Bergvesenet

Postboks 3021, N-7441 Trondheim

Rapportarkivet

Bergvesenet rapport nr	Intern Journal nr	Internt arkiv nr	Rapport lokalisering	Gradering
4658	0872/98			Fortrolig

Kommer fra ..arkiv	Ekstern rapport nr	Oversendt fra	Fortrolig pga	Fortrolig fra dato:
		Mindex ASA	Muting	

Tittel

Memo: Disseminated Cu and high-P, magnetite mineralization in Supracrustals at Nissedal - a possible Olympic Dam-type deposit in Norway?

Forfatter	Dato År	Bedrift (Oppdragsgiver og/eller oppdragstaker)
Petersen, J. S.	1996	Mindex ASA Nordic Minerals AS

Kommune	Fylke	Bergdistrikt	1: 50 000 kartblad	1: 250 000 kartblad
Nissedal	Telemark		16133	Skien

Fagområde	Dokument type	Forekomster (forekomst, gruvefelt, undersøkelsesfelt)
Geologi		Søftestad Kleivåsen

Råstoffgruppe	Rastofftype
Malm/metall	Fe Au Ce

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

Olympic Dam-type deposit?

MEMO:

Disseminated Cu and high-P, magnetite mineralization in Supracrustals at Nissedal - a possible Olympic Dam-type deposit in Norway?

Nordic Minerals as -1996.
J.S. Petersen

Summary:
Olympic Dam-type deposit has been proposed for a suite of unusually large, ore deposits formed by of igneous-hydrothermal systems, tapped through deep crustal structures. The ore deposits are usually associated with intense Fe-metasomatism and pervasive alteration of host rock assemblages and ore bodies form discordans veins and breccias as well as massive concordant horizons (e.g. Hitzmann 1990). Kiruna-type magnetite deposits have been suggested as a subtype of this suite of mineralizations (Hitzman et al., 1992). Olympic Dam-type deposits form economic Cu-Au-REE mineralizations associated with high-P, low-Ti, Fe-deposits.

Recent detailed mapping and prospecting in the Nissedal area by us since 1995 has brought attention to mineralization features, not be previously reported, which may have economic potential. The discovery of disseminated chalcopyrite, locally abundant, in a variety of altered supracrustal rock types in the Kleivaasen area during field work in 1996 is particularly important in this respect. In addition, the presence of both massive vein, qz-magnetite breccias and disseminated, euhedral magnetite, impregnated homogeneously throughout many of the host rocks are other significant features.

The Søftestad magnetite deposit in Nissedal, is a typical Kiruna-type magnetite-hematite deposit with high-P and low-Ti (Svinndal, 1977). Recent litterature has pointed to analogies between many Kiruna-type iron deposits and the giant Olympic Dam, hydrothermal hematite breccia deposit in Australia and elsewhere (e.g. Hitzman et al.,, 1992). In a recent study of the Søftestad deposit it has been demonstrated that contact relations are inconsistent with either a magmatic or exhalative origin, as previously suggested for the Søftestad deposit, and the mineralization exhibits textural and field evidence of being a hydrothermal replacement deposit hosted in highly altered country rocks (Mesfun, 1996).

Kleivaasen, located less than 3 km North of Søftestad, exhibits a remarkably large magnetic anomaly, which has the geometrical signature of an upright cylinder or pipe. The fact that several magnetite-veins and cross-cutting magnetite-quartz breccies occur in and around the Kleivaasen area which consists of Proterozoic supracrustal rocks, points to a possible analogy with the setting of Olympic Dam deposits. The recent recognition of disseminated Cu- and iron-oxide mineralization at Kleivaasen therefore makes the comparison with Olympic Dam-type deposits a particularly attractive possibility, as a giant magnetite replacement orebody with disseminated Cu and possibly Au. The economic upside of such an ore deposit would be +1000 mill tons with 0.3-0.5 % Cu and 0,5-1 ppm Au, and would classify a discovery among world-class deposits elsewhere.

