The Tectonostratigraphic Setting of Stratabound Sulphide Deposits in the southern Trondheim Region, Central Norwegian Caledonides

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The large number of mainly massive, polymetallic, stratabound sulphide deposits within the southern Trondheim region are spatially confined to the different nappe units of the central Scandinavian Caledonides. The rocks of the parautochthon and Lower Allochthon comprise metasandstones and arkoses which are virtually barren of any sulphide mineralizations, except for a few showings of "sandstone lead' disseminations. The middle and lowermost parts of the Upper Allochthon are dominated by sediment-hosted chalcopyrite/pyrrhotite assemblages within calcareous mixed pelitic and psammitic rocks with minor mafic metavolcanic and plutonic intercalations. The structurally higher Gula and Støren/Meråker units of the Trondheim Nappe Complex of the Upper Allochthon contain chiefly pyrite-dominated assemblages in mafic and mixed mafic/felsic volcanogenic settings and have highly variable Cu, Zn and Pb contents. The stratabound sulphides of the Trondheim region were deposited during successive stages and within restricted sedimentary and volcanosedimentary environments related to the development of the Iapetus Ocean. Deposition started in basin sediments during Late Proterozoic rifting, but was mainly the result of early subduction and the development of an active island-arc magmatism in the Early Ordovician. The structural and stratigraphical sequences were subsequently affected by Caledonian folding and metamorphism prior to and during eastward transport as composite nappe units in Silurian times. The post-depositional tectonic and metamorphic events have affected the different ores and their wallrocks to various degree as revealed by apparent tectonic control and the internal metamorphic fabric of the deposits.

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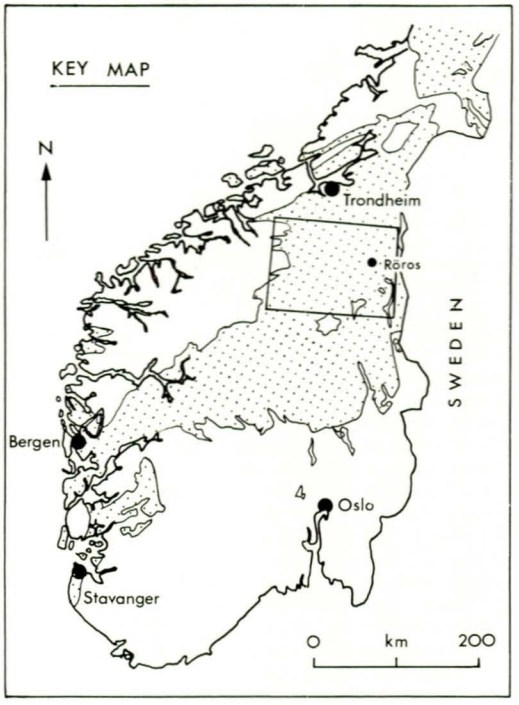
Introduction

Recent research has led to significant advances in our general understanding of the structural geometry and the tectonostratigraphical relationships between the different major tectonic units of the Scandinavian Caledonides. In particular, within the context of IGCP Project no. 60 (CCSS) the palaeogeographic and palaeotectonic environments of deposition of the massive sulphide deposits of the orogen have been reexamined and redefined (Zachrisson 1977, 1980, 1986, Bjørlykke et al. 1980, Grenne et al. 1980, Vokes 1980, Stephens et al. 1984, Grenne & Lagerblad 1985). However, in comparison with similar deposits in the Caledonides of Sweden and the western and north-sentral parts of the Norwegian Caledonides, limited attention has been paid over the last decade to the setting and nature of these deposits in the south-sentral part of the Trondheim region (Fig. 1).

The Trondheim region constitutes one of the most important mining districts in the Scandinavian Caledonides. For more than 350 years the district has served as a main producer of copper and pyrite, and the region can still be reagarded as one of the most important copper districts in Norway.

The geology of the southern part of the region covered by 1:250.000 map-sheet "Røros' has recently been compiled (Nilsen & Wolff, in press), and the present account covers the geological setting of the stratabound sulphide mineral deposits of this map area, with special reference to the tectonostratigraphical framework of the region. Earlier reviews on the stratabound sulphide deposits of the region have been given by Helland (1873), Holmsen (1919), Foslie (1925, 1926), Wolff (1967), Vokes (1976), Rui (1977), Bugge (1978) and Nilsen (1978).



