Mo AND Zn MINERALIZATIONS RELATED TO GRANITES IN CALDERA ROOTS IN THE ELSJÆ AREA, OSLO PALEORIFT, NORWAY

SVEIN OLERUD*

ABSTRACT The Oslo Paleorift evolved in the Proterozoic basement of southeastern Norway and the Skagerak Sea in the Permian; it forms a part of a larger system of taphrogenic elements occurring at the margin of the Baltic Shield. It consists of alkaline igneous rocks and Cambro-Silurian sediments. The most prominent epigenetic mineralization types are: A. intramagmatic Mo-deposits; B. contact metasomatic deposits (Zn, Pb, Fe etc.); C. rift margin deposits (Ag etc.). The Elsjæ area shows good examples of the A and B types. The Elsjæ area is situated in the northern part of the paleorift at the point of intersection between two deeply eroded caldera structures. Cambro-Ordovician shales and limestones form a 2 km² infill enclosed in Permian intrusives. The sediments are contact metamorphosed and altered by metasomatic processes. The sphalerite mineralization is found in skarn altered limestone layers and lenses at several levels in the Cambro-Ordovician hornfelsed sediments. The Elsjæ area is underlain by Permian granites which are hydrothermally altered and brecciated and carry low-grade molybdenite mineralization in zones dominated by quartz-sericite-pyrite alteration. Field evidences indicate that the Zn-skarn mineralization are related to the Storeåyungen granite, which was intruded earlier than the ring dyke system of the calderas, while the Mo-mineralization was formed at a late stage in the development of the calderas.

INTRODUCTION This paper reports the results of a study of the hydrothermal molybdenum and zinc mineralization within the Elsjæ area in the Oslo Paleorift in South Norway.

The Oslo Paleorift evolved in the Proterozoic basement of southeastern Norway and the Skagerak Sea during the Permian, and forms part of a larger system of taphrogenic elements occurring at the margin of the Baltic Shield in northwest Europe (Fig. 1). It mainly consists of alkaline Permian igneous rocks and Cambro-Silurian sedimentary rocks. A great variety of mineralization types, both orthomagmatic and epigenetic, is related to the magmatism of the Oslo Paleorift. The most prominent epigenetic mineralization types are: A. intramagmatic Mo-deposits; B. contact metasomatic deposits (Zn, Pb, Fe etc.); C. rift margin deposits (Ag etc.) (Ihlen 1986a). The Elsjæ area shows good examples of the A and B types. The metallogeny of the Oslo Paleorift is recently described in detail in a volume edited by Olerud & Ihlen (1986).

The Elsjæ area is situated in the deeply eroded northern part of the paleorift. It consists of contact-metamorphic Cambro-Ordovician sedimentary rocks which occur as a 2 km² large rift in Permian intrusives (Olerud 1984) (Fig. 1). The area is located on the eastern margin of the Stryken ring complex, interpreted as a cauldron root by Scott (1979), where syenite porphyry and felsites make up a system of ring dykes. To the north, a circular alkali granite intrusion occurs with remnants of porphyric syenite along the borders forming an incomplete circular structure (Scott 1980). No supracrustal Permian rocks are preserved inside this ring structure, as it is in the Stryken ring complex. The alkali granite is interpreted as a late intrusion in the central, deeper part of the caldera, where it has completely destroyed the supracrustal and subvolcanic rocks found elsewhere in the Oslo Rift calderas. The Elsjæ area is situated at the point of intersection of these two main ring structures (Fig. 1). The Cambro-Ordovician rocks are in contact with five different intrusives (Scott 1979, Olerud 1982) (Fig. 2) and are underlain by various Permian granites, which have produced extensive contact metamorphism and skarn alteration in the limestones.