Geological setting of the Nissedal area

The geology of the Nissedal area has been previously presented by Mitchell (1967). The Nissedal supracrustal area constitutes an outlier of metavolcanic and sedimentary rocks completely surrounded by Setesdal granitic gneisses. The supracrustal rocks belong to the Telemark Supergroup (Dons, 1960) and several authors have correlated the series with the lowermost portion of the Telemark series: Rjukan Group (Dons, 1960; Torske, 1980), which consist of a lower acid-volcanic series: the Tuddal Formation and an upper basic-volcanic series: the Vemork formation. There is no direct connection between the proper Telemark rocks and the Nissedal supracrustal outlier and the correlation is not obvious from simple lithological comparison. The Rjukan formation formed in a time interval between 1500 Ma and 1200 Ma, the latter dating refers to the deposition of Bandak Group supracrustals in SW Telemark which form the youngest series. More detailed studies regarding lithologies, structures and exploration in the Nissedal outlier have been presented in: Grahl-Madsen & Bech (1983); Ekremsæter (1983); Carter et al. (1984); Bielak (1984); Juve & Wilberg (1984).

During the Sweconorwegian orogeny around 1000 Ma, the supracrustal rocks were metamorphosed in lower amphibolite facies and subsequently invaded by post kinematic granite (Tørdal granite ~950 Ma) and numerous pegmatites. Many of the cleavelandite-amazonite pegmatites in the Nissedal-Tørdal area are famous for their rare metal assemblages including Sc, Ta, Nb, Sn, REE, Be and others (e.g. Bergstøl & Juve, 1988).

The Supracrustal rocks of the Nissedal outlier may have been preserved as a result of normal faulting in a roughly SW-NE trending rift basin. Large fault contacts along the northern border of the outlier support this view. The SW-NE trending fault direction is a prominent lineament in the Telemark Supracrustal area. The direction is parallel to a major fault-direction in South Norway: the Great Friction Breccie in the Bamble region and the faulting is possibly related to relaxation rifting along this zone following the Sweconorwegian Orogeny.

The Kleivaasen area.

The geologic setting of the Kleivaasen area is still uncertain as detailed mapping in scale 1:5000 is currently in progress. The majority of rocks consist of EW trending, folded metabasic rocks, mostly metabasalts and basic tuffs with a number of metadolerites and metagabbroic bodies. Intermingled with these are felsic units (leptites) which can be recognized as felsic metavolcanics, because of relict flow banding with oriented trails of quartz-feldspar phenocrysts. A few horizons of metasandstones, andesitic tuffs and other colcaniclastic rocks have also been encountered, but mapping has not yet succeded in tracing the distribution of these. Furthermore, ultramafic rocks occur as narrow layers, which may be metamorphosed ultramafic cumulates of the metagabbroic bodies or ultramafic rock units in their own right.

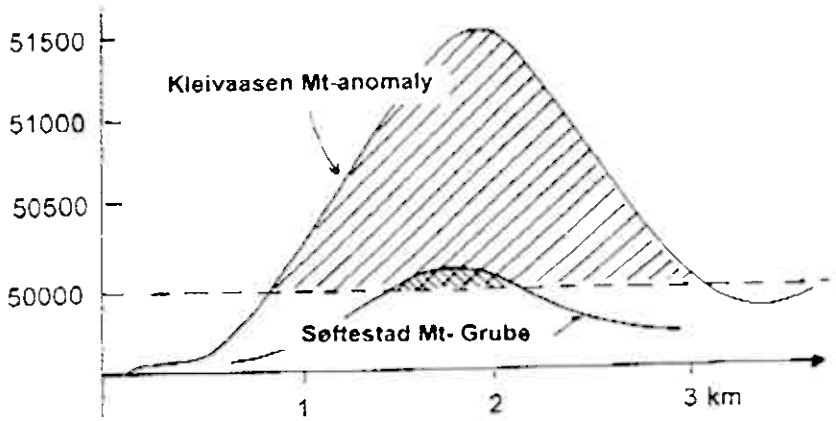
The rocks have suffered various degree hydrothermal alteration particularly in the Nissedal-Søftestad area. The common presence of "ödegaardite", which is a coarse

grained recrystallized and altered metagabbro, now appearing as a hornblende-scapolith rock with abundant apatite, is an example of altered gabbros, whereas felsic rocks become variably silicified and sericitized. As the mapping is not complete, more detailed account for the alterations and altered rocks will not be included here.

