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MINING SECTION
EXPLORATION

GULF ORKLA
LØKKEN VENTURE

Report no: LV 22 Date: April 5.,1984

Title: The Segelvann-Svinsås area:
Geological and lithogeochemical
investigations

O R K L A I N D U S T R I E R A.s

MINING SECTION, EXPLORATION

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geological and lithogeochemical investigations

Prepared by: Tor Grenne Area: Segelvann-Svinsås

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Summary:

Detailed geological mapping has been carried out in the area between lake Segelvann in the north and Svinsås in the south. Most of the metevolcanic pile is represented in the area, although the inverted sequence is highly dissected by faults and thrusts. The mapping, together with a lithogeochemical survey, has revealed several zones of weak mineralization and minor, local alteration. Most of these zones probably represent 'failed' hydrothermal feeder-zones, where the metal-sulphide content of the solutions precipitated at depth, below the sea-floor, as irregular thin veins and disseminations. One zone stretching ENE from the lake Bjørtjønna, through the lower part of the metabasaltic pile, may possibly reflect a major hydrothermal upflow zone, although the degree of alteration is also here lower than would be expected in the very deep parts of such zones.

Key words: Lava types, hydrothermal activity, lithogeochemistry, faults.

TABLE OF CONTENTS

ENCLOSURES

5. Ti-Cr discrimination diagram
6. Frequency distributions
   - 6.1 SiO_2-Al_2O_3
   - 6.2 Fe_2O_3-MgO
   - 6.3 CaO-Na_2O
   - 6.4 K_2O-Mn
   - 6.5 TiO_2-P_2O_5
   - 6.6 Zr-Y
   - 6.7 Sr-Ba
   - 6.8 Cr-Ni
   - 6.9 V-Co
   - 6.10 Zn-Cu
   - 6.11 S-Pb
   - 6.12 B-Hg

7. Cumulative frequency diagrams
   - 7.1 SiO_2
   - 7.2 Al_2O_3
   - 7.3 Fe_2O_3
   - 7.4 MgO
   - 7.5 CaO
   - 7.6 Na_2O
   - 7.7 K_2O
   - 7.8 Mn
   - 7.9 TiO_2
   - 7.10 P_2O_5
   - 7.11 Zr
   - 7.12 Y
   - 7.13 Sr

INTRODUCTION

The Segelvann-Svinsås area is situated some 5 to 8 km west of Løkken, limited to the east and west by the river Orkla and the N-S trending valley just east of Dragset mine; to the north and south approximately by lake Segelvann and the brook Spjøtåa (se map, encl.1). This area has received a good deal of attention particularly in the past three-four decades, mainly because it is situated immediately west of the western termination of the Løkken orebody, and a possible extension of the ore has been thought to occur somewhere at depth in this area. Several Turam geophysical surveys were performed by NGU during 1959-60 (NGU reports no 235A, 256A, 289), from which a large number of EM anomalies were detected. A stream sediment geochemical survey was also done by NGU in 1969 (NGU report no 886), however, no significant anomalies were found. Geological mapping has been mostly of regional character; investigations in the period 1965-67 by E.H.Rutter, R.Chaplow and J.E.Matthews resulted in a geological map in the scale 1:30.000 that covered essentially the area from just east of the Løkken valley to west of Dragset mine (Norges Geol.Unders., nr. 255, p. 21-36). The northern part of the area was the object of renewed interest from 1979, when a series of deep-seismic reflection surveys were performed (Report no. LV9) with the purpose to detect a possible deeply buried extension of the Løkken orebody. AMT measurements were done contemporaneously with these investigations in the same area (Report no. LV 8). On the basis of seismic and partly also AMT anomalies, three drill-holes were drilled in 1981-82, however, with negative results (Report no. LV 13). The most recent investigations in the Segelvann-Svinsås area have, as a consequence of the results in the northern part around lake Segelvann, been concentrated further south, essentially from the brook Druggu (Merkesbekken) southwards, where zones of sulphide-disseminated greenstones were observed already during reconnaissance mapping in 1981 (Report no. LV 5).

