly of diopside and basic plagioclase. In the marginal parts the uralitization of diopside has occurred but not in the inner part of the cluster. The rhombic pyroxene does not occur at all, and therefore it was not to be supposed that the inner part of the cluster would correspond to the pyroxene-hornfels facies, but that the mineral association diopside-plagioclase would here correspond to the amphibolite facies also. That there uralitization has not taken place, must be attributed to lack of the water needed for the uralitization of pyroxene. Consequently the assemblage diopside-plagioclase corresponds to the ''dipsenic'' stage of the amphibolite facies, if the definition of ROSENQVIST (1952) is used. Since the ore minerals are similar both in the marginal and in the inner parts of the cluster, in any case the metamorphism during the deposition of the sulphides must have been similar in all parts of the cluster. Now pentlandite often occurs in the form of flame-shaped bodies in the pyrrhotite, a manner of occurrence which has usually been interpreted as the result of unmixing of the pentlandite from solid solution in pyrrhotite. Such an ex-solution of pentlandite from pyrrhotite occurs at 425—450° C (see the table above) indicating that the metamorphism of the host rock during the deposition of the ore must also have taken place under conditions corresponding to the amphibolite facies; hence from the study of ore minerals new evidence is obtained in favour of the interpretation of the diopside-plagioclase assemblage as corresponding to the dipsenic stage of the amphibolite facies.

The Saussurite Facies.

The saussurite facies of the rocks corresponds to the temperature range between 200 and 400° C. Among the commonest sulphides of the Finish ore minerals the following ex-solutions have been observed corresponding to the temperature conditions of the saussurite facies (se EDWARDS, 1947, p. 72):

TABLE II.

Host mineral	Ex-soluted mineral	Temperature below which unmixing occurs ° C	Authority
Sphalerite	chalcopyrite	350—400	Borchert (1934)
Chalcopyrite	pyrrhotite	300	Hewitt-Schwartz (1937)
Bornite	chalcosite	175—225	Schwartz (1928)

The last-mentioned ex-solution corresponds already to the tran--itional conditions between the saussurite and the green schist facies.

As an example of the use of the ore minerals in the determination of degree of metamorphism of some lesser known mineral assemblages an instance from Nokia, South Finland, will be taken. There the main rock is normally phyllite, but embedded in this there is a strip of sulphide schist, containing pyrrhotite in abundance but also chalcopyrite and sphalerite as sparse constituents.

The biotite of normal phyllite is quite common, somewhat dark and distinctly pleochroitic with an axial angle of about zero. Sulphide schist contains biotite also, but this is very pale and with axial angle of about zero, exceptionally, however, exceeding upto 16°. This pale biotite is chloritized along its margins, and in extreme cases completely, and then the assemblage corresponds to the saussurite facies. Hence it has been supposed that if pale biotite occurs without chlorite, the assemblage pale biotite — quartz — pyrrhotite belongs to the lowermost degree of the amphibolite facies or to the saussurite facies, and if muscovite is also present, the last-mentioned facies is evident. Among the sulphides, as mentioned in foregoing, chalcopyrite and sphalerite often also occur, and even in the schists containing pale biotite, sphalerite containing unmixed grains of chalcopyrite is common. This phenomenon of ex-solution indicates, as is seen in table II, a temperature of 350—400° C during the deposition of the ore, this being also the temperature governing the metamorphism of the rock during the same period of time; this temperature indicates that at least in the case of Nokia the assemblage pale biotite — quartz — pyrrhotite is that of a transitional stage between the amphibolite and the saussurite facies. Still it may be mentioned, that the sulphide schists of Nokia usually contain some nickel also, and the pyrrhotite separated from sulphide schist of Nokia (with pale biotite) contained 0.06 % nickel (Marmo and Mikkola, 1951, p. 36). The flame-shaped bodies of exsolution of pentlandite from pyrrhotite, however, has been observed at Nokia only exceptionally, and then only in schists containing dark biotite, but never in connection with pale biotite. Hence the ex-solution characterized by the temperature range of 425—450° C (see table I) does not occur together with pale biotite, but an ex-solution of sphalerite from chalcopyrite characterized by temperature of 350—400° C (see table II) there occurs.

Unfortunately instances of ex-solutions in common sulphide minerals within the temperature range corresponding to the saussurite facies are very sparse, so limiting the possibilities of interpreting the ''sub-stages'' of the saussurite facies by using them as thermometers.

REFERENCES.

EDWARDS, A. B. (1947). Textures of the Ore Minerals and their Significance. Austr. Inst. of Min. and Metall. Inc. Melbourne.

MARMO, VLADI and MIKKOLA, AIMO (1951). On Sulphides of the Sulphide-bearing Schists of Finland. Bull. Comm. géol. Finlande 156, pp. 1—42.

ROSENQVIST, IVAN TH. (1952). The Metamorphic Facies and the Feldspar Minerals. Univ. i Bergen Årbok 1952. Naturvitensk. rekke No. 4, pp. 1—104.

Manuscript received January 29, 1953.