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ORE TEXTURES IN TURKISH VOLCANOGENIC MASSIVE SULFIDE DEPOSITS IN LIGHT OF EXHALATIVE SULFIDE DEPOSITS FROM AXIAL SEAMOUNT AND EXPLORER RIDGE, NORTHEASTERN PACIFIC OCEAN

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ABSTRACT

The textures displayed by volcanogenic massive sulfides from deposits in the Eastern Pontids of Turkey can be reinterpreted in the light of similar textures in massive sulfides from spreading centers in the eastern Pacific Ocean. Recently formed sulfides from the caldera of Axial Seamount and Explorer Ridge show the same radiating cockscomb structures in marcasite as do Turkish pyritic sulfides, confirming that the latter are pseudomorphous after marcasite. "Radial-bomb" textures are identical in both suites of samples, and suggest dewatering of gel-like sulfide precipitates. Collomorphically banded pyrite in the Turkish sulfides can now be inferred to have grown in the seafloor environment, by comparison with the recent sulfides. Also, round shelly pyrite "balls" apparently grew around tube-worm holes. Overprinting of these primary depositional textures by recrystallization and precipitation of later coarse euhedral pyrite also are evident in both suites, and confirm that such activity happens soon after initial precipitation.

Keywords: volcanogenic massive sulfides, textures, cockscomb, radial-bomb, collomorphic, tube-worm holes, overprinting, Turkey.

SOMMAIRE

Les textures des sulfures massifs volcanogéniques provenant des gisements situés dans la région des Pontides orientales en Turquie ressemblent beaucoup à celles qui caractérisent les sulfures massifs des rides océaniques de l'Est du Pacifique. Les sulfures formés récemment dans la caldéra du guyot Axial et le long de la crête Explorer montrent les mêmes textures radiaires en "crête de coq" dans la marcasite que les amas pyritiques turcs; ces derniers résulteraient donc d'une pseudomorphose de la marcasite. Les textures radiaires en "bombes" sont identiques dans les deux suites, et font penser qu'il s'agit d'un phénomène de déshydratation d'un précipité sulfuré colloïdal. La pyrite à bandes collomorphes dans les sulfures turcs serait une manifestation d'un milieu sous-marin, tout comme les sulfures récents. De plus, des sphères pyriteuses recouvertes de coquillages se seraient formées dans les parois des tubes d'annélides. La recristallisation de ces textures primaires de déposition et la précipitation d'une génération tardive de pyrite idiomorphe à grain grossier sont évidentes dans les deux suites, et confirment que de tels processus agissent peu de temps après la précipitation initiale.

(Traduit par la Rédaction)

Mots-clés: sulfures massifs volcanogéniques, textures, "crête de coq", bombe radiaire, collomorphe, tubes d'annélides, recristallisation, Turquie.

INTRODUCTION

Hannington's & Scott's (1988) detailed description of the mineralogy and textures of exhalative massive sulfide deposits at the Axial Seamount shield volcano in the eastern Pacific Ocean provides a wealth of new information of these deposits and insights into the genesis of their ancient analogues, volcanic-rock-associated massive sulfide deposits on land. In this regard, important comparisons and inferences have been previously made also by Oudin (1983), Oudin & Constantinou (1984), Koski *et al.* (1984), and Haymon *et al.* (1984) for sulfides formed at spreading ridges. The textures and paragenesis of sulfides in Kuroko-type deposits have been described by Eldridge (1981) and Eldridge *et al.* (1983), and their observations have been compared to similar textures in sulfides formed at spreading ridges by Koski *et al.* (1984).

Textural studies yield important information that is useful in interpreting the history of sulfides in ancient deposits. In this note, some of the textures of modern sulfides, from both Hannington's & Scott's (1988) discussion and my observations of their samples (Fig. 1), are compared to some very similar textures in two Turkish Cretaceous volcanogenic massive sulfide deposits of the Eastern Pontids: Lahanos and Kizilkaya (Leitch 1981).

Leitch (1981) described several characteristic textures of the Turkish sulfides: a) radiating cockscomb structures in pyrite defined by chalcopyrite and sphalerite "septae", b) round spherules with "radial-bomb" texture, c) collomorphically banded pyrite–chalcopyrite, d) round, layered, "shelly" pyrite balls, e) atoll textures and "frog's-egg" texture formed by pyrite framboids infilled by chalcopyrite, and f) overgrowth and recrystallization, causing destruction of original fine framboidal and collomorphic textures. Following examination of samples of modern sulfides from the Axial Seamount and Explorer Ridge, the hypotheses made in Leitch (1981) about the origin of such textures in the Turkish deposits can now