A prospecting programme for this southern part of the Segelvann-Svinsås area was initiated in the summer 1982, and involved detailed geological mapping in the scale 1:5.000 (reduced to 1:10.000 in enclosure no. 2), as well as a lithogeochemical study of greenstones with the aim to detect chemical alteration

patterns and primary dispersion haloes related to possible sulphide feeder-zones. Following the earliest results of the mapping, a detailed IP geophysical survey was started in June 1982, also this with the aim to find sulphide disseminations that could be relatable to sulphide feeder-zones, and if possible, determine the orientation of such zones at depth. Recognition, by mapping and IP of a broad zone of sulphide disseminations and partly veining stretching from the lake Bjørtjønna eastwards with an apparently southerly dip, was followed up by drilling from mid-August to December 1982, in an attempt to trace the possible feeder-zone and its development towards originally higher levels (stratigraphically), at depth in the inverted sequence (Report no. LV 23).

Geologically, the area covers the central to southern part of the greenstones of the Løkken Synform, in a section from north to south. The core of this large synform can be traced approximately over the hill Segelvassåsen and lake Segelvann towards lake Malisetertjønna. Immediately north of here, across a marked shear-zone, the greenstones are underlain by a thick coarse-grained gabbro. Highly deformed, steeply dipping greenstones with jasper and various chert-like interlayers then reappear north of Segelvann and Hoslynga in a ca. 500 m wide belt before stratigraphically overlying sediments probably of the Lower Hovin Group are encountered further north. Comparable but less deformed Lower Hovin sediments are overlying the inverted, north-dipping greenstone sequence in the extreme south of the investigated area, immediately south of the farm Espåslykkja. Large parts of the area, which is between 250 and 380 m above sea level, are highly covered by marshes or wooded moraines. Areas where overburden has complicated geological interpretations are marked as 'cover' on the geological map (encl. 2); elsewhere it has been attempted, as fas as possible, to draw connections between the generally scattered outcrops. Faults and zones of fracturing ore inferred largely from air photos.

GEOLOGY

Lower pillow lavas

The lowermost part of the greenstone sequence exposed in the investigated area comprise mainly pillow lavas intruded by numerous basic dykes and sills. Characteristically these pillow lavas are non-vesicular or contain only a few very small vesicles along the rims. Variolitic varieties are common, but these structures are found also higher up in the volcanic pile. A feature characteristic of the lower lavas however, is the commonly very irregular shape of the pillows. Large and small pillows of varying forms often occur together, and each pillow is usually surrounded by a relatively thick zone of hyalocalstite, comprising a mixture of glass shards and larger fragments of pillow crusts. Due to their irregular pillows shape, such flows which are reminiscent of so-called 'knobbly pillow lavas' (see discussion, p), are often difficult or impossible to use as way-up indicators. The lavas of this type are found north of the marsh Dammyra and the southern end of lake Bjørtjønna, northwards to the lakes Drugguvatnet and Nedre Gruvedam. To the east and northeast this zone is limited by a series of faults, but apparently similar lavas reappear further east, across the marked N-S trending fault near Kloppåslykkja (see map, encl. 2).

Upper pillow lavas and massive flows

Alternating pillowed and massive greenstones with thin interbedded jaspers, vasskis and related sediments and also relatively local greenstone breccias, constitute the middle and upper portions of the volcanic pile. Although some of the massive, coarse-grained greenstones may be of intrusive character, it is apparent that the majority are lava flows. Many of them are moderately vesicular like the pillow lavas here, particularly in the upper parts of the flow-units. The massive greenstones apparently pass into pillowed flows towards the top of individual flow units; in some cases also lateral transitions into pillowed lavas can be demonstrated, with interfingering relationships between the massive and pillowed parts

of what was probably the same flow unit. Characteristic of the pillowed flows in this upper portion of the volcanic sequence is a very close packing and a regular morphology of the individual pillows, commonly with the typical 'pedunculate' shaped cross-sections allowing very reliable way-up determinations. Pillow margins are normally thin with very litte or no hyaloclastite between the pillows. However, broken pillow breccias occur locally, apparently separating different lava flows. Highly variolitic pillow lavas are found also in this part of the stratigraphy; in particular they are abundant in the pillowed upper parts of the very thick, dominantly unpillowed flows that are overlying the jasper and vasskis horizons west and southwest of Svinsås. (encl. no. 2). The lavas here apparently have the definitely greatest flow thickness recorded in the investigated area. It must be emphasized however, in view of the rapid chilling of submarine basalts which consequently are likely to show rapid lateral variations in thickness, that this is not necessarily a general stratigraphic feature, but possibly a reflection of varying proximity to the volcanic 'centers' or vents.

