

DISCUSSIONS

APPLICATION OF SPHALERITE GEOBAROMETRY AND SULFUR
ISOTOPE GEOTHERMOMETRY TO ORES OF THE
QUEMONT MINE, NORANDA, QUEBEC

See: In a recent paper Lusk et al. (1975) examine the FeS contents of sphalerites coexisting with pyrite and pyrrhotite from the Quemont Mine, Noranda, and interpret these in terms of the sphalerite geobarometer of Scott (1973). Despite their comments that the FeS contents of sphalerites indicate higher pressures (6 to 8 kb) than might be anticipated from the metamorphic grade (greenschist facies) of the enclosing rocks, and that the assemblages may have equilibrated at pressures lower than those indicated by the sphalerite geobarometer, Lusk et al. conclude "that phase equilibrium in the Zn-Fe-S system was attained throughout the deposit at a constant pressure that is correlatable with Kenora low-grade regional metamorphism." They furthermore suggest that the similarity between FeS contents of sphalerite coexisting with pyrite and pyrrhotite in ores affected by intrusion of diabase dikes (330°C) and those of sphalerite in unaffected ores (300°C) indicates that the pressures of regional and contact metamorphism were the same, even though they were separated by 0.8 to 1.3 billion years.

It is unlikely, as Lusk et al. point out, that pressures of 6 to 8 kb deduced from the sphalerite geobarometer can be consistent with greenschist facies metamorphism at 300°C, the metamorphic temperature tentatively suggested by isotope geothermometry. They suggest that such pressures could be applicable if the isotopic temperature estimates were 50° to 100°C too low.

Despite numerous studies of orebodies in the Noranda area, no silicate assemblages diagnostic of the metamorphic conditions appear to have been recorded. Gélinas and Brooks (1974) note that the dominant metamorphic grade in the Abitibi belt is probably prehnite-pumpellyite to low greenschist facies, and Spence and de Rosen-Spence (1975) state that the metamorphic grade in the Noranda area is low greenschist facies. Kyanite has been reported from the Normetal mine (Tolman, 1951), but as the observation has not been substantiated by later workers in the area, there seems to be no well-documented evidence for a high pressure metamorphism in the Noranda area.

Observations in Archean "greenstone belts" indicate that metamorphism is generally of the low or intermediate pressure type. Unless an anomalously high pressure style of metamorphism can be justified for the Noranda area, it appears doubtful that the pressures of 6 to 8 kb (or even the "order of 5 kb" compromise of Lusk et al.), derived from the sphalerite geobarometer, can be correct and an alternative explanation should be sought for the compositions of the sphalerites.

The restricted composition of 11.9 ± 0.3 mole % FeS in sphalerite from all pyrite-pyrrhotite-sphalerite assemblages at Quemont is similar to that of sphalerites from several metamorphosed Fe-Ni sulfide deposits in Western Australia (Groves et al., 1975), which show a range in mean composition from 9.6 to 11.7 mole % FeS. The latter are also inconsistent with experimental data relevant to likely prograde metamorphic pressure-temperature conditions but are compatible with predicted sphalerite compositions for equilibration with pyrite and monoclinic pyrrhotite below 300°C (although experimental and natural data here are sketchy; see Scott and Kissin, 1973). Similarly, studies of orebodies in the Flin Flon and Snow Lake districts of Manitoba (metamorphosed under greenschist and amphibolite facies conditions) show that the pressures inferred from sphalerite compositions, assuming equilibration with pyrite and pyrrhotite during the metamorphic climax, are also higher than the maximum permissible pressures indicated by metamorphic silicate assemblages (Bristol, 1974; Koo and Mossman, 1975). For example, at the Flin Flon (South Main) mine, the pressures indicated by the sphalerite geobarometer are 6.5 to 9.5 kb when the metamorphic grade is low greenschist facies (an equilibration temperature of about $470 \pm 80^\circ\text{C}$ has been assumed). In two of the four deposits in which pyrrhotite-pyrite-sphalerite assemblages coexist, the mean sphalerite compositions of 11.3 mole % FeS (Flin Flon, South Main) and 10.3 mole % FeS (Osborne Lake) cluster around the values shown by sphalerites from the Quemont ores and the Western Australian nickel ores, and for one deposit (Stall Lake) the composition is slightly more Fe rich (12.7 mole % FeS).

Sphalerites from Chisel Lake deviate markedly from these compositions, but in this deposit the iron content in some sphalerites coexisting only with pyrite (13.5 to 15.3 mole % FeS) is higher than in those coexisting with both pyrite and pyrrhotite (11.5 to 14.8 mole % FeS). This is contrary to experimental studies in the Fe-Zn-S system and suggests disequilibrium between associated pyrite, pyrrhotite, and sphalerite.