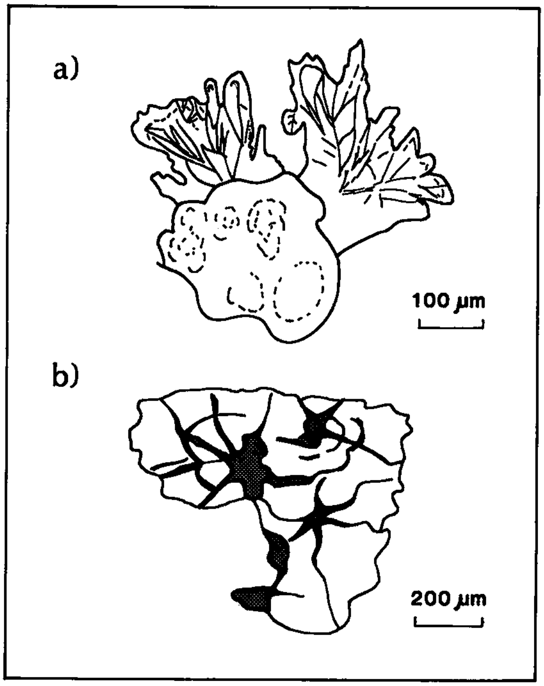

FIG. 1 a). Radiating cockscomb texture of marcasite, growing on collomorphically banded, fine-grained marcasite and sphalerite. Axial Seamount sample, reflected light, partly crossed polarizers. b). "Radially cracked" or "radial bomb" texture of marcasite in Axial Seamount sample. Plane polarized, reflected light.

be confirmed. Each of these textures is elaborated on below.

Comparison of Textures from Recent and Ancient Deposits

The radiating cockscomb structures of marcasite in the Axial Seamount and Explorer Ridge samples (Fig. 1a) are identical to those in the Turkish ores (Fig. 5a of Leitch 1981). This identity confirms that the cockscomb structures in the Turkish ores probably were, as postulated, originally formed of marcasite that has now recrystallized to pyrite. In a specimen from Explorer Ridge, sphalerite also grew in the same fashion, with the "septae" in this case defined by marcasite.

"Radially cracked" textures in marcasite also present in the Axial Seamount samples (Fig. 1b) are strikingly similar to those found in the Turkish pyrite, infilled by chalcopyrite (Fig. 5b of Leitch 1981). The descriptive terms "radial-bomb" and "cracked porcelain" were in fact applied to these textures much earlier by Lasky (1930), Rust (1935) and Schouten (1946a). These authors suggested that the radially cracked spherules reflect shrinkage or "syneresis" cracking that formed as gel-like sulfide precipitates dewatered after precipitation. In the case of the Turkish samples, Leitch (1981) postulated that this dewatering may have occurred during diagenesis, but it is obvious that such changes can take place very soon after formation of the sulfides, long before burial and diagenesis.

Collomorphically banded sulfides, including pyrite, chalcopyrite and sphalerite, with the banding defined by the differing sulfides or by curved rows of gangue inclusions, also are characteristic of both sulfides on the recent seafloor (Hannington & Scott 1988, Koski *et al.* 1984, Oudin & Constantinou 1984) and in the Turkish deposits (Figs. 2a, 2b and 5d of Leitch 1981). Such banding was taken in the Turkish specimens to indicate growth in open spaces on the sea floor; this suggestion can now be confirmed with the discovery of these textures in the samples from currently precipitating sulfides (Koski *et al.* 1984). The parallelism is complete, even to the brown "melnikovite-pyrite" (Hannington & Scott 1988) at the centers of the collomorphically banded marcasite or pyrite.

An explanation can now be offered for the origin of the round layered "shelly" pyrite balls found at the Lahanos deposit in Turkey (Fig. 2; see also Fig. 6b of Leitch 1981). They are almost identical to structures in Axial Seamount samples, which originated by deposition of sphalerite and marcasite around tube-worm holes (Hannington & Scott 1988, Fig. 10a). Such a conclusion also has been drawn by Haymon *et al.* (1984) for massive sulfides formed at a Cretaceous fossil spreading ridge now preserved in the Samail ophiolite in Oman, and by Oudin & Constantinou (1984), who compared the textures of sulfides from the late Cretaceous Cyprus-type deposits found in the Troodos complex, Cyprus, to sulfides observed in recently formed deposits near the Juan de Fuca ridge (Normark *et al.* 1983), the Galapagos ridge (Law *et al.* 1981), the East Pacific Rise (Francheteau *et al.* 1979, Hekinian *et al.* 1980) and the Guaymas basin in the Gulf of California (Lonsdale *et al.* 1980, Peter & Scott 1988).