Mafic intrusive rocks

Greenstone dykes with compositions comparable to those of the lavas are found throughout the volcanic sequence. They are, however, definitely most frequent in the lower portion of the pile in the area south of the lake Langdalsvatnet (see map, encl. no. 2). Ranging in thickness from a few centimetres to more than a metre, they intrude lavas or other dykes with clear, fine-grained chilled margins. Central parts are usually more coarse-grained, depending on the thickness of the intrusions. Thin or thicker off-shoots are common out from the otherwise relatively regular fine-grained margins. Flowbanding with zones of varying grain-size can be seen locally, particularly along the chilled contacts of the dykes. Feldspar-phyric varieties do occur (similar to some lavas), with 1 - 3 mm plagioclase phenocrysts set in a fine-grained groundmass. Many of these intrusions are obviously sill-like rather than true dykes, occuring subparallel or obliquely to the bedding planes. In the lower pillow lavas south of Langdalsvatn, however, a high

proportion are clearly perpendicular to the igneous layering. The majority of these of which many are multiple dykes, strike in a SW-NE direction with comparatively steep SE dips (see map, encl. no. 2), such that intersection lineations between the bedding plane and the probable lava feeder fissures plunge approximately towards east in this area.

Greenstone-jasper breccias

Breccia units composed essentially of angular greenstone clasts with local jasper in a finer grained green matrix are found within the middle to upper part of the volcanic sequence particularly to the south in the mapped area. At one locality, west of the hill to the north of the marsh Dammyra, a comparable breccia contains also fragments of a coarse dolerite or gabbro together with trondhjemite-like rocks. The units range in thickness from a few metres up some 20 m, and appear to form discontinuous, relatively local depositions along strike, at two stratigraphic levels separated by some 100 - 200 m of lavas. Nearly all breccias are evidently closely related to horizons of jasper, and they may occur both immediately below or on top of (or locally within) jasper beds.

Jasper

More or less continuous beds of jasper are found at several stratigraphic levels within the middle to upper part of the volcanic sequence. Some of them are not more than a couple of centimetres in thickness, while those occuring immediately west and south of Svinsås have an apparent thickness of up to 50 metres. The jaspers are usually very fine-grained with a massive, relatively homogeneous appearance. Although hematite is the main iron oxide of the red to reddish-brown or reddish-blue rock, considerable amounts of magnetite may be present in places, especially in the thick jasper near Svinsås.

Vasskis

Vasskis and associated 'svartfjell' and cherts are found in two widely separated parts of the investigated area: one near lake Litlvatnet to the north (see map, encl. no. 2 and report no. LV6), the other one related to the level of very thick jaspers west and south of Svinsås in the southern part of the area. Here millimetre to centimetre thick compact laminae of very fine-grained pyrite with subordinate pyrrhotite alternate with layers of 'svartfjell' (often magnetite-bearing) in sedimentary units up to a few metres thick. Normally the vasskis/svartfjell horizons rest directly upon (stratigraphically) the jasper beds although it is possible that jasper may locally also overly the vasskis layers.

Later intrusives

Two types of non-basaltic rocks are found as small, relatively local bodies within the mapped area. Thin quartz-porphyrites or quartz keratophyres west of Svinsås are probably genetically related to the larger massif of acid porphyritic and felsitic rocks occuring to the northeast in the Segelvann area, and may in part be of effusive origin. A quartz-feldspar porphyrite dyke in greenstones near the brook Druggu - Merkesbekken in the north appears to be more like trondhjemitic rocks that intrude and postdate the greenstone sequence elsewhere in the Løkken area. A NNE-trending dyke of Hølonda porphyrite, with characteristic large euhedral feldspar phenocrysts, transects pillow lavas at one locality NE of Svinsås, in the eastern part of the area.

Alteration and zones of sulphide disseminations

Minor zones of pyrite disseminations occur locally in the greenstones immediately underlying the jasper horizons south in the area, west and south of Svinsås and partly also northeast of Dammyra (see map, encl. no. 2). In a few places thin veins of comparatively coarse-grained pyrite can be seen. Trace amounts of chalcopyrite have been found in these zones quite locally, and

comparable zones rich in magnetite also accur. Many of these mineralizations are accompanied by some alteration of the host-rocks, commonly to darker green or occasionally very light greyish varieties. This is to a certain extent reflected also by the greenstone geochemistry; for instance, Na_2O may be both depleted and enriched in these rocks, CaO may show some depletion and a trace element like Cr is commonly highly depleted (Encl. 3) However, none of the analysed rocks from such zones show the chemical patterns that charaterize variously altered basalts in the feeder-zones related to massive sulphide ores in the district. Moreover, also the apparently very limited extension towards depth, of the mineralized zones subjacent to the jaspers indicate that they do not represent major feeder channels.