From this discussion, the following general points might be made:

(1) Interpretation of sphalerite compositions from several Archean volcanogenic Cu-Zn ores, including Quemont, and from Archean nickel ores in Western Australia in terms of the sphalerite geobarometer of Scott (1973) indicates pressures that are consistently too high when compared to metamorphic pressures indicated by the silicate mineralogy of surrounding rocks.

(2) Although the compositions of sphalerites in monoclinic \pm hexagonal pyrrhotite + pyrite + sphalerite assemblages vary from deposit to deposit, they lie in the restricted range 9.6 to 12.7 mole % FeS, and most cluster between 11 and 12 mole % FeS.

(3) These compositions appear better explained by equilibration below 300°C, although experimental studies below this temperature are by no means definitive (Scott and Kissin, 1973). If this is correct, sphalerite may not be as refractory as generally thought, or perhaps unloading and temperature decline following the metamorphic climax was particularly slow in Archean terrains. Small variations in composition may be due to differences in the temperature and pressure of final equilibration below 300°C, particularly if the monoclinic pyrrhotite-pyrite-sphalerite boundary does not have a fixed composition at low temperatures or if it is pressure dependent (Scott and Kissin, 1973, fig. 2).

(4) The composition of some Quemont sphalerites was possibly affected by equilibration with pyrite and pyrrhotite during diabase emplacement, and these sphalerites may have subsequently re-equilibrated below 300°C. However, it appears more likely that the thin nature of the dikes, combined with

the high conductivity of the sulfide ores, ensured that the ores were not held at high temperatures sufficiently long for equilibration to have occurred above 300°C, particularly if reaction rates are indeed slow in the Fe-Zn-S system.

(5) Applications of sulfide geothermometers and geobarometers in metamorphosed ores should be preceded or accompanied, wherever possible, by a study of silicate assemblages that help diagnose the pressure and temperature conditions during metamorphism. Only in this way can the usefulness of these sulfide geobarometers and geothermometers be more fully assessed. Unfortunately, such studies are scarce, particularly for ores in Archean terrains.

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REFERENCES

- Bristol, C. C., 1974, Sphalerite geobarometry of some metamorphosed orebodies in the Flin Flon and Snow Lake districts, Manitoba: *Canadian Mineralogist*, v. 12, p. 308-315.
- Gélinas, L., and Brooks, C., 1974, Archean quench-texture tholeiites: *Canadian Jour. Earth Sci.*, v. 11, p. 324-340.
- Groves, D. I., Binns, R. A., Barrett, F. M., and McQueen, K. G., 1975, Sphalerite compositions from Western Australian nickel deposits, a guide to equilibria below 300°C: *ECON. GEOL.*, v. 70, p. 391-396.
- Koo, J., and Mossman, D. J., 1975, Origin and metamorphism of the Flin Flon stratabound Cu-Zn sulfide deposit, Saskatchewan and Manitoba: *ECON. GEOL.*, v. 70, p. 48-62.
- Lusk, J., Campbell, F. A., and Krouse, H. R., 1975, Application of sphalerite geobarometry and sulfur isotope geothermometry to ores of the Quemont Mine, Noranda, Quebec: *ECON. GEOL.*, v. 70, p. 1070-1083.
- Scott, S. D., 1973, Experimental calibration of the sphalerite geobarometer: *ECON. GEOL.*, v. 68, p. 466-474.
- and Kissin, S. A., 1973, Sphalerite compositions in the Zn-Fe-S system below 300°C: *ECON. GEOL.*, v. 68, p. 475-479.
- Spence, C. D., and de Rosen-Spence, A. F., 1975, The place of sulfide mineralization in the volcanic sequence at Noranda, Quebec: *ECON. GEOL.*, v. 70, p. 90-101.
- Tolman, C., 1951, Normetal Mine area, Abitibi-West County: Quebec Dept. Mines Geol. Rept. 34, 34 p.

APPLICATION OF SPHALERITE GEOBAROMETRY AND SULFUR ISOTOPE THERMOMETRY TO ORES OF THE QUEMONT MINE, NORANDA, QUEBEC—A REPLY

Sir: Groves et al. have challenged our claims that "phase equilibrium in the Zn-Fe-S system was attained throughout the Quemont deposit at a constant pressure that is correlatable with Kenoran low-grade regional metamorphism," and that pressure

during dike emplacement was similar or not appreciably lower than that of regional metamorphism. Their response is welcomed because a previously unnoticed inconsistency in part of our interpretation is now evident.