Overgrowth, recrystallization and overprinting of original framboidal and collomorphic textures by later euhedral or more massive, coarser-grained sulfides (*e.g.*, Fig. 10f of Hannington & Scott 1988) were also postulated for the Turkish deposits by Leitch (1981, Figs. 4 and 6). This process also has been proposed by many others, including Eldridge (1981), Eldridge *et al.* (1983), Oudin & Constantinou (1984) and Koski *et al.* (1984), who called the process an "intensifying hydrothermal system", causing overprinting, overgrowth, recrystallization and zoning of the sulfides. It is interesting to note the ease and rapidity with which chalcopyrite recrystallizes, even in the recent samples from the Axial Seamount

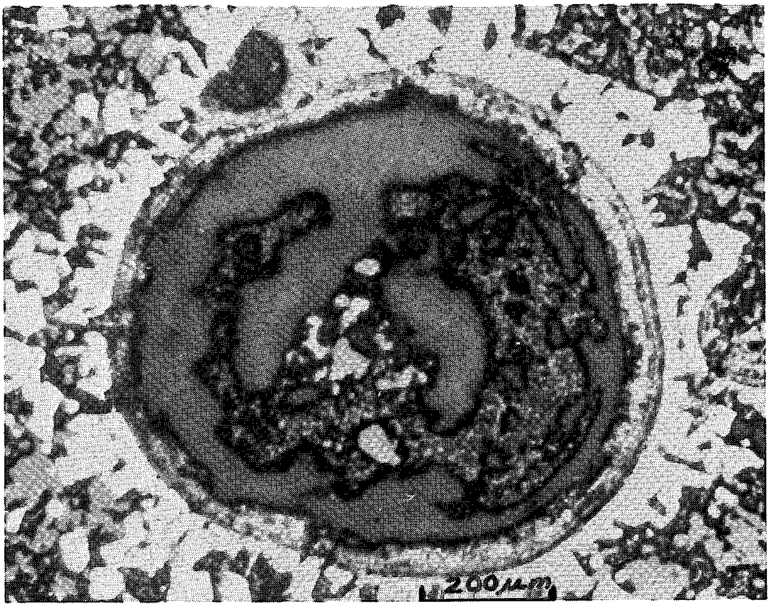

FIG. 2. Large round "shelly" pyrite ball ("ball" only in cross-section), probably formed by filling in or growing around a tube-worm hole, and overgrown by later euhedral pyrite. Sample taken from Lahanos deposit, northeastern Turkey; compare with Figure 10b of Hannington & Scott (1988).

and Explorer Ridge. In one of these samples, chalcopyrite varies from very fine-grained relict balls (or possibly framboids) 10 μm across on one side of the section to a smooth, even, completely recrystallized and homogeneous mass a few centimeters away. Such textures are common in the Turkish samples, with chalcopyrite almost always infilling cracks and spaces between the more brittle pyrite (Figs. 5b and 5d of Leitch 1981). This gives rise to the "frog's-egg" texture (Rust 1935) shown in Figure 5c of Leitch (1981), and to the atoll textures (Schouten 1946b) shown in Figures 3a and 3b of Leitch (1981). As would be expected from observations on the relative ease of recrystallization of sulfides (Vokes 1969), sphalerite in the Axial Seamount sulfides also shows this tendency to recrystallize, but to a lesser extent. Of course, galena would recrystallize more easily than chalcopyrite (and such was observed in the Turkish samples), but it is much less abundant than chalcopyrite in both the Turkish and the recent seafloor sulfides. The iron sulfides pyrite and marcasite, which are the most brittle, tend to preserve their original textures best.

At the Lahanos deposit in Turkey, pyrite seems to pseudomorphose earlier marcasite, and preserves the radiating cockscomb texture of the marcasite. This relation conflicts somewhat with Hannington's & Scott's (1988) observation that marcasite is later and forms at lower temperature than pyrite. The explanation preferred here for the Turkish pyritic framboids is that they formed after marcasite framboids, which are ubiquitous in the recently formed sulfides described by Hannington & Scott (1988, Fig. 10e).

Although the Turkish deposits are, strictly speaking, comparable to Kuroko deposits formed in a back-arc setting, whereas the seafloor deposits of the Eastern Pacific are comparable to Cyprus-type deposits formed at spreading centers, the textures of both are similar. This similarity has previously been suggested by Eldridge (1981) and Koski *et al.* (1984). Thus despite the differences between these two types of volcanogenic massive sulfides in their tectonic setting and metal ratios (*e.g.*, Hutchinson 1973, Franklin *et al.* 1981), the sulfides were precipitated by similar processes.