A wide belt of marked increase in sulphide content of the greenstones is found also in an easterly derection from lake Bjørtjønna, and partly to the south and north of this areas (see map, encl. no. 2). Here dominantly pyrrhotite with subordinate pyrite and locally traces of chalcopyrite form disseminations and in places thin interconnected veins in zones transecting the lower pillow lavas, apparently far from jasper horizons and probably of another type than those described above. The mineralization is commonly found within, or along the margins of, basic dykes and sills in the greenstones.

Another type of alteration is found locally in the stratigraphically upper lavas, which are sometimes highly oxidized to reddish-brown hematite-rich metabasalts or magnetite-bearing varieties. Such rocks can be seen in the small hill just north of the farm Svinsås (sample 417) as well as in the greenstones east/south of Svinsås. Similarly altered greenstone fragments occur in the breccias within the Lower Hovin sediments overlying the sequence to the south.

Structural relationships

Bedding planes within the mapped area are generally dipping 30-40^{o} to the NNE. Folding is rarely seen in outcrops, and the rocks appear to be only slightly affected by deformation, although the sequence is obviously inverted, with younging direction to the

south. Only occasionally can jaspers be traced along apparent fold structures, such as those immediately SW of Svinsås and north of Dammyra. Here, right way up structures in pillow lavas can locally be seen in the strongly sheared short limbs of the possible folds. Otherwise, foliated greenstones are found in relatively local shear zones through the whole area. Foliation planes strike in about the same direction as the bedding, but genarally with somewhat more gentle dips. The contact between the greenstones and the sediments to the south is apparently tectonic, and although it is completely covered it seems likely that this reflects some thrusting along such sheer-zones as mentioned above.

The whole area is dissected by faults and zones of fracturing. Most conspicuous topographically are the N-S-trending faults, particulary the one through the lakes Bjørtjønna - Gruvedammen.
A set of SE-NW trending faults, with moderate NE dips, are apparently conjugate to the N-S-faults. Faults and fractures which strike about E-W postdate these early movements. Where observed in this area, the dips of the E-W trending faults are consistently at about 40-50^{o} to the north. Sets of such faults are found particularly along the topographic depressions stretching from Blokkum towards lake Druguvatnet, and across Dammyra - Lomtjønna just north to NW of Svinsås. Here ½ m - 1 m thick zones of extensive crushing, with abundant clay material, can be seen in road-cuttings.Very long fractures, apparently with very little or no faulting are trending ca. SE-NW to ESE-WNW and seem to be later than also the E-W faults. Zones of closely-spaced thin fractures appear to be parallel with these latest structures, with steep SSW dips.

The relative movements along the various faults are difficult to estimate due to the lack of good marker horizons. Assuming normal-faulting (based on the minor displacements of the steeply dipping shear-zones north of the mapped area), and on the basis of correlation between jasper horizons, it seems likely that the area W of the N-S-trending Bjørtj.-Gruvedam fault has moved upwards in relation to the area immediately E of the fault. Similarly the rocks from Svinsås northwards to Litlvatnet and Mjovatnet have

probably been 'up-faulted' in relation to the rocks E and W-SW of this region.

LITHOGEOCHEMISTRY

Sampling and anolytical techniques

171 greenstone samples were collected for a lithogeochemical survey of the investigated area. Sampling was done by sledge hammer; highly weathered and rusty rock surfaces were removed. Each sample comprised 1-4 representative hand-specimens, totally averaging ½ kg, of relatively homogeneous greentone from the locality; avoiding hyaloclastites, pillow rims and sediments. The samples were collected essentially along 5 profiles approximatley perpendicular to the strike of the layering. Profile spacing was about 500 m, sample interval along the profiles averaged ca. 50 m.

All analyses were performed by Bondar-Clegg & Co. Ltd., Ottawa, Canada, using X-ray fluorescence, atomic absorbtion spectroscopy (after multi-acid total digestion), DC-Plasma and specific ion techniques (see enclosure 3). All 171 samples were analysed for Cu, Pb, Zn, Co, Ni, Mn, Cr, Hg, B and S; 36 of these samples were also analysed for SiO_2, Al_2O_3, Fe_2O_3 (total iron) TiO_2, MgO, CaO, Na_2O, K_2O, P_2O_5, Sr, Rb, Ba, V, Zr and Y. Cl was measured in every 10 samples; the concentrations were however below the detection limit of 200 ppm.