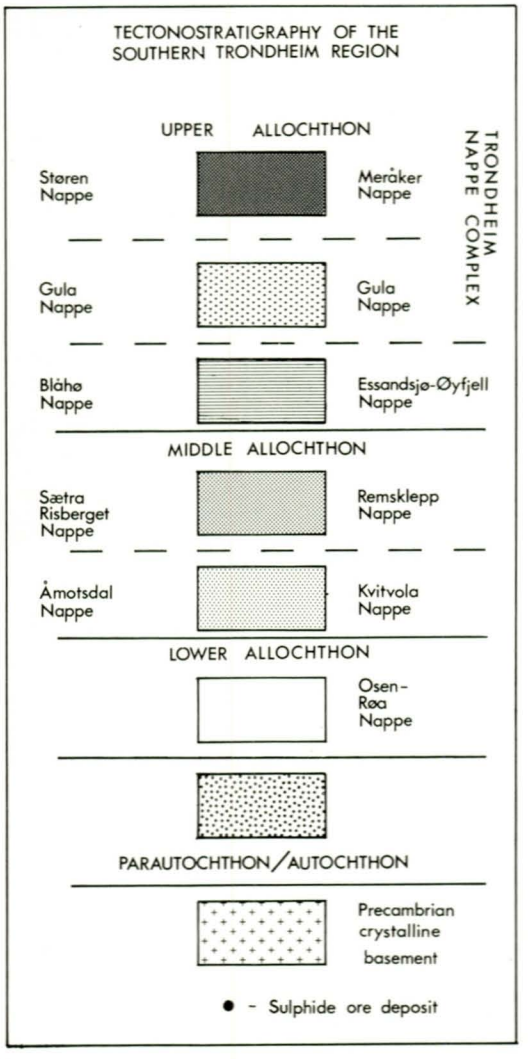


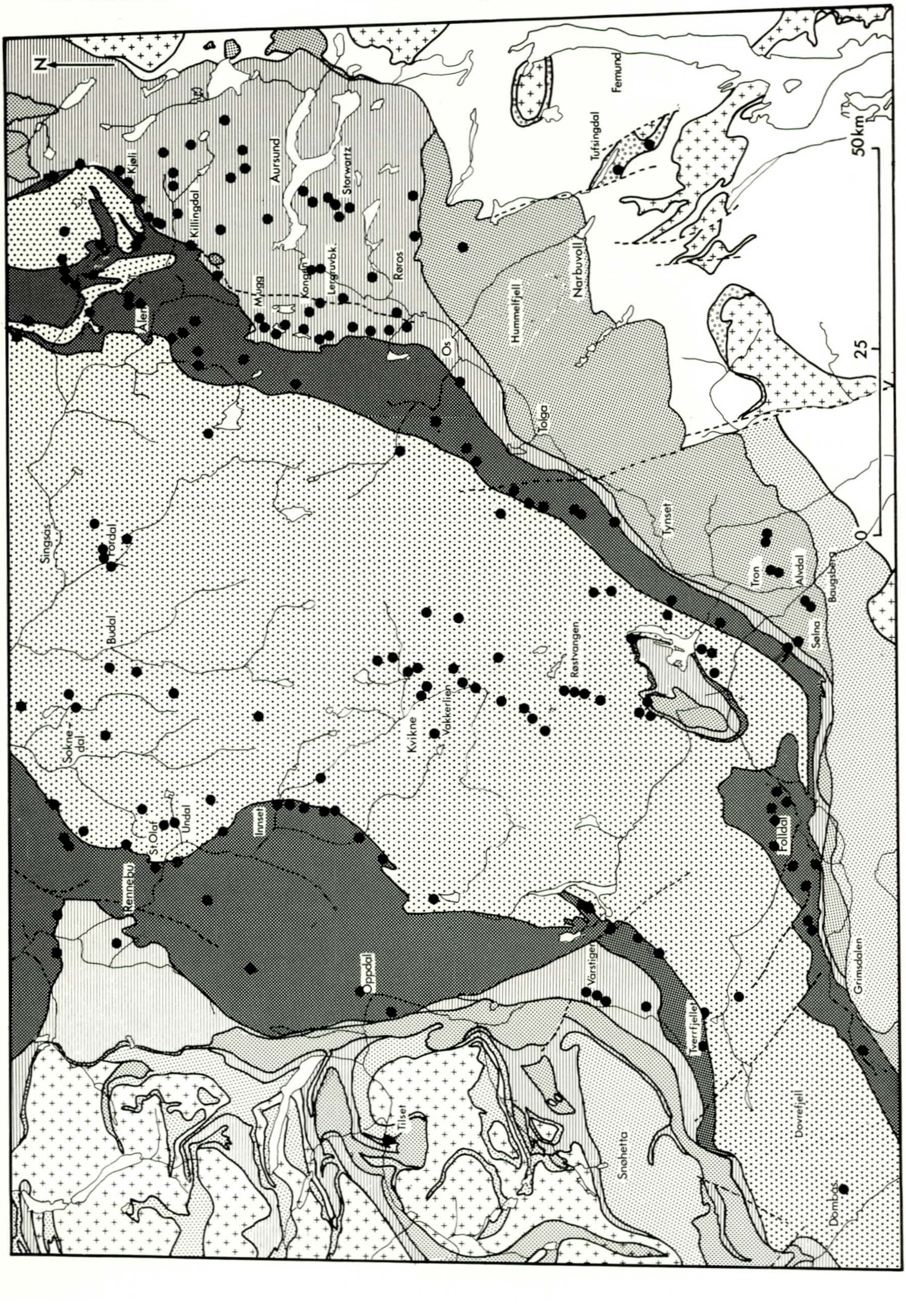
Fig. 1. Tectonostratigraphic map of the southern Trondheim Region, central Norway (on facing page). In the key map (above) the Caledonian allochthon is stippled. In the legend (this page), nappe names to the left are for the western part of the region, and those to the right for eastern areas.

