Metallogeny

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Introduction

A considerable number and variety of metallic and non-metallic mineral deposits appear to be genetically connected with the tectonic and magmatic activity in the Oslo Region. With some few notable exceptions, these deposits have not proved to be of great economic importance, either actual or potential. However, what they mostly lack in size, they make up for in the number of metallic and other elements present in a wide variety of combinations and deposit types. These include oxide deposits of Fe, Mn, Ti and W, sulphide deposits mainly of Zn, Pb, Cu, Mo and Bi, and deposits of native silver/Co–Ni-arsenides, as well as fluorite, barite, apatite and, locally, beryl and helvine deposits.

Previous work

The mineral deposits connected with the Oslo Rift have been the subjects of an extensive literature over the years, extending in some cases as far back as the final decade of the last century. However, a complete synthesis of the metallogenetic aspects of the Oslo rifting and magmatism has yet to be given. The deposits of the Oslo Region proper were dealt with in now classical papers by Vogt (1884a, b) and Goldschmidt (1911). Brøgger (1933a), Nielsen (1967) and Bergstøl (1972) have described various aspects of potentially important magmatic deposits within the eruptive rocks of the southern part of the region.

The supposedly related deposits lying outside the Paleozoic rocks of the Oslo Region have, on the whole, been only sparsely touched upon in the geological literature. One very significant exception is to be found in the historically important native silver-bearing vein deposits of the Kongsberg area, which have been described and discussed in a long series of both published and unpublished reports. Among the former, mention may be made of those of C. Bugge (1917), A. Bugge (1923, 1929, 1931) and Neumann (1944).

Røsholt (1967) described zinc-bearing quartz veins in Precambrian rocks in the Tråk area (Rafnes), near Porsgrunn. Vogt (1884b) pointed out the existence of minor representatives of the Kongsberg veins along the Skagerrak coast in the vicinity of Arendal.

The Swedish deposits, in Skåne, of the same metallogenetic epoch as the Oslo Region deposits, have been described by Tegengren (1924), Wickman et al. (1963) and, briefly, by Frietsch (1975). Tegengren and Frietsch also