Stratigraphic variations

The 36 samples analysed for both major and trace elements have been divided into groups of 'normal' and 'altered' greenstones on the basis of a field examination of the samples and localities. Furthermore the same samples have been grouped into 'upper' and 'lower' greenstones according to their stratigraphic position where this was clear. Where plotted in the well-known discrimination diagrams of Pearce and Cann (enclosure no 4 and 5), these analyses demonstrate clearly the ocean-floor tholeiite chemistry of the

greenstones from this area. The analyses conform well to previous data from the Løkken greenstones. A tendency to plot above the OFB field in the Ti-Zr diagram may be ascribed to slightly too high TiO_2 or too low Zr values obtained by these semi-quantitative analyses. The Ti-Cr diagram shows that the 'altered' greenstones are relatively depleted in Cr compared to the 'normal' rocks, also this in accordance with previous studies which indicate commonly a loss of Cr during strong spilitic alteration of the basalts. As indicated by the Ti-Zr diagram, there is a marked tendency to a more 'primitive' composition of the upper greenstones as compared to the lowers, with significantly lower TiO_2 and Zr values in the former group. These stratigraphic differences are also reflected by other elements, such as P_2O_5, Y, total iron as Fe_2O_3, and to some extent Cr. The bimodal distribution (Encl. 6) of TiO_2, P_2O_5, Y, Fe_2O_3 and Zr (not so well-defined) is clearly related to the straigraphic variations. Most of this is a primary chemical feature of the basalt sequence. It is obvious that such variations in the original basalt composition, which are likely to be found - to greater or lesser extent - for all elements, must be taken into account in the discussion of possible geochemical alteration patterns.

Geochemical alteration

The greenstone analyses do not indicate significant alteration that may be related to major sulphide feeder-zones. The variations in major elements are well within the limits of what can be expected as 'background alteration', i.e. alteration not necessarily related to major upflow zones in hydrothermal systems. CaO and Na_2O for instance, are strongly affected by alteration in the presence of water, under various temperature conditions, and their relatively small depletions and enrichments seen here do not alone signify particularly interesting hydrothermal conditions. Likewise, K_2O, which is commonly highly enriched in the uppermost parts of sulphide feeder-zones, may also be considerably enriched during low-temperature alteration nearly anywhere in the basalts. Low-temperature K_2O enrichment is however most likely to occur in the stratigraphic upper parts of the basalt sequence. Here it

should also be noted that large positive K_2O 'anomalies' may also be due to accidental sampling of 'greenstones' which are not directly related to the Løkken metabasalts, for instance later diabase dykes of calc-alkaline composition where the high K_2O is essentially a primary feature. The relatively large variations in Sr also reflect the mobility of the alkali and alkaline earth elements during alteration, although strong depletions characteristic of major feeder-zones have not been detected here.
Cr is strongly depleted in several of the samples. Although Cr has generally been considered as a 'stable' trace element, and although it is very susceptible to primary magmatic depletion by crystal fractionation of certain phases, there appears (in the Løkken region, including the Svinsås area) to be a marked negative correlation between Cr and the 'degree of spilitization', as expressed by the Na_2O/CaO ratio. Cr depletion is found at many localities in 'spilitic' greenstones to the south, stratigraphically below the thick jaspers at Svinsås. Low Cr abundances also charachertize the belt of increased sulphide mineralization stretching ENE from the lake Bjørtjønna. This may indicate more extensive hydrothermal activity here. It must be emphasized however, that this latter zone is within the area of stratigraphic lower lavas which are originally more fractionated and thus more likely to hve low primary Cr concentrations. Nickel shows an abundance pattern essentially similar to that of Cr, while Co shows only small and insignificant variations.

Manganese is generally within the range of normal basaltic compositions, but a few marked anomalies are found in the southern part of the area. Here both high and low values may indicate some hydrothermal activity with deposition or depletion of Mn depending on the physico-chemical conditions. In the same rocks, Na_2O and K_2O are somewhat depleted and enriched, respectively, however without any large-scale alteration of the chemical composition.