The southern Trondheim region comprises a sequence of nappes emplaced above an autochthonous or parautochthonous Precambrian crystalline basement with a thin cover of Vendian to Lower Palaeozoic sediments. The allochthonous complexes are derived from av wide variety of environments and include elements of the Precambrian basement. Syntheses of the tectonostratigraphic development of the Trondheim region Caledonides have been given by Roberts (1978), Wolff (1979), Wolff & Roberts (1980) and Roberts & Wolff (1981), and a description of the central-southern part of the Scandinavian Caledonides has been presented by Gee et al. (1985b). Roberts & Wolff (1981) distinguished three major allochthonous complexes within the Trondheim region; the Basal, Lower and Upper Allochthons. More recently, a compilation of the tectonostratigraphy of the Scandinavian Caledonides has been published in a 1:2 M map by Gee et al. (1985a). They distinguish between four groups of allochthonous complexes: the Lower, Middle, Upper and Uppermost Allochthons, the last-mentioned not being present in the area under discussion. A correlation of the different formal and informal nappe units of the region in the framework of this tectonostratigraphy is presented in Table 1, and the setting of the stratabound mineralizations will be described according to these subdivisions (Table 1, Fig. 1).

Tectonostratigraphy and mineralizations

Lower Allochthon

The Lower Allochthon is developed in the eastern and southern part of the region (Fig.


N
Kjeli
Killingdal
Aursund
Storwartz
Kongens
Lergruvbk
Røros
Mugg
Ålen
Os
Hummelfjell
Narbuvoll
Tufsingdal
Femund
Tolga
Tynset
Tron
Alvdal
Baugsberg
Selna
Singsås
Fordal
Budal
Rostvangen
Kvikne
Vakkerlien
Sokne-
dal
St.Olaf
Undal
Innset
Rennebu
Oppdal
Folldal
Grimsdalen
Vårstigen
Tverrfjellet
Tilset
Dovrefjell
Snøhetta
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0
25
50km

<table>
<tr><td colspan="3" rowspan="2">WESTERN SUCCESSION</td><td colspan="2">TECTONOSTRATIGRAPHY</td><td colspan="3" rowspan="2">EASTERN SUCCESSION</td></tr>
<tr><td>Roberts & Wolff (1981)</td><td>Gee et al. (1985)</td></tr>
<tr><td></td><td>Hovin Gp.
Støren Gp.</td><td>STØREN NAPPE</td><td rowspan="2">UPPER ALLOCHTHON
(Trondheim Nappe Complex)</td><td rowspan="3">UPPER ALLOCHTHON</td><td>MERÅKER NAPPE</td><td>Sulåmo Gp.
Fundsjø Gp.</td><td></td></tr>
<tr><td>Undal Fm.
Singsås Fm.</td><td>Gula Gp.</td><td>GULA NAPPE</td><td>GULA NAPPE</td><td>Gula Gp.</td><td>Åsli Fm.
Singsås Fm.</td></tr>
<tr><td colspan="2" rowspan="3"></td><td>BLÅHØ NAPPE</td><td rowspan="2">LOWER ALLOCHTHON</td><td>ESSANDSJØ–ØYFJELL NAPPE</td><td>Aursund Gp.</td><td>Røsjø Fm.
Stugusjø Fm.</td></tr>
<tr><td>SÆTRA–RISBERGET NAPPE</td><td rowspan="2">MIDDLE ALLOCHTHON</td><td>REMSKLEPP NAPPE</td><td>Tynset Gp.
Augen gneiss unit</td><td></td></tr>
<tr><td>ÅMOTSDAL NAPPE</td><td rowspan="2">BASAL ALLOCHTHON</td><td>KVITVOLA NAPPE</td><td colspan="2" rowspan="2"></td></tr>
<tr><td colspan="2"></td><td>LOWER ALLOCHTHON</td><td>OSEN–RØA NAPPE</td></tr>
<tr><td colspan="7">PARAUTOCHTHON</td></tr>
<tr><td colspan="7">AUTOCHTHON</td></tr>
<tr><td colspan="7">PRECAMBRIAN CRYSTALLINE BASEMENT</td></tr>
</table>

Table 1. Tectonostratigraphy of the southern Trondheim region. The main tectonic units according to Roberts & Wolff (1981) and Gee et al. (1985a, b) are shown in the centre of the diagram. They are flanked by their corresponding sub-units of the western and eastern parts of the region which are mentioned in the text. The nomenclature of major units adopted in this account is that of Gee et al. (1985a, b).

1), and includes part of the *Osen—Røa Nappe Complex* (Nystuen 1981). It comprises Late Proterozoic sandstones, arkoses and quartzites of the so-called "Sparagmite basin". In the western part of the region major repetitions of parautochthonous basement gneisses appear as slices within the Lower and Middle Allochthons which, in this district, were more strongly recumbently folded and refolded during the Caledonian orogeny than correlatives in the eastern and southern areas.

The Lower Allochthon is virtually barren of any sulphide mineralization of economic significance. However, several low-grade lead mineralizations have recently been discovered within the autochthonous and parautochthonous sandstone/black shale sequences close to the contact to the Precambrian basement granites in the Femund area in the southeastern part of the region (Krause & Bakke 1986). There, galena occurs as disseminations within the Late Proterozoic to Cambrian sandstones, and apparently represents the class of "sandstone lead' ores of the Laisvall-type which extent along the Caledonian front zone through Sweden and Norway (Bjørlykke & Sangster 1981). No economic sandstone lead deposits are known within the region, but two minor pyritic lead/zinc prospects in Tufsingdalen are confined to an intercalated black phyllite unit.