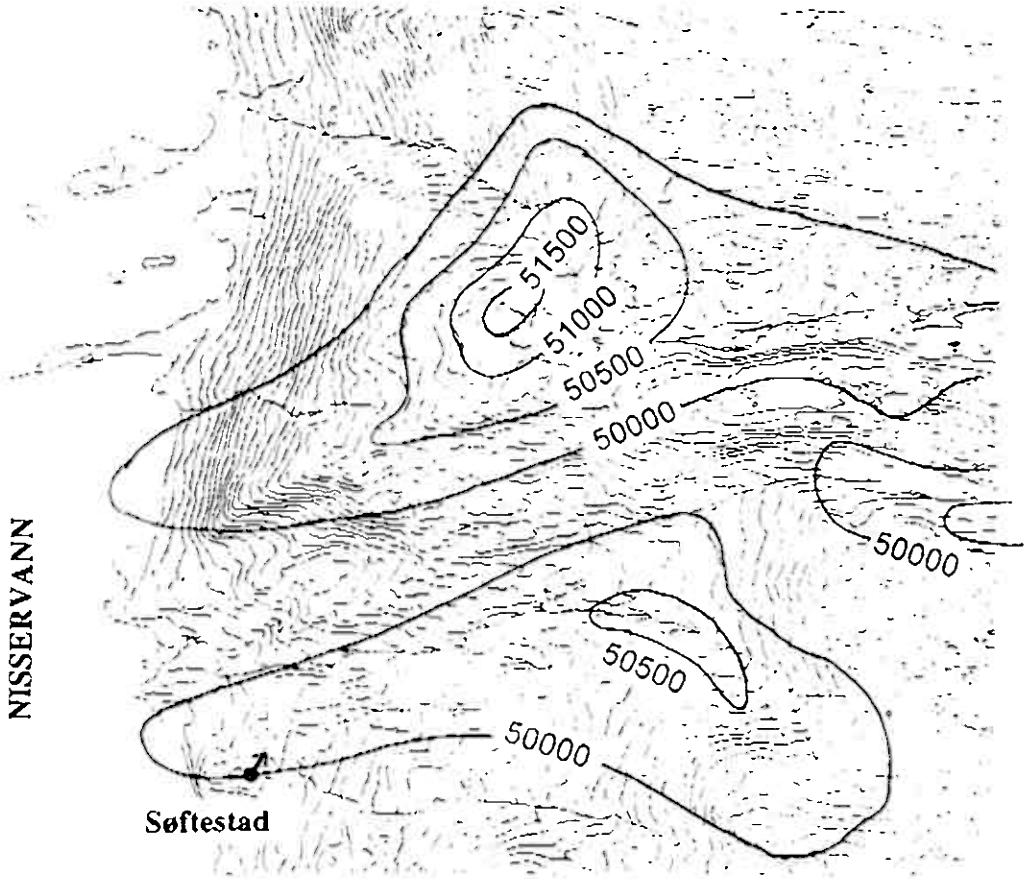
Geophysical Structure

The aeromagnetic map of Nissedal (1613-III) reveals an interesting pattern. A moderate, positive magnetic band with a broadly circular outline is seen in the central part of the Map Sheet, in contrast to the rest of the Sheet which has a quiet magnetic pattern around 49500 gamma. Near the center of this circular band is the Søftestad deposit, located on the southern margin of a smaller, central, cusp-shaped anomaly marked by the contour of 50000 gamma. This anomaly follows the outline of the drainage in the area and increases slightly as the topography lowers in a major stream. The anomaly picture is conformable with a topograpic unroofing of a flat-lying magnetic source of moderate field strength. There is no obvious correlation between the anomaly pattern and the distribution of different rock types in the area. The magnetic field intensity is trending E-W whereas the Søftestad deposit strikes roughly N-S and dips to the east.