Pb and Zn are sporadically slightly enriched in the southern part of the area, mainly stratigraphically below the Svinsås jaspers. Relatively high values are found also along the mineralized belt stretching ENE from Bjørtjønna, as well as local anomalies just east of Gruvedammen to the north and stratigraphically just below

jaspers north of Dammyra (NW of Svinsås). Although Cu shows a more uniform distribution, small positive anomalies also of this element have been detected near Gruvedammen and Dammyra, the last two anomalies localities mentioned above. Sulphur is also locally enriched to the south as well as near Gruvedammen. Most conspicuous, however, is the sulphur anomaly ENE-wards from Bjørtjønna. Boron and mercury have very regular distribution patterns; B showing only one signifacant anomaly just W of the lake Druguvatnet, Hg showing a possible zone of slight enrichment just north of the Svinsås jaspers.

CONSLUSIONS

The investigated area comprises a thick sequence of submarine metabasalts, which can be divided into:

- A stratigraphic lower part consisting of more and less irregular generally non-vesicular pillow lavas with abundant hyaloclastites and a high density of basic dykes and sills. Geochemically these lavas are somewhat fractionated.

- An upper portion of alternating thick massive fows and close-packed pillow flows indicative of increased eruption rates and more voluminous eruptions. These lavas, which may be fairly vesicular, are less fractionated than the lower ones, with lower values of stable incompatible elements, total iron etc. Acid flows (quartz keratophyres or 'felsites') are locally found among the upper lavas, although they are very sparse (except in the Segelvatn area to the NE).

  Within the series of upper lavas can be recognized at least 3 periods of accumulation of thick jaspers on the see-floor. Greenstone (-jasper) breccias interpreted as talus deposits are locally associated with these horizons. 'Vasskis' (sulphide/oxide/silicate iron-formations) occurs stratigraphically on top of or slightly above the middle, and decidedly thickest jasper horizon west of Svinsås.

- The greenstones are stratigraphically overlain in the south by lower Hovin sediments.

The rocks are generally fairly little deformed, although the sequence is completely inverted, showing way up to the south. Stronger deformation is restricted to relatively local WNW-ESE striking
shear-zones with moderate NNE dips. Evidence of folding is found only rarely, although this may in part be due to the general lack of good marker horizons. The greenstone/sediment contact to the south is apparently tectonic, and it is tentatively suggested that thrusting along this contact has moved the greenstones southwards in relation to the sediments, such that a part of the original stratigraphic sequence is now lacking here. It is also possible that this zone corresponds to the shear-zone (or zones) which is traceable from Damlia further east, bending around the hill Høgåsen before it turns north towards Fagerlivatnet/Bjørnlivatnet, where it also appears above the Løkken orebody.

The area is highly dissected by faults of several generations. Most conspicuous are extensive N-S trending faults with a set of NW-SE trending conjugate faults. Considerable normal movements have taken place along some of these faults, with alternating up- and downward movements of the various segments, in a horst- and graben-like manner. Sub-parallel sets of E-W to ESE-WNW trending faults with moderate northerly dips postdate the early movements; movements along the latter zones appear to be appreciably smaller in most cases although individual zones of extensive crushing and clay formation are up to one metre wide.

The lithogeochemical survey performed does not indicate the presence of major hydrothermal feeder-zones in the area. However, a wide zone of increased sulphide disseminations and minor geochemical anomalies is found ENE-wards from the lake Bjørtjønna, cutting the stratigraphic lower part of the lava sequence. Local, minor alteration and Cu, Zn, Pb, S, B, Hg, Cr and Ni anomalies occur up to 400-500 m north of the thickest Svinsås jaspers (i.e. stratigraphically below the jaspers). It is suggested that this relates to precipitation from accending hydrothermal solutions, in many small hydrothermal

systems. High influx of normal sea water through permeable zones/horizons in the upper 400-500 m (?) of the oceanic crust led to near-complete, but very dispersed precipitation of sulphides at depth, whereas the hydrothermal silica could rise to the seafloor and form the very thick jasper beds seen near Svinsås. Thus, although there are several geological and geochemical indications of wide-spread, extensive hydrothermal acitivty at about the Svinsås jasper level, this activity does not at all indicate that massive sulphides were likely to form here. More favourable physical conditions for conservation of undiluted hydrothermal solutions to the seafloor might, of course, have existed in this obviously hydrothermally active area, some distance away (possibly at greater depth, along dip). It is possible, although rather speculative, that the mineralized zone stretching ENE from lake Bjørtjønna represents the deeper parts of such a hydrothermal feeder-zone, at some distance from the 'failed' hydrothermal actitity reflected near the jaspers outcropping at Svinsås. To determine the higher-level character of this possible feeder-zone, needs further geophysical- and diamond drilling (combined with lithogeochemistry) investigations.

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