Middle Allochthon

The Middle Allochthon comprises a complex of several separate nappe units above the Lower Allochthon. In its lower part the *Kvitvola* and *Åmotsdal Nappes* consist of barren arkoses and feldspathic quartzites, generally developed as flagstones. A conspicuous zone of mylonites and phyllonites usually separates the Kvitvola and Åmotsdal Nappes from the overlying Remsklepp Nappe.

The *Remsklepp Nappe* (Wolff 1979) comprises an augen-gneiss unit which has been correlated with the *Tännäs Augen Gneiss Nappe* in southern Jämtland in Sweden (Asklund 1960, Strömberg 1962). The major part of the Remsklepp Nappe consists of a series of strongly imbricated, mostly flat-lying sheets of feldspathic quartzites with intercalations of quartz phyllites, crystalline limestones, mafic metavolcanites and black phyllites. The entire

unit will here be referred to informally as the *Tynset group.* This unit is especially well developed in the Grimsdalen—Alvdal region (Heim 1968, 1972, Kleine-Hering 1969) and in the Tynset-Hummelfjell district (the "Hummelfjell formation' of Rui (1972, 1981a, Rui & Bakke 1975)).

The quartzitic sandstone sequence in the Hummelfjell and Tron area is intruded by a dolerite dyke swarm of tholeiitic composition which is believed to mark the first episode of rifting associated with the opening of the Iapetus Ocean. A correlation with the Ottfjäll diabases of the Särv Nappe in Sweden (Strömberg 1962), which were intruded around 650 to 700 m.y. ago (Claesson 1976), seems evident, as suggested earlier by Törnebohm (1896), Asklund (1961) and Point et al. (1976). A correlation of the Tynset group of this area with the Tossåsfjället Group of the Särv Nappe (Kumpulainen 1980) appears more likely than with units of the Essandsjø Nappe as indicated by Guezou (1981) and Roberts & Wolff (1981) or with parts of the high-grade Seve Nappes and equivalent units of the Upper Allochthon by Gee et al. (1985a), Stephens & Gee (1985), Stephens (1986) and Zachrisson (1986).

At Oppdal, in the western part of the region, dolerite-intruded meta-arenites (the *Sætra Nappe).* tectonically overlying the *Risberget Augen Gneiss Unit* (Krill 1980), are likely correlatives of the Remsklepp Nappe complex. The metadolerite dykes here have yielded a Rb/Sr isochron age of 745±37 m.y. (Krill 1980). Based on lithology and tectonostratigraphic position of the Sætra, Särv and Remsklepp units and the chemistry and geochronology of the associated dolerites, a correlation of these nappe units appears likely (Gee 1980). The feldspathic quartzites of the Sætra Nappe are strongly tectonized and are quarried as flagstones in the Oppdal district (Krill 1986).

A few minor stratabound sulphide deposits are associated with the metasandstones and metapelites of the Tynset group in the Alvdal area (Fig. 1). There, the Baugsberg and Tron deposits constitute the most important of the stratabound sulphide deposits of the district. In general the ores are of a chalcopyrite-pyrrhotite type with a minor sphalerite content. Pyrite and galena generally occur as accessory minerals. The ores occur as flat-lying, E-W-trending ruler-shaped lenses, isoclinally folded within calcareous chlorite-sericite-quartz phyllites of the Tynset group, and have no apparent spatial relationship with the thin horizons of mafic metavolcanites and metadolerites in the area. A weak dissemination of chalcopyrite is commonly present within the adjacent feldspathic quartzites. The affiliation of the ores with adjacent stratabound disseminations of magnetite and hematite within the lithic sandstones of the Tynset group has not yet been investigated, but a spatial relationship with Upper Proterozoic red-beds cannot be excluded. Hence, cupriferous red-bed conglomerates are reported from the parautochthon in the Brydal area (Krause & Bakke 1986). Hematite and magnetite disseminations occur sporadically as distinct strata within the Osen—Røa Nappe as well as within the Tynset group (Kleine-Hering 1969) and the Särv Nappe in Sweden (Strömberg 1962).

In the Sølna deposit in Alvdal, chalcopyrite-pyrrhotite disseminations occur in strongly sheared metadolerites (epidote-amphibolites) within quartzites of the Tynset group. The deposit reveals a geological setting similar to that of the solitary Lundörren deposit in the Särv Nappe in Jämtland (Vogt 1887, Tegengren 1924). A weak pyrrhotite dissemination is also present in prospects within a black schist horizon in the uppermost part of the Remsklepp Nappe.

No sulphide mineralizations have been recorded in the western (Sætra) equivalent of the Remsklepp Nappe.

Upper Allochthon

The Essandsjø-Øyfjell and Blåhø Nappe

The *Essandsjø-Øyfjell Nappe* unit constitutes the lowermost part of the Upper Allochthon in the eastern part of the region. The rock-types in this tectonic unit are generally in a higher tectonic and metamorphic grade as compared with the Lower Allochthon, and comprise a series of calcareous metapelites and metagreywackes of the *Aursund Group* (Rui 1981a, Bakke 1978) which was formerly designated as "Røros schists'. In northeastern areas they are generally developed as garnetiferous garben schists (Bryn 1959, Bakke 1978), but in the Røros area muscovite-biotite-chlorite schists dominate. An upper unit of the Aursund group comprises greenish-grey metagreywackes with tuffitic intercalations and subordinate horizons of mafic metavolcanites (the *Røsjø formation* of Rui & Bakke (1975) and Rui (1981a)).