Our suggestion of the probable inapplicability of Scott's (1973) geobarometer to the Quemont sphalerites *unaffected* by dikes is contradicted by our suggestion (p. 1802) that the lack of change in FeS contents of sphalerites heated by dikes is possible, provided the pressures of regional and contact metamorphism were similar (≤ 5 kb) and temperatures were less than 600°C." While this correctly suggests that Scott's geobarometer is potentially applicable to sphalerite-bearing assemblages *affected* by the dikes, it wrongly implies that the geobarometer is also applicable to Zn-Fe-S assemblages *unaffected* by dikes. Nevertheless, this contradiction in no way weakens our claim that the uniformity of sphalerite (with pyrite and pyrrhotite) compositions is correlatable with a steady Kenoran regional metamorphic pressure, even if sphalerite compositions are T-dependent as well under these conditions.

Any reappraisal of the P and T of equilibrium for the Quemont data must await proper investigation of Zn-Fe-S relations below 300°C, as Groves et al. pointed out, and also confirmation or refinement of the sulfur isotope thermometers applied by us. However, the isotopic temperatures implied by our Quemont samples merit further comment because Groves et al. have suggested that the similar narrow ranges shown by sphalerite compositions for Quemont and other regionally metamorphosed Archean deposits are better explained by equilibrium attainment below 300°C and, for Quemont, at a pressure(s) below those tentatively suggested by us, namely, ~5 kb for initial Kenoran regional metamorphism and ≤ 5 kb for later thermal metamorphism by diabase dikes. Our implied isotopic temperatures for samples *unaffected* by dikes appear to be consistent with an equilibrium temperature below 300°C (e.g., ~220° to 260°, averaging ~240°C), but a temperature of ~300°C clearly separates this group from samples which have been slightly(?) to strongly affected by dikes. In view of this and uncertainties associated with these thermometers, 300°C was accepted as an approximate temperature for Kenoran regional metamorphism.

Groves et al. also suggested that some of the Quemont sphalerites affected by diabase emplacement may have subsequently re-equilibrated below 300°C. This speculation, combined with their doubts about our claim that existing sphalerite compositions are correlatable with Kenoran regional metamorphism (greenschist or lower), appear to imply a preference for linking sphalerite compositions to retrograde rather than prograde equilibrium effects. This inference was made recently in *Economic Geology* by Groves et al. (1975), who reported on sphal-

erite compositions in three nickel deposits of Western Australia.

While our tentative P-T estimates will undoubtedly require reappraisal as new experimental data become available, our linking of sphalerite compositions and isotopic partitioning data with the two known main geological events affecting Quemont appears to be very soundly based. This is because any *postdike* retrograde effects that were capable of re-equilibrating sphalerite in the Zn-Fe-S system would certainly have obliterated existing isotope differences which clearly reflect the effects of nearby dikes. Furthermore, the compositional *uniformity* of Quemont sphalerites coexisting with pyrite and pyrrhotite is believed much more likely to have developed under relatively steady P-T conditions of prograde regional metamorphism (perhaps at $T < 300^\circ\text{C}$ and $P < 5$ kb) than during retrograde re-equilibration which, if important, could be expected to occur over a range of temperatures (and perhaps pressures) within massive sulfide deposits. However, even sulfur isotopes do not appear to show significant readjustment for many deposits metamorphosed to higher grades than those considered.

Perhaps Groves et al. (1975) should consider alternative explanations for the striking "similarity of sphalerite compositions from the different deposits and ore types, despite the form of pyrrhotite present or the abundance of pentlandite, . . ." in Western Australian nickel deposits. For example, if the deposits they considered are volcanic-exhalative, as Lusk (1976) suggests, the ores never formed from oxysulfide melts, and the sphalerite (which was always present) may have undergone more than one metamorphic event. If this is correct, any attempt to link sphalerite compositions entirely to retrograde re-equilibration effects could well prove an erroneous exercise.

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REFERENCES

- Groves, D. I., Binns, R. A., Barrett, F. M., and McQueen, K. G., 1975, Sphalerite compositions from Western Australian nickel deposits, a guide to equilibria below 300°C: *ECON. GEOL.*, v. 70, p. 391-396.
Lusk, J., 1976, A possible volcanic-exhalative origin for nickel sulfide deposits of volcanic association, with special reference to those in Western Australia: *Canadian Jour. Earth Sci.*, v. 13, p. 451-458.
Scott, S. D., 1973, Experimental calibration of the sphalerite geobarometer: *ECON. GEOL.*, v. 66, p. 466-474.

