A Reply. Geology of the Kvikne Mines with Special Reference to the Sulphide Ore Mineralization

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Several comments have been made by Vokes & Morton (1973) on our paper on the geology of the Kvikne mines (Nilsen & Mukherjee 1972). In general their comments and criticism can be useful to the progress of our work with the Caledonian sulphide deposits. Their general objection to the paper seems to be our apparently ill-founded assertions and the somewhat vague concepts used in the paper in favor of an epigenetic origin of the Kvikne ores. Further they complain that we have not recognized the possibility that the Kvikne mines may be of an originally volcanogene or synvolcanic nature in spite of our documentation of the stratabound volcanic-associated nature.

However, we find their criticism somewhat biased in that they emphasize the less conclusive arguments (viz. the Co:Ni-'criterion') and reject the most important arguments in favor of our epigenetical *Anschauung*. Vokes' and Morton's assertion that our evidence for retaining the epigenetic hypothesis '. . . consists of nothing more than a "constant prevalence of Co over Ni in the pyrites"' is a deplorable misinterpretation of our paper. Our opinion that the ore formation is of an 'epigenetic nature' is *not* based upon 'considerations of the Co:Ni ratios in the sulphides present' as stated by them, but merely upon the apparent tectonic control of the ore and the wall rock alteration present – arguments which we perhaps should have stressed and worked out more in detail. We were indeed aware of the ambiguity in using the Co:Ni-ratio as a geochemical characteristic to differentiate between 'epigenetic' and 'non-epigenetic', thus we put it vaguely in the text (p. 190) with references. It is therefore amazing that they approve the same dubious argument in favor of a sedimentary 'vasskis' origin for our barren pyrrhotitic mineralizations on the basis of the general Ni-dominance of these deposits. The pyrrhotitic black schist ores (e.g. Odden mine and -prospect) represent in all probability metamorphic equivalents of the 'vasskis' type of sedimentary sulphides, but the greater part of the pyrrhotite deposits (i.e. the impregnated cummingtonite/hornblende-bearing garnet quartzites) bear no petrogenetic relation to the black schists. In this connection it is pertinent to affirm that we did *not* reject the kinship of the pyritic/chalcopyritic ores at Kvikne with

the massive sulphide deposits of the Caledonides (p. 188, 1.6–7) as inferred by Vokes & Morton.

Nor is it correct to infer that the Rødhammeren ore (Nilsen 1971) is an exception to the rest of the Caledonian sulphide deposits. As stated (Nilsen 1971, p. 351, 1.32 ff.) the Rødhammeren ores fall well within the principal classes of the Caledonian sulphide ores discussed by Vokes (1962). The sulphides at Rødhammeren were thought to have been conveyed and/or redeposited from horizons of black shale and layers of sedimentary sulphides (Nilsen 1971, p. 350). Inferring that the Rødhammeren ores 'are not being of a metamorphosed nature' is thus an attempt to turn the arguments upside down.

As long as tectonic transport is accepted without doubt as being the principal agent responsible for the ore deposition at Kvikne as well as at Rødhammeren, the present writers refuse to describe it as a syngenetic occurrence. We did not speak of yesterday's sulphide accumulations because their features are overshadowed by the features of the ore body of today. The absence of relics of a primary, volcanogene origin permits only a classification of the sulphide mineralization itself which corresponds to an epigenetical model. Hence we do *not* reject the idea of an original volcanogene or a synvolcanic proto-ore at Kvikne – however, we have not found the traces left. We have tried to delineate the conditions for the ore deposition at Kvikne by means of structural, petrological and geothermometrical considerations. On the basis of the metamorphic/metasomatic nature of the *actual* ore body and its wallrocks we favoured an epigenetic origin of the deposit.

However, we realize that usage of the terms 'epigenetic', 'non-epigenetic', 'syngenetic', etc. in a metamorphic terrain is bewildering and may lead to objections such as those put forward by Vokes & Morton. We used the terms 'epigenetic origin' and 'epigenetic nature' in the conviction that we were dealing with deformed and replaced ore bodies (Jenks 1971) or a pure lithogene deposit (Lovering 1963). These genetical aspects have recently been discussed by Sangster (1971) and Smirnov (1972).

One of us recently drew attention to the importance of the relationship between sulphide ore deposition and evidence of strong tectonic activity, comprehensive wallrock alteration and the close relationship with amphibolite horizons in the Trondheim region (Nilsen 1972, p. 321). In most cases, however, the origins of the ore constituents are difficult to delineate – but the present writers do not reject a 'syngenetic', original volcanogenic deposit as the ultimate source and/or progenitor.