A distinction between two separate nappe units, a lower *Essandsjø* and a higher *Øyfjell Nappe,* has been made further north in the Essandsjøen area by Wolff (1979). These were correlated with the Seve and Köli Nappes, respectively, in the Helag-Tännfors area of western Jämtland on the Swedish side of the border (Roberts & Wolff 1981, Sjöström 1983). Due to a pervasive imbricate tectonic style, and an extensive retrogressive alteration of garnet and hornblende to chlorite and biotite, a distinction between the Seve and Köli Nappe equivalents has been difficult to establish in the Røros area. A transitional boundary between the Seve and Köli units has also been recognized in the western Helag-Tännfors region (Sjöström 1983). In the present account the Essandsjø and Øyfjell units are informally combined into one — the Essandsjø-Øyfjell Nappe.

The Essandsjø-Øyfjell Nappe is characterized by a great number of rootless, lensoid and concordant sill-like bodies of metagabbro and amphibolite within the metasediments of the Aursund Group. Close to the strongly tectonized boundary to the subjacent Remsklepp Nappe there are a large number of serpentinized, chromite-bearing, ultramafic bodies, from the Røros area to Gudbrandsdalen in the south, a distance of more than 150 km (Kjerulf 1879, Carstens 1920, Rui 1972, Stigh 1979). In view of the structural position, character and host lithologies of these ultramafic rocks the Essandsjø-Øyfjell Nappe is thus comparable to units of the Seve Nappes, although in Sweden the serpentinized ultramafic bodies in the Seve generally lie close to the contact with the overlying Köli Nappes.

In the western part of the map area, the Blåhø unit (Hansen 1971, Krill 1980) is characterized by strongly deformed and metamorphosed garnetiferous biotite-hornblende gneisses and amphibolites with intercalations of metagabbros and with pods and small bodies of chromite-bearing serpentinites close to the tectonically underlying Sætra Nappe. On account of the characteristic lithologies, metamorphic development and tectonostratigraphical position, a correlation between the Blåhø unit and the Essandsjø-Øyfjell Nappe (Gee et al. 1985a) seems evident.

In the Røros district a great number of stratabound cupriferous sulphide deposits are confined to the Aursund Group of the Essandsjø-Øyfjell Nappe. The Røros Mining Company (Røros Kobberverk) was founded in 1644 and was, at the time of its closure in 1977, the oldest operating mining company in Norway. Over the years a great number of mines were operated by the company and the total production was of the order of 120.000 tons of copper.

As with the majority of the Caledonian stratabound sulphide deposits, the ore bodies of the Røros district have a lensoid or ruler-shaped morphology, generally with their long axes parallel to prominent tectonic linear elements (e.g. the Mugg, Storwartz and Kongen deposits). The general conformability between linear structures and massive sulphide ores in the Norwegian Caledonides was demonstrated earlier by Vogt (1952) and later by Rui (1973 a,b) and Nilsen (1978) from the southern Trondheim region.

As with the deposits in the Alvdal district the ores of the Røros district have no apparent spatial relationship with metavolcanites and must be considered to be of a sediment-hosted type, concordantly intercalated within the calcareous muscovite-biotite-chlorite schists of the Aursund Group and generally in close proximity to gabbro bodies. In general, the deposits of the structurally lowermost *Stugusjø Formation* of the Aursund Group are characterized by the assemblage of chalcopyrite and pyrrhotite with subordinate or accessory pyrite and sphalerite. Galena is virtually absent in most of the ores in question; where present, galena may be accompanied by rare minerals such as dyscrasite, native Bi and naumannite (Jøsang 1964). Usually the ores display a through plastic "durchbewegt' texture which reflects the pervasively sheared and brittle tectonic style of the nappe unit, as revealed by the great number of adjacent, flat-lying sheets of ultramylonite ("hårdart') within the Aursund Group meta-arenites.

The *Røsjø Formation* occupies the western part of the Aursund Group and hosts a great number of pyritic ores (Lieungh 1973, Rui & Bakke 1975). There, sphalerite may constitute an important component of the ores, e.g. at the Lergruvbakken deposit, which was the last mine in operation with ore grading 0.74% Cu and 7.8% Zn (Bugge 1978).

To the south and southwest the Essandsjø-Øyfjell Nappe wedges out and only a few, minor, pyritic sulphide deposits are associated with the Aursund Group. In the Tynset area a thin (‹3m), stratabound manganiferous horizon of the Aursund Group (e.g. the Storåsen prospect) is composed of bedded spessartite,