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Sphalerite mineralization occurs in skarn horizons within the Cambro-Ordovician sequence of carbonaceous and marly shales and limestones. The limestone beds and fault zones are partly replaced by zinc bearing skarn. Skarn alteration with associated Zn-W mineralization also occur along fault zones in the argillaceous hornfelses. Scattered molybdenite mineralization is found related to hydrothermal alteration zones in the underlying Permian granites. This molybdenite mineralization is found in one deep (475 m) drill hole (DDH2, Fig. 2), and the description of the mineralization is based on data from this drill hole.

**SPHALERITE SKARN MINERALIZATIONS**

Underground mapping in the abandoned mines by Ihlen (1980) and surface mapping by Olerud (1984) show that the most important zinc mineralizations in the western part of the Elsje area are related to limestone lenses at a single stratigraphic level in the Cambrian graphitic shales. The limestones lenses have irregular shapes from small nodules to discoid-formed lenses with maximum sizes of 2 x 40 x 50 m (Ihlen 1980). The zinc mineralizations were described by Goldschmidt (1911) and recently in more detail by Ihlen (1980). Sphalerite occurs in a medium-grained skarn rock dominated by hedenbergite, garnet, and small amounts of calcite, amphibole sulphides, and scheelite. Between the skarn rock and the surrounding Cambrian graphitic shales there is always a zone of garnet-graphite rock. This characteristic zonation is found all over the Elsje area. The zinc content of the skarn lenses seldom exceeds 10%, and the average is estimated to be 5% (Mathiesen et al. 1976).

Underground mapping and drilling show that only a small fraction of the limestone lenses is altered to skarn. The Zn-mineralized skarn lenses are to widespread and low grade to be recoverable.

Other sphalerite occurrences in the eastern part of the Elsje area are described as mineralized fault zones and as thin skarn-altered limestone beds (Goldschmidt 1911, Mathiesen et al. 1976, Ihlen 1978).
PERMIAN ROCKS, ALTERATION AND MOLYBDENITE MINERALIZATION

Permian Rocks Core drilling through the Cambro-Ordovician rocks (Olerud 1983) showed that the Elsjæ area is underlain by permin intrusives (Fig. 2). These rocks are hydrothermally altered and brecciated and carry low grade molybdenite mineralization locally.

Based on field observations of the intrusive contacts by Scott (1980), Gaut (1981) and Olerud (1982b, 1984) and drillcore data by Olerud (1983, 1984) the relative ages can be outlined:

• Youngest: Alkali granite, Syenite, Granite porphyry II, Storøyungen granite, Granite porphyry I; and
• Oldest: Granite I.

THE ALKALI GRANITE It is a pale pinkish granular rock ranging from medium to coarse grained. It comprises alkali feldspar, a variable amount of quartz (10-30%) and one or more alkali pyroboles and dark mineral. The alkali granite has a peralkaline chemical composition and is the youngest known intrusive of the area. It is probably intruded into the deeper parts of a now destroyed cauldron complex (Fig. 1).

THE SYENITE It is coarse grained, equigranular intrusive with a orange colour. A porphyritic variety with dark bluish feldspar phenocrysts is known from the southern border of the Cambro-Ordovician rocks of the Elsjæ area. The rock consists alkali feldspar, plagioclase, and less than 10% quartz. Biotite and hornblende are the main dark minerals. The syenite probably formed the ring dyke of a later destroyed cauldron complex. The intrusion

Figure 2 – Geological map of the Elsjæ area, from Olerud (1984)
post-date the propylitic alteration and Zn-skarn mineralization of the Elsjæ area, and pre-date the phyllic alteration with molybdenite mineralization.

**THE GRANITE PORPHYRY II** It is an aplitiomorphic granular rock with grain size 0.1-1.0 mm. It occurs with and without phenocrysts of partly rounded quartz of hypidiomorphic alkali feldspar and often shows granophytic texture with irregular intergrowths of quartz. The rock is characterized by red spots, which occur as haloes around disseminated pyrite grains. The granite porphyry II intrudes the granite porphyry I in DDH 2 and is found as dykes and irregular bodies inside the Storøyungen granite. Wholerock chemistry (Table 1) of the granite porphyry II and the Storøyungen granite also confirm the close relationship.

