A Discussion. Supracrustal Rocks and Mo-Cu-bearing Veins in Dalen

FRANK M. VOKES

Vokes, F. M.: A discussion. Supracrustal rocks and Mo-Cu-bearing veins in Dalen. *Norsk Geologisk Tidsskrift*, Vol. 52, pp. 323–326. Oslo 1972.

F. M. Vokes, Geologisk Institutt, Norges Tekniske Høgskole, 7034 Trondheim – NTH, Norway.

Zia-Ul Hasan's (1971) account of the Mo-Cu mineralization in the Dalen area is of interest since it represents a modern account of examples of the classical Telemark veins originally described by J. H. L. Vogt (1886, 1888). Nevertheless it seems that there are several points concerning the deposits which can be taken up for discussion and that some of the facts described are possibly open to interpretations alternative to those suggested by the author. The following remarks are offered in the hope that they may contribute to an eventual better understanding of the nature of these deposits. The Dalen-Askom veins seem to be typical examples of the so-called 'copper-tourmaline veins', which in most convential ore genetical classifications are usually referred to the hypothermal class (following Lindgren 1933, 684–686) or the pneumatolytic class (Schneiderhöhn 1955, 89–90). The main reason for so classifying this type of deposit seems to be the presence of the mineral tourmaline, which has always been regarded as an undoubted hypothermal/pneumatolytic mineral in classical ore geological thinking.

In addition, the veins in question contain the mineral molybdenite which is also conventionally taken as evidence for high-temperature deposition. Whether these pieces of mineralogical evidence are, in fact, admissible, has never really been satisfactorily tested. Tourmaline, for example, is known to crystallize from marine pelitic sediments at temperatures well under the hypothermal range. Unfortunately there seems to be a lack of suitable geothermometers in the deposits in question which might be used to obtain a firmer indication of the temperature of crystallization. Hasan (1971) cites a temperature of 'below approximately 500 °C' on the basis of the presence of both the 3R and 2H polymorphs of MoS_2. Such a temperature, if it is valid, would fall within the range ascribed by Lindgren (1933, 212) to his hypothermal class.

Another piece of circumstantial evidence for classifying ores as 'hypothermal' or 'pneumatolytic' is a near spatial relationship to a body of magmatic intrusive rock.

Although Hasan reports that 'no intrusive rocks occur in the present area', his Fig. 1 shows the presence of 'granites' at no great distance from the deposits and, not unreasonably, these granites may be present in depth under the deposits in question. However whether these can be regarded as the possible magmatic source rocks of the Dalen-Askom ores is highly debatable.

Another mechanism for the attainment of high temperatures in the earth's crust, apart from magmatism, is, of course, metamorphism. 'Hypothermal' temperatures can be attained, for example, during regional metamorphism in the upper part of the greenschist facies (Winkler 1965, Fig. 28) which corresponds to the epidote-amphibolite facies to which, as Hasan informs us, the rocks of the Dalen area have been subjected. Metahydrothermal solutions could possibly be generated under these facies conditions, leading to the mobilization and redeposition of quartz and the metal suphides in the ores. More specifically; if, as is advocated by more than one Norwegian geologist, the granites of central Telemark are of a granitization origin, the generation of the metahydrothermal solutions could have occurred at the granitization front. This view is, for example, held by Dons (1963), and by Oftedahl and Svinndal (pers. com. 1972). The question of the timing of the mineralization, of whatever origin, is also of interest. It is very tempting to postulate the mobilization (possibly accompanying granite intrusion or granitization) of ore-forming elements present in the supracrustals of the Telemark suite or their basement, during the 9–1100 m.y. Telemarkian orogeny. Published information on the absolute age of ore minerals of the Telemark area is practically non-existent. Moorbath & Vokes (1963) reported a lead-lead model age of 920 ± 80 m.y. for galena from the Nordre Bygstøl (Drithol) prospect, some 20 km east of Dalen. If this age can be relied on, it would be at least an indication of an ore-forming event of the same age as the orogenic event in Telemark.