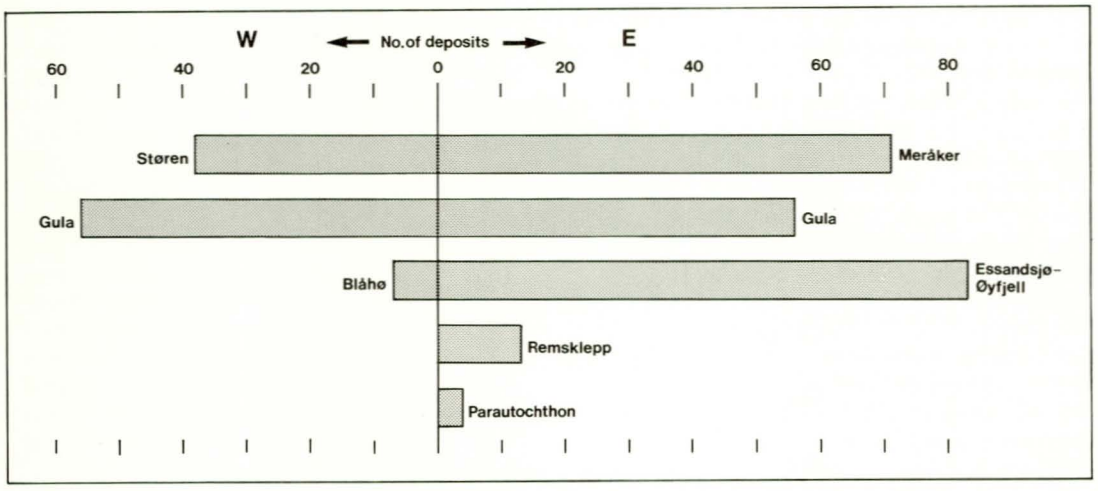

Fig. 2. The distribution of stratabound sulphide deposits within the correlatable tectonostratigraphic units in the western (W) and eastern (E) parts of the southern Trondheim region (map-sheet "Røros' 1:250,000).

Mn-ankerite and braunite, and may represent the southernmost distal facies of the sediment-hosted Aursund Group deposits.

In the western Blåhø unit correlative, a few stratabound sulphide deposits are present (Fig. 2). They were exploited for pyrite and copper on a limited scale at the turn of the century, but the reserves were small and not easily accessible. The deposits occur as thin (‹1 m) but massive pyritic strata intercalated within the strongly contorted Blåhø garben-gneisses in close proximity to garnet amphibolites (e.g. the Vårstigen prospects), or as heavy, stratabound, chalcopyrite-pyrrhotite disseminations in the latter (e.g. the Tilset prospects). As with the Røsjø deposits in the eastern part of the region (Rui & Bakke 1975), a possible volcanogenic affiliation may be attributed to the deposits in question, but due to the pervasive metamorphic and tectonic imprint of the ores and wallrocks of the Blåhø deposits, this question remains unsettled.

The Trondheim Nappe Complex

In the Trondheim region the upper part of the Upper Allochthon is generally referred to as the *Trondheim Nappe* (Wolff 1967) or *Trondheim Nappe Complex* (Guezou 1978, Roberts & Wolff 1981). This nappe complex comprises three principal nappe units, from west to east the *Støren, Gula* and *Meråker Nappes.*

The Gula Nappe occupies the central part of the region in the core of a complex antiformal structure. The Meråker and Støren Nappes were apparently emplaced upon the Gula rocks (Furnes et al. 1980) prior to the emplacement of the entire Trondheim Nappe Complex above the Essandsjø-Øyfjell and Blåhø units. In this model, the eastern part of the area of the Meråker Nappe occurs in an inverted position above the Essandsjø-Øyfjell Nappe (Fig. 3), but there is still an uncertainty over this question as structural and textural evidence of thrust faults is sparse and inconsistent.

In the southern Trondheim region the *Gula Nappe* comprises two principal units. A lower, calcareous, high-grade metapsammitic unit, the *Singsås Formation,* contains intercalations of black schists, mafic metavolcanites and bituminous ribbon quartzites. The Singsås Formation is flanked by dark, metapelitic units (the *Undal* and *Åsli Formations,* respectively, in the west and the east) with subordinate horizons of quartzite conglomerate and crystalline limestone (Nilsen 1978). The age of the Gula rocks is uncertain, but Tremadocian fossils in the Åsli Formation suggest that the greater part of the Gula unit may be of Cambrian age (Størmer 1941, Gee 1981).

Thin horizons of mafic metavolcanites, in places with ultramafic inclusions, occur within the Gula Nappe, in particular along the boundary between the Singsås and the Åsli Formations (Nilsen 1974). A great number of pyritic, cuprife-