**Table 1 — Average analyses of intrusive rocks in the Elsjæ area.**

*Analysed by X-ray fluorescence at the Geological Survey of Norway, except the alkali granite, which is analysed by the same method by Dr. P. W. Scott, University of Hull, U.K.*

**Granite I**

**Granite porphyry I**

**Storøyungen granite**

**Granite porphyry II**

**Syenite**

**Alkali granite**

**Average of seven samples; l.o.i. — Loss on ignition; * Average of two samples.**

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<th>Sample (weight)</th>
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<th>St.gr.</th>
<th>GP II</th>
<th>Sy.</th>
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<td>SiO₂</td>
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<td>Or</td>
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<th>192</th>
<th>324</th>
<th>260</th>
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<td>Sr</td>
<td>351</td>
<td>216</td>
<td>57</td>
<td>62</td>
<td>400</td>
<td>10*</td>
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<tr>
<td>Ba</td>
<td>815</td>
<td>483</td>
<td>126</td>
<td>146</td>
<td>1,800</td>
<td>92*</td>
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**THE STORøyUNGEN GRANITE** At the south of the Elsjæ area it is a coarse grained biotite-bearing subaluminous granite with hypidiomorphic granular texture. It consists of alkali feldspar, 25-35% quartz and less than 30% of plagioclase. Biotite and magnetite are the most common accessory minerals (Gaut 1981).

**GRANITE PORPHYRY I** It is only found in the DDH 2. The phenocrysts of this porphyry make up more than 40% of the rock volum. The alkali feldspar grains are 3-10 mm across, partly rounded hypidiomorphic crystals, which often are zoned and mantled by plagioclase. The plagioclase grains are hypidiomorphic, partly rounded with grain size of 2-6 mm. The quartz occurs as partly rounded and corroded grains less than 3 mm. The matrix is dominated by quartz and plagioclase with grain sizes less than 0.1 mm. The granite porphyry I is intruded by the granite porphyry II but intrudes the granite I.

**GRANITE I** It is a medium to coarse grained granite with equigranular texture. It is only found in the DDH 2. The fresh red coloured alkali feldspar constitute approximately 50% of the rock, while the quartz content is ca 20%. The plagioclase appears as white to grey crystals. The rock appears very similar to the Storøyungen granite, but the whole rock chemistry is clearly different (Table 1 and Fig. 3).

**Figure 3 — The ternary relationship of Rb, Sr, and Ba in the intrusive rocks of the Elsjæ area.**

**Whole rock chemistry** Table 1 shows the average whole rock chemistry of the actual intrusive rocks in the area. The alkali feldspar of these Oslo Region intrusives all have a high content of microperthite, this must be kept in mind as it causes clearly different values in the alkali feldspar content seen in specimens and the one obtained in the CIPW norm calculation. The Table 1 shows a clear tendency of increasing silica content from the early (granite I) to the relatively later granite porphyry I and the latest Storøyungen granite and the granite porphyry II. The differentiation index shows the same tendency. The alkali granite is clearly different from this serie of peraluminous granites (Table 1) as it has only one feldspar and shows a peralkaline composition.

The trace elements Rb, Sr, Ba are plotted in the ternary diagram of El Bousaily and El Sokkary (1975) in figure 3. The actual rock types plot in distinct areas. The Storøyungen granite and the granite porphyry II are found
in the area of the most differentiated granites and differ markedly from the less differentiated granite porphyry I and the least differentiated granite I. The dark syenite occurs as thin dykes in DDH 2.