However, there are other aspects of the ores, as described and illustrated by Hasan, which must be taken into consideration, and these have to do with the relation of the mineralization to the already mentioned epidote-amphibolite metamorphism. That the Dalen-Askom ores have been affected by folding and other forms of deformation is already clear from Hasan's account, where the deformation of the non-sulphide minerals is well documented by his Figs. 7 and 8. The sulphides, as is usual, show less evidence of this deformation due to their marked ability subsequently to anneal to polygonal mosaic textures (see, e.g., Stanton 1964). Such an annealed polygonal mosaic is well-illustrated in Hasan's Fig. 18, where the prevalence of the triple junction points between chalcopyrite and bornite shows clearly. (The bornite-bornite and chalcopyrite-, chalcopyrite triple junction points would doubtlessly also have shown if the section had been etched.) Thus the chalcopyrite and the bornite annealed (recrystallized) together *in the solid state* under the influence of an elevated temperature; a temperature most probably related to the epidote-amphibolite metamorphism. Fig. 18 thus provides no evidence that the chalcopyrite 'remained mobile' after the bornite had solidified as suggested by Hasan. On the other hand there seem to be good indications that the Dalen-Askom ores may have been recrystallized and deformed during a regional metamorphic event of epidote-amphibolite grade at some period after they were deposited. The timing of this metamorphism raises difficult questions. If, as suggested above, the ore deposition is related to the Telemarkian orogenic event, the only possibility seems to be that the recrystallization and deformation occurred during a late phase of this same orogeny. Evidence for metamorphic events later than the Telemarkian is slender. Priem et al. (1967) report evidence of a thermal event at 260 ± 7 m.y. in acid volcanics dated at 1525 ± m.y. in the Hjartdal area of Telemark, 40 km NE of Dalen. This Permian event, if confirmed, would seem to be purely thermal, possibly connected with the intrusion of magma to shallow depths beneath the present erosion surface in Telemark. Such an event could possibly account for sulphide recrystallization or annealing but not for the deformation exhibited in the non-sulphide components of the ores. Hasan's description and illustrations show that the ores in question have been further subjected to changes, most certainly of a supergene character, at a much later period. Again it is not easy to be certain of the dating of this alteration; it could have been Tertiary or even Recent. This supergene alteration is shown firstly by the cracks which traverse both bornite and chalcopyrite, but which are lined with covelline only where they intersect bornite (Hasan's Fig. 18). This feature is almost universal in ores of this type. It may be ascribed to the lesser stability of bornite during supergene alteration as compared with chalcopyrite. The feature has been described previously from other Norwegian sulphide deposits with a similar mineralogy; see for example Krause (1965, Figs. 1 and 2).

Krause's Figs. 1 and 2 are also very similar in other respects to Hasan's Fig. 16 (see also Vokes 1957, Pl. 1) and one is tempted to query Hasan's identification of the spindles or plates as chalcocite. Usually in this texture, these are chalcopyrite, and are most probably the result of the initial supergene breakdown of the bornite. Idaite usually appears in this association, but possibly at a somewhat later stage than the chalcopyrite lamellae (Krause 1965, 418).

Finally, a word of warning on the question of 'exsolution' textures and their supposed geothermometric significance. Hasan's paper contains at least two references to temperatures deduced from the presence of such textures; significantly perhaps, neither of these references is later than 1931. It is already eight years since Brett (1964) warned us of the danger of continuing to ascribe the textures in question to 'exsolution' at any particular temperature, irrespective of other variables in the system. Yet these textures still continue to be cited as evidence for the attainment of definite temperatures during the crystallization of many types of sulphide ore. One of our leading experimental ore mineralogists, B. J. Skinner (1971) recently pointed out that it is now no longer justified to continue to emphasize the role of temperature in such cases as the above, where we know that 'variations in the partial pressure of sulfur play an even larger and more important role in sulfide phase relations and consequently the textures developed. Many textures we would now suspect to involve the addition or subtraction of material as the partial pressure of sulfur (or oxygen) changed are labelled exsolution and treated as the products of isochemical processes'. Recent studies of sulphide systems have clearly demonstrated 'that the solubility is essentially insensitive to temperature changes, but exceedingly sensitive to changes in sulfur pressure, and hence that isochemical exsolution must be rare, and when observed, a minor effect'.

5 March 1972

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