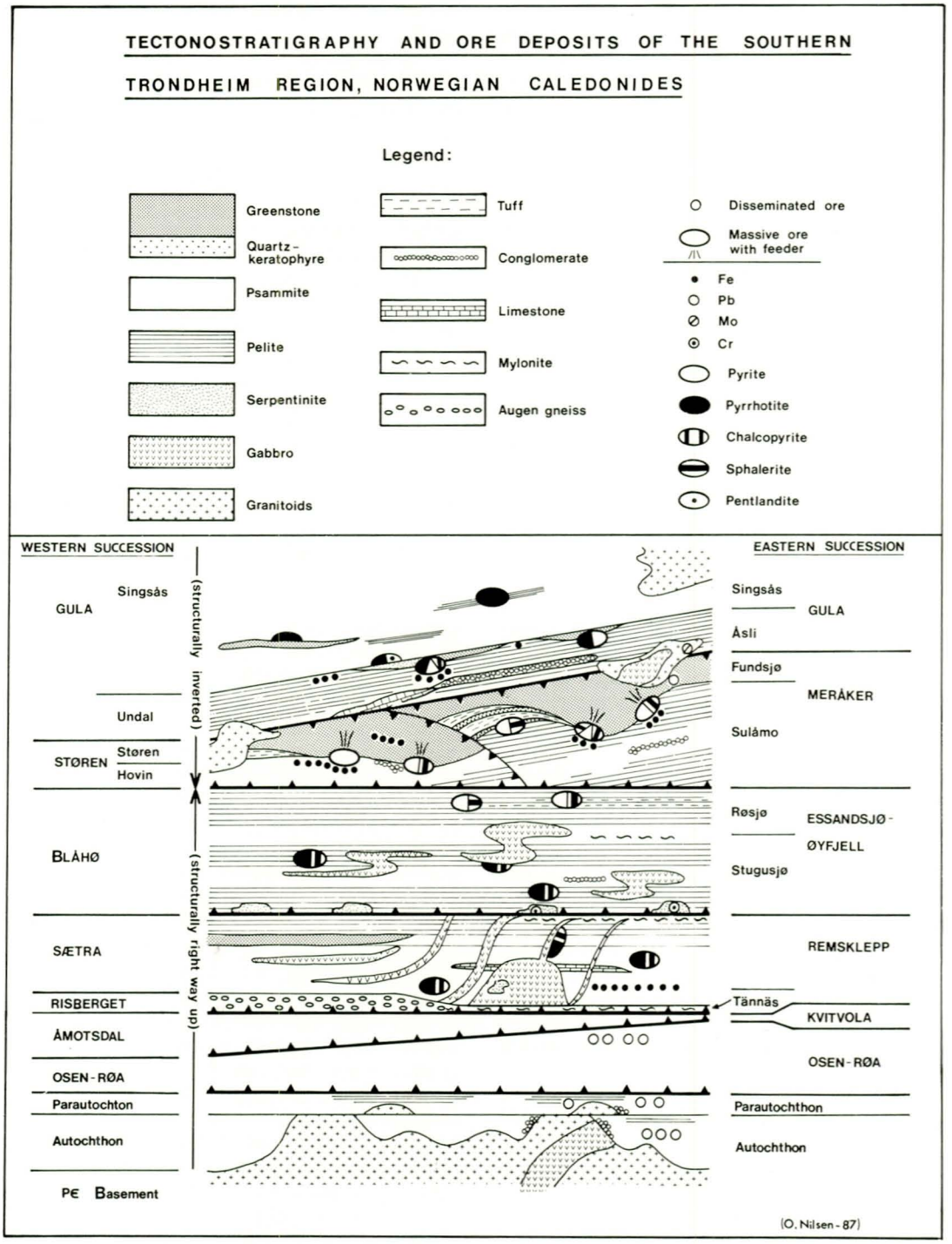

Fig. 3. Tectonostratigraphy and ore deposits of the southern Trondheim region, Norwegian Caledonides.

rous, stratabound sulphide deposits are confined to these Gula amphibolites which are capped by, and laterally wedge out into, thin, cherty iron-formations (Nilsen 1978). The sulphide deposits are pyritic, with chalcopyrite and pyrrhotite as minor constituents. Sphalerite occurs locally, and galena is absent from most of the Gula ores. The orebodies are small, with tonnages well below 1 million tons, and with grades of from 1 to 3% Cu and less than 1% Zn. The associated iron-formations are mostly developed as magnetite-bearing ferruginous grunerite-garnet quartzites. A few nickeliferous ore deposits are associated with the ultramafic and gabbroic inclusions within the Gula amphibolites. Exploration work at the Vakkerlien prospect during the late 1970's revealed an ore body of 400.000 tons of ore with 1% Ni and 0.4% Cu (Thompson et al. 1980).

A large number of prospects are confined to sulphide-disseminated black schists and ribbon-chert intercalations within the Gula Nappe. The mineralizations are chiefly pyrrhotitic with subordinate pyrite and with a negligible content of copper.

The *Meråker* and *Støren Nappes* constitute the main volcano-sedimentary units within the southern Trondheim region, and form the uppermost nappe units of the region — the Støren Nappe in the west and the Meråker Nappe in the east. These include pillowed tholeiitic greenstone units in their stratigraphically lowermost parts which are metamorphosed in low to medium grade. Intercalations of quartz-keratophyre are prominent in the ensimatic island-arc related *Fundsjø Group* metavolcanites in the east (Wolff 1967, Nilsen 1978, Grenne & Lagerblad 1985), while a thick pile of greenstones of ocean-floor tholeiitic character (Gale & Roberts 1974, Grenne et al. 1980) with associated local volcanoclastics and ribbon-cherts characterize the western *Støren Group* unit. Both these basal metavolcanites are followed unconformably upwards by low-grade shallow-marine sediments which are succeeded by thick sequences of mainly turbidite-facies metagreywackes and siltstones with polymict conglomerate horizons in both the western (Hovin and Horg Groups) (Vogt 1945, Chaloupsky 1970, Walsh 1986) and the eastern (Sulåmo, Kjølhaugen and Slågån Groups) parts of the region (Wolff 1967, 1979, Hardenby 1986). Thick units of greenstone and local andesites and rhyolite tuffs also occur within these mainly Ordovician sequences, especially in western areas (Roberts et al. 1984).