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REFERENCES

ELDRIDGE, C.S. (1981): *Mineral Textures and Paragenesis of Kuroko Ores from the Uwamuki No. 4 and some Other Kuroko Deposits, Hokuroko District, Japan*. M.Sc thesis, Pennsylvania State University, University Park, Pennsylvania.

______, BARTON, P.B., JR. & OHMOTO, H. (1983): Mineral textures and their bearing on formation of the Kuroko orebodies. *In* The Kuroko and Related Volcanogenic Massive Sulfide Deposits (H. Ohmoto & B.J. Skinner, eds.). *Econ. Geol., Mon.* **5**, 241-281.

FRANCHETEAU, J., NEEDHAM, H.D., CHOUKROUNE, P., JUTEAU, T., SEGURET, M., BALLARD, R.D., FOX, P.J., NORMARK, W., CARRANZA, A., CORDOBA, D., GUERRERO, J., RANGIN, C., BOUGAULT, H., CAMBON, P. & HEKINIAN, R. (1979): Massive deep-sea sulphide ore deposits discovered on the East Pacific Rise. *Nature* **277**, 523-528.

FRANKLIN, J.M., LYDON, J.W. & SANGSTER, D.F. (1981): Volcanic-associated massive sulfide deposits. *Econ. Geol., 75th Anniv. Vol.*, 485-627.

HANNINGTON, M.D. & SCOTT, S.D. (1988): Mineralogy and geochemistry of a hydrothermal silica–sulfide–sulfate spire in the caldera of Axial Seamount, Juan de Fuca Ridge. *Can. Mineral.* **26**, 603-625.

HAYMON, R.M., KOSKI, R.A. & SINCLAIR, C. (1984): Fossils of hydrothermal vent worms from Cretaceous sulfide ores of the Samail ophiolite, Oman. *Science* **223**, 1407-1409.

HEKINIAN, R., FÉVRIER, M., BISCHOFF, J.L., PICOT, P. & SHANKS, W.C. (1980): Sulfide deposits from the East Pacific Rise near 21°N. *Science* **207**, 1433-1444.

HUTCHINSON, R.W. (1973): Volcanogenic sulfide deposits and their metallogenic significance. *Econ. Geol.* **68**, 1223-1246.

KOSKI, R.A., CLAGUE, D.A. & OUDIN, E. (1984): Mineralogy and chemistry of massive sulfide deposits from the Juan de Fuca Ridge. *Geol. Soc. Am. Bull.* **95**, 930-945.

LASKY, S.G. (1930): A colloidal origin of some of the Kennecott ore minerals. *Econ. Geol.* **25**, 737-757.

LAW, S., MALAHOFF, A., EMBLEY, R. & FORNARI, D. (1981): Massive polymetallic sulfides of the Galapagos Rift. *Am. Geophys. Union Trans.* **62**, 1027 (abstr.).

LEITCH, C.H.B. (1981): Mineralogy and textures of the Lahanos and Kizilkaya massive sulphide deposits, northeastern Turkey, and their similarity to Kuroko ores. *Miner. Deposita* **16**, 241-257.

LONSDALE, P.F., BISCHOFF, J.L., BURNS, V.M., KASTNER, M. & SWEENEY, R.E. (1980): A high temperature hydrothermal deposit on the seabed at a Gulf of California spreading center. *Earth Planet. Sci. Lett.* **49**, 8-20.

NORMARK, W.R., MORTON, J.L., KOSKI, R.A., CLAGUE, D.A. & DELANEY, J.R. (1983): Active hydrothermal vents and sulfide deposits on the southern Juan de Fuca Ridge. *Geology* **11**, 158-163.

OUDIN, E. (1983): Hydrothermal sulfide deposits of the East Pacific Rise (21°N). 1. Descriptive mineralogy. *Mar. Mining* **4**, 39-72.

______ & CONSTANTINOU, G. (1984): Black smoker chimney fragments in Cyprus sulphide deposits. *Nature* **308**, 349-353.

PETER, J.M. & SCOTT, S.D. (1988): Mineralogy, composition and fluid-inclusion microthermometry of seafloor hydrothermal deposits in the southern trough of Guaymas Basin, Gulf of California. *Can. Mineral.* **26**, 567-587.

RUST, G.W. (1935): Colloidal primary copper ores at Cornwall mines, southeastern Missouri. *J. Geol.* **43**, 398-426.

SCHOUTEN, C. (1946a): Some notes on micropseudomorphism. *Econ. Geol.* **41**, 348-382.

______ (1946b): Synthetic replacements as an aid to ore genetic studies. *Econ. Geol.* **41**, 659-667.

VOKES, F.M. (1969): A review of the metamorphism of sulphide deposits: *Earth-Sci. Rev.* **5**, 99-143.

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