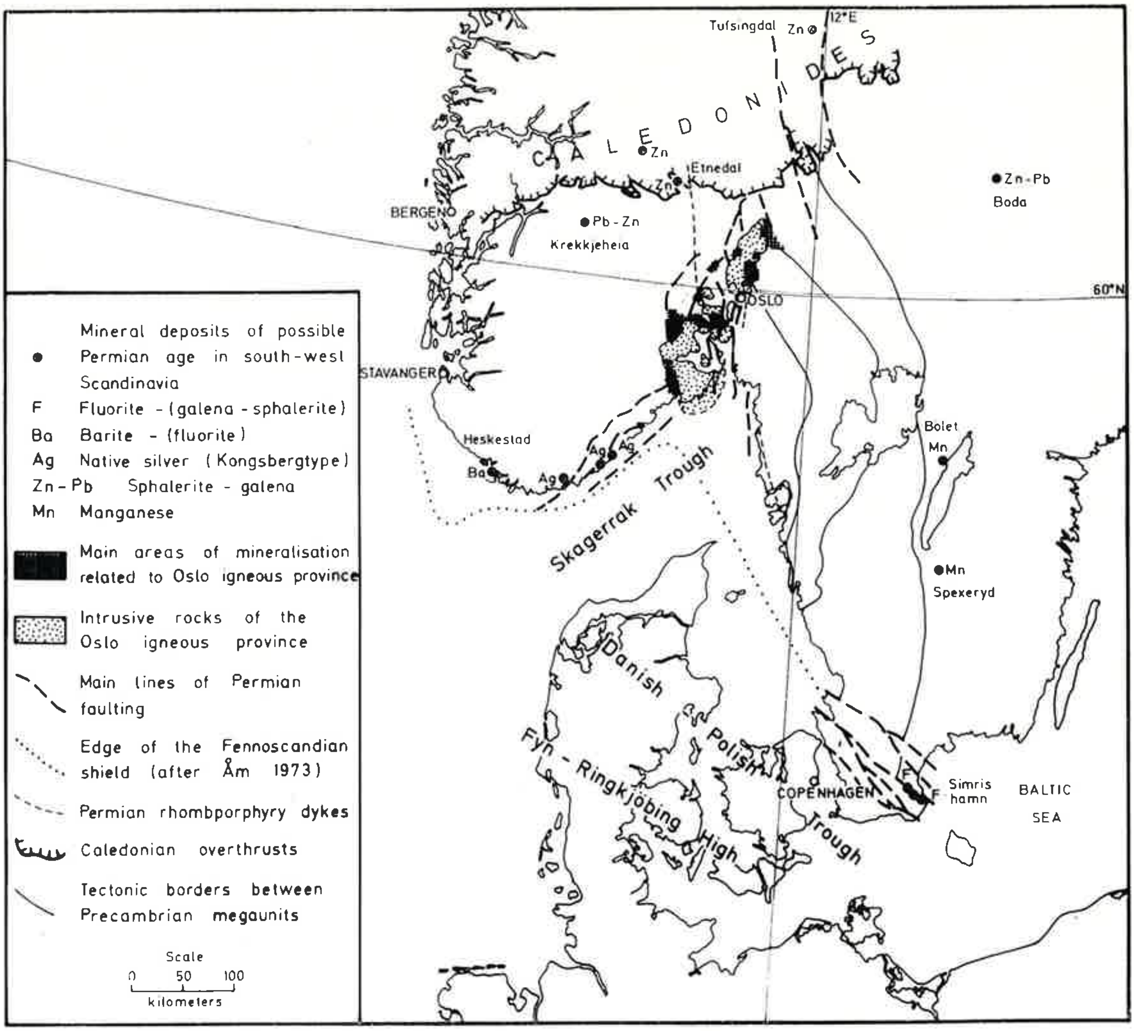


Fig. 1. Map of Southern Scandinavia showing ore deposits of assumed Permian age outside the Oslo Region proper. Modified from Vokes & Gale, 1976, fig. 6.

mention deposits in the Swedish Precambrian to the east of the Oslo Region which are possibly relatable to this epoch.

Recently, Vokes (1973) and Vokes & Gale (1976) have given summary reviews of the Oslo Region metallogeny and have discussed it in terms of plate tectonic concepts. Ineson et al. (1975) have demonstrated the usefulness of K-Ar dating of clay mineral alteration assemblages in fixing the metallogenetic events chronologically.

Distribution and areal extent of the deposits

The deposits under consideration comprise, in general, two main groupings; 1) those within the magmatic rocks of the Region or very closely related to these (roughly within the contact–metamorphic aureoles); and 2) those occurring within the surrounding Lower Paleozoic sedimentary rocks and the Precambrian rocks of the Sveconorwegian (Grenville) province of the Baltic Shield. It will be convenient to review the distribution of deposits according to these two main groupings.

Those deposits most closely associated with the Oslo Region rocks, *per se,* show apparently irregular groupings or concentrations, the causes of which are as yet not clear. Probably the most important is a belt some 25 km wide extending from east of Drammen and westwards to the Eikeren area (See Plate 4), a distance of some 40 km. A similar, but smaller and less intensely mineralized area is found in the northern part of the region in the Hurdal–Skreia area. Other concentrations of smaller size are to be found along the south-western margin of the igneous rocks in the Skien–Brevik area, in the central, Finnemarka area, in the area north-east of Oslo (Grorud–Nittedal–Hakadal), and in the Grua area.

In certain areas, the distribution of the deposits appears to coincide with the exocontact zone of certain of the intrusive magmatic rock bodies. However, it can be argued that even within the Oslo Region proper, the spatial distribution of the ore deposits often seems to be parallel to, or in continuation of, certain linear tectonic zones within the surrounding Precambrian basement.

The distribution and extent of the deposits in the Lower Paleozoic and Precambrian rocks surrounding the Oslo magmatic rocks (see Fig. 1) is now being shown to be more complex and widespread than has hitherto been believed. They are also, on the whole, very clearly associated with marked tectonic zones within the Precambrian basement, zones which have obviously been reactivated during the Upper Paleozoic rifting.

One of the difficulties in assessing the extent of the Upper Paleozoic mineralization in the Precambrian areas surrounding the Oslo Region is the presence of deposits of actual, or supposed, Precambrian age. It is not always possible from field inspection to decide whether a given deposit is a Precambrian one, or whether it stems from the late Paleozoic activity in the Oslo Region. The application of isotopic dating methods, described below, is one of the means being employed in an attempt to sort out the affiliations of the deposits in this part of the southern Norwegian Precambrian.