So if the above mentioned statements can be interpreted as a 'conversion' we hope our critics will be satisfied.

As regards the final comments of Vokes & Morton we would like to put the following right:

Though no detailed structural symbols were given in Figs. 1–3, yet broader attitudes of foliations were given in Figs. 1 and 3.

Figs. 6A to 15B were primarily meant to illustrate the salient textural and

microstructural features of the different classes and types of ores of varying mineral assemblages. Specimens collected from different mines show more or less the same mineral assemblages irrespective of their abundance as well as textural features. Hence statement of actual location of specimens appeared to be of less importance. An overall survey of textural features of ores of different mines was made to decipher the temperature of formation of different classes of ores. The authors thus maintain that a closer study of the section 'Description of the ore minerals' together with the mineral assemblages (Table 2) will clearly demonstrate the purpose of the illustrations.

The authors admit the minor errors in calculation in Tables 7 and 8 but in no way do these errors contradict the statements made regarding their distribution ratios.

Electron microprobe analyses were done by an ARL-EXM microprobe analyser. Copper-free pyrite was used as a standard for determining Fe and S and chemically pure Cu, Ni and Co as standards for determinations of Cu, Ni and Co respectively. Analyses were carried out at 20 kV and at a specimen current of 10^{-8} amp. Output correction programme of Springer (1967) was followed.

We realize that the term 'hydrothermal quartzite' caused some confusion, and we admit that it might have been discussed in more detail in the text. We hope the following petrogenetical considerations will justify its use.

The quartzites in question, which occur adjacent to the Gula greenstone in the Kvikne area, have not been found within the less metamorphic terrains, e.g. in the Budal-Soknedal region north of the Kvikne area. We suggested (p. 172) that their formation was related to the general silification of the ore-bearing border zone based on textural and mineralogical features of the wall rocks. We thus concluded that metamorphic/metasomatic processes in a large scale were involved in their formation. Based on the general coarse grained and sutured texture of undulose quartz, veining and in part cross-cutting features, we favored the term 'hydrothermal quartzite'.

In analogy with our arguments for an epigenetical model for the massive sulphide deposits at Kvikne, we will not reject the idea of cherty iron oxide facies within the original greenstone suite, nor 'Kuroko'-type sequences in general, but repeat that the metamorphic and metasomatic imprints on the lithologies have determined our nomenclature. The ores and rocks under consideration await further investigations in the progress of our studies on the Gula greenstones.

One gets the impression that running discussions on the genesis of the Caledonian sulphide deposits often turn out to be at cross purposes. So far, we have attached importance to the metamorphic/metasomatic imprints on the ores and have chosen to treat their genetical implications; others tend to overlook these features in their effort to interpret the original nature of the deposits. It is to be expected that a 'diplogenetic' conception in Lovering's (1963) sense may turn out to give the most satisfactory treatment of the origin of some of our sulphide deposits.

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REFERENCES

Jenks, W. F. 1971: Tectonic transport of massive sulfide deposits in submarine volcanic and sedimentary host rocks. *Econ. Geology 66,* 1215–1224.

Lovering, T. S. 1963: Epigenetic, diplogenetic, syngenetic and lithogene deposits. *Econ. Geology 58,* 315–331.

Nilsen, O. 1971: Sulphide mineralization and wall rock alteration at Rødhammeren mine, Sør-Trøndelag, Norway. *Norsk geol. tidsskr. 51,* 329–354.

Nilsen, O. 1972: A reply. Sulphide mineralization and wall rock alteration at Rødhammeren mine, Sør-Trøndelag, Norway. *Norsk geol. tidsskr. 52,* 319–321.

Nilsen, O. & Mukherjee, A. D. 1972: Geology of the Kvikne mines with special reference to the sulphide ore mineralization. *Norsk geol. tidsskr. 52,* 151–192.

Sangster, D. F. 1971: Metamorphism as an ore-forming process. *Econ. Geology 66,* 499–500.

Smirnov, V. I. 1972: The time factor in formation of stratiform ore deposits. *Int. Geol. Rev. 14,* 1124–1132.

Springer, G. 1967: Die Berechnung von Korrekturen für die quantitative Elektronenstrahl-Mikroanalyse. *Fortschr. Mineralogie 45,* 103–124.

Vokes, F. M. 1962: Mineral parageneses of the massive sulfide ore bodies of the Caledonides of Norway. *Econ. Geology 57,* 890–903.

Vokes, F. M. & Morton, R. D. 1973: A discussion. Geology of the Kvikne mines with special reference to the sulphide ore mineralization. *Norsk geol. tidsskr. 53,* 333–336.