Along the northern rim of the large circular magnetic band, there is a remarkably strong anomaly which peaks at more than 51500 gammas (Fig 1, page 4). This anomaly is nearly symmetrical in all directions and has an outline of more than 2 km^2 when measured by the 50500 gamma contour. In contrast to the smaller Søftestad anomaly however, which can be explained by topographical unroofing of a subhorizontal magnetic source, this anomaly is located near the crest of the highest topography in the area and therefore represent a considerable magnetic source. (The NGU aeromagnetics were flown at constant height between 100 and 150 m and therefore has been corrected for topography). Figure 2 below presents a profile of this MAG-anomaly with the Søftestad anomaly shown for comparison. The magnitude of this magnetic source is clearly substantial and calls for an extraordinary and local source. Since the anomaly rises with the topography it also represents a cylinder-shaped body which points towards the surface, rather than a layer or a flat, broad source as some intrusives might produce. A possible interpretation of this anomaly would be a pipe or stock with highly magnetic material.



Aeromagnetic Map:
Kleivaasen Area, Nisssedal
1:50.000



Mineralization
a) Iron-ores

The Søftestad deposit is a typical Kiruna-type iron deposit with low-Ti and high-P. The proven reserves are small, c. 500.000 t with 55% Fe and 1.7 % P and the ore body consist of three lenses with an accumulated length of 450m and a width of 1-3m (Bugge 1978). Previous investigators have suggested Søftestad to be magmatic in origin, mainly because of its dike like appearance and high P-content, derived from a gabbroic magma.(Vogt, 1895, Bugge, 1978) or a volcanic source (Svinndal, 1977). Other workers (Kvien, 1961) have additionally proposed an exhalative origin because of its layered and grossly concordant nature. Søftestad therefore shares some of the controversies on origin that characterizes the Kiruna - Malmberget (Gällivare) deposits in Northern Sweden.

A recent study of Søftestad has drawn attention to several contact relations which suggest that neither of the earlier theories of origin are entirely valid (Mesfun, 1996). The author emphasized a transgressive nature of the iron-oxides in the deposit, and recognized a highly altered state both the hanging wall and footwall gneisses. Substantial Na-alteration was demonstrated geochemically in both footwall and hanging wall gneisses and therefore discredits an exhalative origin. The transgressive oxides are attributed to replacement textures where silicates seem replaced by iron oxides. The author has suggested, with reference to recent litterature (e.g. Hitzman et al., 1992) that Søftestad can be interpreted as a hydrothemal replacement deposit, formed by intensive Fe-metasomatism along well defined, and possibly *en echelon* displaced, zones of weakness.

The study also emphasizes the high amount of REE mostly associated with high amounts of apatite (5-20%) but also through the presence of Monazite (Ce, La, Th)PO_4 within the apatite-rich ore bands. This clearly points to an association with other Fe-P-REE deposits as pointed out by Hitzmann and coworkers. The amount of sulfides is low at Søftestad proper and the deposit classifies as a typical Kiruna high-P, magnetite-hematite deposit.

In addition to the Søftestad deposit it must be added that new mapping has demonstrated massive magnetite veins at several other locations in the Nissedal district. A minor magnetite deposit was mined previously just north of Nissedal settlement in the steep hill side of Kleivaasen. The detailed mapping has revealed several dm-wide veins of massive magnetite in a variety of rock types, including amphibolite, metarhyolite and grey tuffites, particularly around the Kleivaasen anomalous area. In addition, a number of irregular quartz-magnetite "blow-outs" have been recognized, in the area which surround the magnetic anomaly at Kleivaasen.