Zoning of the deposits

While it is not easy to define any clear form for zoning in the distribution of the mineral deposits associated with the Oslo Region, certain types do seem to occupy positions which are consistent in their relationship to the rift system and to the exposed magmatic rocks.

Molybdenite deposits are almost totally confined to an endocontact (apical?) location in the central biotite granite of the Drammen area. The Glitrevann occurrence is located in a cauldron and occurs within a quartz-feldspar porphyry which was earlier considered as belonging to the same series as the biotite granite, but which is now regarded as a separate intrusion. The Fe, Mn and W oxide deposits and many of the Zn-Pb and Cu sulphide deposits show an exocontact relationship to the intrusive rocks, especially to the granitic types; Pb-Zn and Cu, together with fluorite and some barite, are present in vein deposits outside the metamorphic aureole, both in Lower Paleozoic and in Precambrian rocks.

Further out in the Precambrian areas to the west of the region, Ag-bearing calcite veins and fluorite-bearing quartz veins occur in the Kongsberg area.

The mineral deposits apparently related to the late Paleozoic activity at even greater distances from the exposed igneous rocks seem also to conform to the general distribution trends. The small, scattered deposits along the border fractures to the Skagerrak and Polish-Danish troughs (Ag-bearing deposits of the Kongsberg type in the Arendal and Kristiansand areas, barite-fluorite veins in the Farsund area and fluorite-sulphide veins in Skåne), are not obviously related to any plutonic activity, though the evidence for this may be present at depth.

In the area north of the Oslo Region proper, the evidence in favour of late Paleozoic mineral deposition is so far somewhat equivocal. What evidence there is of age of deposition mainly concerns small Pb-Zn deposits in the vicinity of the Precambrian peneplain along the southern edge of the Caledonian allochthon (Fig. 1). The small deposit at Krekkjeheia was considered on structural grounds to be of Permian (Variscan) age by Skjeseth & Vokes (1957), a conclusion which appears to be supported by the Pb/Pb (galena), isotopic model age of 250 ± 70 m.y. published by Moorbath & Vokes (1963).

Other deposits in the same general area have so far not afforded evidence of their age relationships.

Ages of mineralization

The range of ages of deposition of the mineral deposits considered here is usually regarded as generally coincident with that accepted for the Late Paleozoic geological activity in the Oslo Region. In many cases the evidence for such general contemporaneity is quite convincing; in others it is very tenuous indeed.

The endocontact and exocontact deposits within the province proper are assumed to have the same general age as the closely associated plutonic rocks, which are in most cases considered to be the magmatic parents of the ores. There seems no reason for doubting this reasoning, especially in the case of the typical contact-metasomatic deposits and the endomagmatic and closely associated exomagmatic deposit types. In the case of those deposits lying at some distance from the exposed plutonic rocks, however, the grounds for assigning them to the 'Oslo events' are purely geological and intuitive.

The age relationships between sulphide-bearing quartz-breccia veins and presumed Permian diabase dykes in the Kongsberg area have been discussed by several authors (e.g. Bugge 1917, Sæther 1964, Gammon 1966). The main conclusions reached were that there seemed to be a general contemporaneity between the dykes and the mineral veins. The formerly economically important silver-bearing calcite veins in the same area cut the presumed Permian dykes and often follow or transect the quartz-breccia veins and alter their mineralogy, indicating a later age of emplacement. In the Gjerpen (Stulen) area, north of Skien, Kaspersen (1976) records that fluorite-bearing quartz-breccia veins of the Oslo type can be seen to cut a 'Permian' camptonite dyke.