**MOLYBDENITE MINERALIZATION** Molybdenite occurs scattered in Permian granitic rocks in DDH 2 between 370 and 265 m above sea level (a.s.l.) (Fig. 2) and between 170 and 150 m a.s.l. Molybdenite occurs in areas with intensive phyllic alteration and is deposited in the following ways:

A. Molybdenite as a dissemination in zones with phyllic alteration.

B. Molybdenite coatings on fissures.

C. Molybdenite in veinlets of quartz, epidote, and pyrite.

D. Molybdenite as matrix in hydrothermal breccias.

The molybdenum grades found are too low to be of economic interest.

**HYDROTHERMAL ALTERATION** The Permian rocks in DDH 2 show three main types of alteration, *i.e.* phyllic, argillic, and propylitic alteration.

**PHYLLIC ALTERATION** is encountered in the granite intrusions beneath the Cambro-Ordovician rocks in DDH 2 as well as in the Storæyungen granite and the syenite on the western shore of the lake Store Elsjær (Fig. 2). In DDH 2 the phyllic veins are spread along nearly the whole length of the core. They are most abundant in the upper part of the intrusives between 370 and 265 m a.s.l., where approximately 20% of the rock volume is altered. Between 230 and 142 m a.s.l. the rock is more weakly altered, approximately 6-8% of the rock volume. In other parts of the core, phyllic alteration is sparse.

Phyllic alteration occurs as a vein stockwork and is only seen in the intrusives. The thickness of the veins is commonly 2-20 mm, but more pervasively altered zones with thickness of several meters also occur. The typical vein is developed on both sides of a seam of pyrite. Near the centre of the vein, nearly all the feldspar is altered to sericite and quartz. Figure 4 shows a secondary electron image of a completely altered granite porphyry I, where the former feldspar is exchanged by sericite and quartz. The proportion of altered feldspar decreases away from the central veins and the rock gradually changes to a fresh-looking rock. The quartz is unaffected. In thicker veins, the altered rock takes on a light grey colour and a massive and fine-grained appearance. The original intrusive texture is still preserved as ghost-like feldspar grains. The feldspar is altered to sericite and quartz and the rock now consists of quartz and sericite with lesser amounts of pyrite, fluorite, chlorite, carbonates, and molybdenite. Chemical analyses of phyllic altered rock samples show a depletion in the Na content and an increase in the K content. The silica content remains constant, except for the strongest alteration type which shows an increased content.

**ARGILLIC ALTERATION** occurs as a bleaching and slight green colouring of the rock and is mainly found in the uppermost part of the Permian intrusions in DDH 2, between 351 and 328 m a.s.l. In other parts of the core the argillic alteration is scattered, and it is not found any other places. The alteration is characterized by a clay mineral alteration of the plagioclase and a precipitation of hydrothermal minerals such as pyrite, carbonates, and fluorite along the grain boundaries of the silicates. The biotite is altered to aggregates of chlorite, pyrite, and carbonates. Clay minerals also occur as vein-filling in the DDH 2. Dickite and montmorillonite are the main clay minerals according to x-ray diffraction analyses. The alteration can be called a weak pervasive argillic alteration.

**PROPYLITIC ALTERATION** is common in the Cambro-Ordovician sequence of the Elsjæ area and in the underlying Permian intrusions, except for the lowest 40 m of DDH 2. In the surrounding intrusives, veins with propylitic mineral assemblages are seldom found. Propylitic alteration occurs as a stockwork of veinlets, mostly less than 2 mm thick. Locally they can swell out to a few centimetres. The veins consist of epidote, pyrite and/or pyrrhotite, quartz, chlorite, carbonates, fluorite, and garnet. These hydrothermal minerals are restricted to the veins and no alteration of the wall-rock minerals can be seen. In the Cambro-Ordovician hornfelses, pyrrhotite is the most common iron-sulphide, while pyrite is the only iron-sulphide which occurs in the intrusive rocks. The propylitic veinlets cross-cut both the phyllic and the argillic altered rocks. There seems to be two main events of propylitic alteration in the area. The earliest propylitic alteration in an event which is postdated by the syenite ring dike. The phyllic alteration in the DDH 2 is though overprinted by a later propylitic alteration. In the Elsjæ area this latest propylitic alteration probably is following the intrusion of the alkali granite.