A final type of magnetite occurrence, which must be mentioned here, is the presence of heavily magnetite impregnated tuffites and sandstones near the Kleivaasen area. The magnetite form mm-sized, euhedral grains homogeneously disseminated throughout host rocks. This magnetite is clearly secondary and may have formed through intense metasomatic alteration of the original rocks. In some areas it resembles the oxide-alteration halo of certain diorite-type porphyry systems.

Field work is still in progress and the observations are patchy and do not allow for a general interpretation, although there seems to be a clear spatial association between the geophysical anomaly and many of the highly altered rocks and the magnetite mineralization.

Cu-mineralization

One of the most encouraging discoveries in the Kleivaasen area, is the presence of disseminated Cu-mineralization in a variety of rocks ranging from metabasalt, andesite tuffs and grey, arkosic metasandstones. The Cu is found mainly as chalcopyrite occurring in amounts of up to several pct. Polished sections show that the chalcopyrite is secondary and replace the host minerals. In some strongly magnetite-altered andesitic tuffs, chalcopyrite is found in many qz-amygdales as well as in minor fractures, showing the the rock was solid when the Cu-mineralization was introduced.

The Cu-mineralization, which was discovered during field work in 1996, has not been noted in previous litterature, presumably to its disseminated nature and contents below 1-2% and presumably rare examples of coarse remobilization, which often attracted the early prospectors.

Clearly, the recognition of disseminated Cu-mineralization in this environment is important. The association of large iron-deposits and disseminated Cu-deposits is already known from Scandinavia where Europes largest Cu-deposit: Aitik in Northern Sweden is located only a few km from the Gällivara-Malmberget magnetite-hematite deposit. The association is also an integral part of Olympic Dam deposits, sensu stricto, where the large size of the deposit allows for exploitation of very low grade (ca 0.35% Cu at Aitik).

Detailed prospecting and a combination of stream and soil sediment sampling is required to examine the distribution of Cu-mineralization in the area, where minor massive Cu-sulfide mineralization has been mentioned in previous litterature (e.g. Bergstøl & Juve, 1988). It is interesting to note that Arco Norway's sediment program detected gold anomalies in the area but were unable to locate their primary source (Grahl-Madsen & Bech, 1983).

Conclusion:

The Nissedal area and in particular the Kleivaasen concession has a number of features in common with typical Olympic Dam-type deposits elsewhere. These include a large magnetic anomaly, abundant magnetite mineralization of high-P low-Ti type and associated with disseminated Cu mineralization in highly altered country rocks occurring in a broad suite of rocks. The magnitude of the magnetic anomaly and the size of the anomalous area may point to a mineralized potential of extraordinary dimensions. A testing of this indication is important and should include geophysical, geochemical and geological mapping. Below is a comparison of salient features of Olympic Dam deposits compared with recognized features of the Kleivaasen area.

Summary of characteristics:

Olympic Dam-type Fe-Cu-Au deposits:

- Shallow, extensional environments: Cratonic or Continental Margin
- Mid-Proterozoic age: between 1.1 - 1.8 Ga
- Large igneous-hydrothermal systems tapped by deep crustal structures
- Associated with low-Ti, high-P, iron-deposits (~Kiruna type)
- Oxides dominated by magnetite in deep-levels and hematite in high-levels.
- Alteration of host rock generally associated with intense Fe-metasomatism.
- Ore forms discordant veins and breccias to massive concordant horizons with disseminated Fe-Cu-Au minerals.

Kleivaasen Target:

- Occurs in a major, shallow extensional environment with abundant volcanic supracrustals (Telemark Supergroup, Nissedal Group)
- Mid-Proterozic age ~1.6 - 1.2 Ga
- Søftestad Fe-Gruve near Kleivaasen is a Kiruna-type high-P, iron deposit.
- The Søftestad ore is a massive magnetite(-hematite) deposit.
- Highly altered host rocks are seriticized and silicified with intensive Mt-impregnation
- Abundant disseminated chalcopyrite and magnetite occurs in the MAG-anomalous area.

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