A great number of stratabound sulphide deposits are associated with the metavolcanites of the Støren and Fundsjø Groups. In the southern Trondheim Region the deposits are clustered in the Ålen, Folldal and Innset-Rennebu districts, but several deposits also occur within the volcanic horizons from Gauldalen to Gudbrandsdalen. The only sulphide mine in the region in operation today is confined to the metavolcanites of the Støren Nappe, viz. the Tverrfjellet mine. The Tverrfjellet deposit, which was put into production in 1968, represents the next largest sulphide orebody in Norway with a tonnage of 16 mill. tons of ore with 0.86% Cu and 1.07% Zn (Motys 1977, Krupp & Krupp 1985). Formerly, the Folldal area was next to the Røros area the main copper district in the southern Trondheim region (Foslie 1926, Aasgaard 1935, Page 1964). Several mines in this area produced a total of 4.5 mill. tons of ore with 1—2% Cu during the years from 1748 to 1969 (Bugge 1978).

In general, the massive, stratabound sulphides of the Støren and Fundsjø Groups are pyritic with chalcopyrite, pyrrhotite and sphalerite as minor constituent minerals. The copper contents vary between 0.5 and 2% and the zinc content varies greatly from less than 1% up to 5% in the Killingdal mine (Rui 1973). The lead content is generally very low, from nil to 1% Pb. In general, the ores associated with the island-arc related Fundsjø Group reveal a minor, but significantly higher Pb and Zn content in comparison with the ocean-floor related Støren Group deposits (Vokes 1976, Bjørlykke et al. 1980). However, within both settings, lateral and vertical variations with respect to the relative proportions between the three main base metals (Cu:Zn:Pb) reflect the specific stratigraphical and along-strike siting of the massive sulphide deposits. Thus, in the Fundsjø Group the copper content of the ores decreases southwards from the basalt-hosted deposits (Py+Cpy ± Sl) of Ålen (Killingdal) along strike to mafic tuffite/quartz-keratophyre settings (Py+Sl+Mt) with bituminous pelitic intercalations in the Tolga area.

The vertical zonation of the deposits has been difficult to reconstruct due to the general pervasive deformation of ores and wallrocks, and to the general inaccessibility of the abandoned mines. However, at Killingdal, Birkeland

(1986) has recently deduced a possible feeder zone as revelaed by chalcopyrite and pyrrhotite disseminations in chloritic schists, stratigraphically underlying the massive, sphaleritic pyrite ore which is capped by ferruginous cherts.

Minor cherty iron-oxide facies rocks are commonly intercalated with some orebodies (e.g. at Tverrfjellet mine), or occur as separate iron-ore strata, capping or adjacent to the volcanogenic massive sulphide orebodies. Only a few of these have been exploited commercially during the last century (e.g. St. Olaf mine, Rennebu (Nilsen 1978)).

The orebodies are generally lens- og rulershaped, and their present morphology and setting is evidently tectonically controlled. Wallrock alternation is commonly revealed by pervasive chloritization, silicification and sericitization. Evidence of post-ore deformational events associated with sulphide remobilization is revealed in several of the ores by rotation and brittle deformation of pyrite porphyroblasts which are engulfed by plastically deformed pyrrhotite and base-metal sulphides. The unconformably overlying metasediments of the Hovin and Sulåmo Groups of the Meråker and Støren Nappes are barren with respect to ore deposits.

Conclusions

The stratabound polymetallic sulphide mineralizations of the southern Trondheim region were deposited in successive stages and within restricted sedimentary and volcano-sedimentary environments during the development of the Iapetus Ocean. They were deposited from the time of early rifting, as revealed by the partly dolerite-intruded basin sediments of the Remsklepp Nappe, through the early subduction phase with the development of the first ensimatic island-arc magmatism in the Fundsjø Group.

In pre-Middle Arenig time, obduction of ocean-floor (Støren Group) assemblages and the Fundsjø arc rocks upon the rocks of the Gula Nappe took place, with a subsequent uplift and erosion of the volcanic pile before Ordovician sedimentation commenced. The structural and stratigraphic sequences were subsequently affected by Caledonian folding and metamorphism prior to and during an eastward transport as composite nappe units in Middle to Late Silurian times. The stacking of the nappes post-dates the isoclinal folding, penetrative foliation and metamorphism, and in many areas produced inverted metamorphic zonations (e.g. in the Essandsjø—Øyfjell and Blåhø Nappes). The fact that ore provinces within the Caledonides apparently coincide with the major tectonic units has been emphasized by Zachrisson (1977).

As shown in Fig. 2, the complexes of the Upper Allochthon reveal the greatest sulphide ore potentials of the southern Trondheim region. In a broad sense there is an apparent change from Cu-rich, sediment-hosted deposits in the lower allochthonous units towards pyritic, Cu/Zn deposits of volcanogenic affiliation in the upper allochthonous units (Fig. 3). A similar trend has been encountered in the stratabound sulphide deposits within the Caledonian allochthon of Sweden (Zachrisson 1980). The sediment-hosted ore deposits of the allochthonous units below the Trondheim Nappe Complex show no apparent spatial relationship with the early Caledonian mafic magmatism, which may have served as an energy source in the development of convective hydrothermal metal-bearing brines in the initital stages of the orogen development. With the onset of submarine volcanism in the Upper Allochthon, stratabound and laterally zoned exhalative deposits were formed as revealed by the Gula and Støren/Meråker deposits. Here, pyrite+chalcopyrite ± sphalerite and pyrite+sphalerite+magnetite parageneses seem to be confined to proximal centres of tholeiitic volcanism and distal mixed sedimentary/volcanoclastic facies, respectively. A major task in the future will be, by means of detailed petrological, structural and geochemical studies around the deposits in question, to try to establish the ore-forming environments of the different units in this part of the Trondheim region.

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