**DISCUSSION** The succession of geological events in the Elsjæ area in the Permian is listed in the table underneath, where the relatively oldest event is at the bottom and the youngest is at the top.
Propylitic alteration
Alkaline granite intrusion
Phyllic alteration and molybdenite mineralization
Syenite (ring dyke) intrusion
Propylitic alteration and Zn-skarn mineralization
Granite porphyry II intrusion
Storæyüngen granite intrusion
Granite porphyry I Intrusion
Granite porphyry intrusion

The alkali granite is from the existing field data considered to be the latest intrusion of the area. The whole rock chemistry (Table 1) of the alkali granite clearly indicates that it is unrelated to the other granite intrusion in the area.

The succession of intrusives and alteration phenomena suggests that the early phase of propylitic alteration and Zn-skarn mineralization are earlier than the syenite ring dyke and contemporary or later than the Storæyüngen granite and its dyke rock, the granite porphyry II. The Zn-skarn is not overprinted by later alteration. The Storæyüngen granite resembles the biotite granite I group of Gaut (1981), which is assumed being the source of the metals in a lot of small contact deposits of Zn, Pb, Cu etc., in the Oslo Region e.g. the Konnerudkollen mine in Drammen (Ihlen 1986b) and the Grua deposits (Olerud 1977). The Storæyüngen granite is interpreted being the source of the Zn-skarn mineralization in the Elsjæ area. From the Glitrevann caldera, Pedersen (1975) assume that the Zn-mineralization of the Glomsrudkollen deposit, which occurs in contact with the ring dyke, is on the contrary, later or contemporary with the intrusion of the ring dyke.

In the Elsjæ area, the early propylitic alteration is cut by the syenite ring dyke, which again is altered by phyllic alteration. This suggests a distinct event of phyllic alteration and Mo-mineralization, which is clearly later than the early propylitic alteration and the intrusion of the syenite ring dyke. The phyllic alteration is overprinted by a later propylitic alteration which possibly is a low temperature alteration following the latest intrusive event; the alkali granite. The argillic alteration is difficult to relate to time and space in the system, but is probably a late and low temperature alteration.

The location of Mo-mineralization to caldera structures of different erosion levels is an important feature of the ore geology of the Oslo Region. The Nordli deposit is a large subeconomic porphyry-like molybdenum deposit situated in a deeply eroded caldera structure (Pedersen 1986). Molybdenite occurs in three shells, each above different granitic intrusives. The molybdenite mainly occurs in a quartz-sericite-pyrite stockwork of veins. In the Glitrevann caldera the Mo mineralization is associated with the resurgent granitic stock and with vent erupted ignimbrites (Schenwanndt 1986). The Mo mineralization associated with the resurgent stock has phyllic alteration and Mo-mineralization in the roof zone which resembles the Elsjæ type. This molybdenite bearing alteration associated with the resurgent granitic stock is, as in the Elsjæ area, clearly later than the ring dyke.

In the Drammen granite batholith, where no caldera structures are known so far, some small molybdenite mineralization occur in areas with intense quartz-topaz-biotite or quartz-sericite alteration. These mineralizations mainly consist molybdenite in thin quartz veins and they occur in apical position to the main intrusives (Ihlen et al. 1982, Ihlen & Martinsen 1986). These Mo-mineralizations are in many respect unlike the one related to calderas.

The Elsjæ area is probably located to the intersection between two main structures which are interpreted as caldera roots by Scott (1979). The Mo-mineralization of the Elsjæ area is spatially located to the granite I and the roof zone of the granite porphyry I. These intrusions seem to be deep level intrusions with relative age older than the ring dyke intrusion, while the Mo-mineralization and phyllic alteration seem to be related to late events in the deeper part of the evolving caldera.

REFERENCES

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As florestas precedem os povos, os desertos seguem-nos.

Chateaubriand