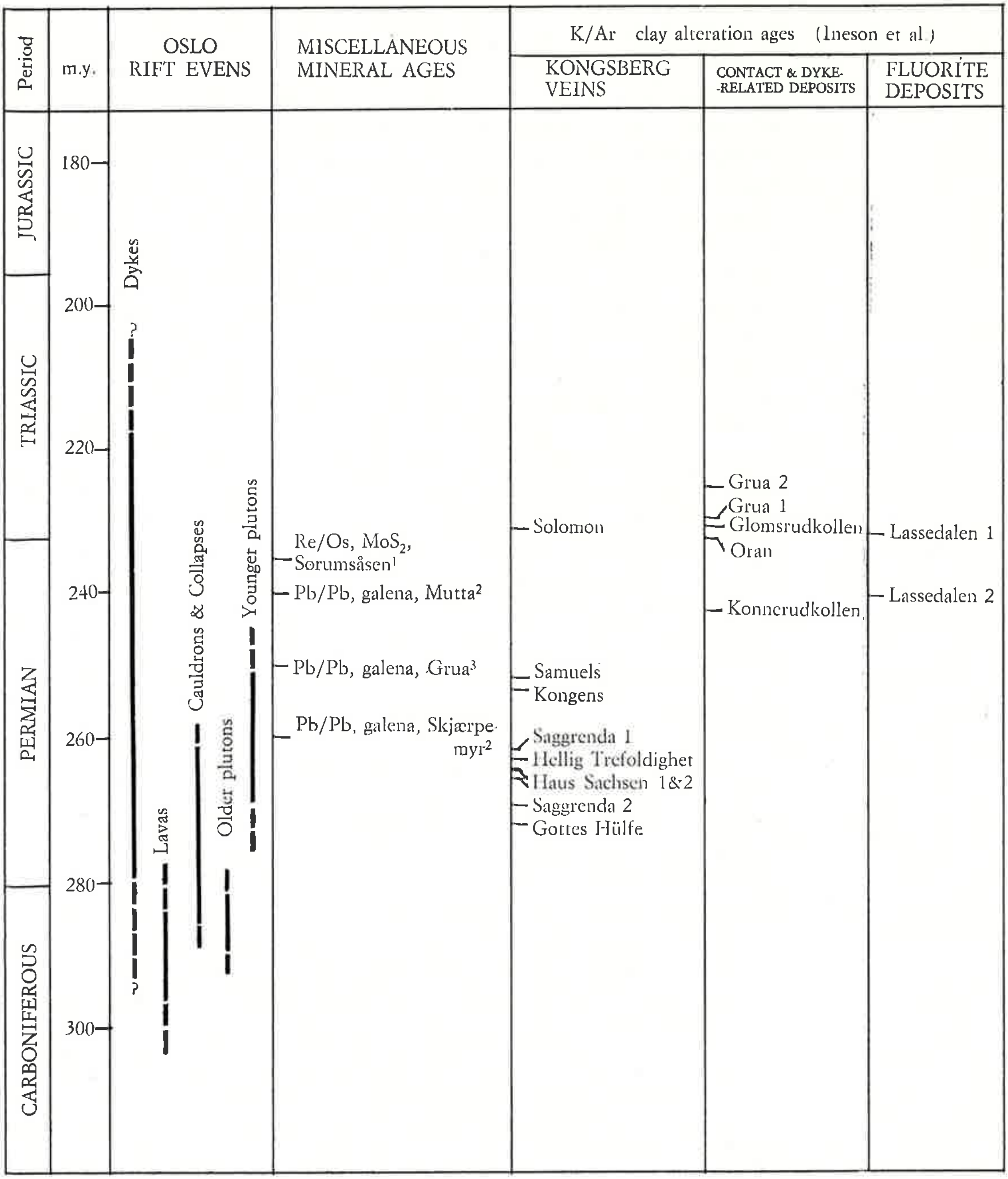
Evidence such as the above suggests that there was an extended period of vein deposition in the Precambrian rocks around the Oslo Region, with vein emplacement of both older and younger age than the Permian to (?)Triassic dykes of the area (see Table 1).

Isotopic geochronological data on the Oslo mineralization are still very limited. A Re/Os age of 235 m.y. B. P. is quoted by Neumann (1960) for molybdenite from the Sørumsåsen deposit lying in the central biotite granite mass east of Drammen. Pb/Pb isotopic determinations on galenas from several of the deposits under consideration have yielded results of varying degrees of reliability from a geochronological point of view. Moorbath (1962) reported a model age of 250 ± 30 m.y. for galena from 'an undoubted Permian vein-type deposit near Grua'. Moorbath & Vokes (1963) also obtained 'reasonable' model ages for galenas from the Grua area; 260 ± 70 m.y. and 240 ± 50 m.y. for material from the Skjærpemyr and Mutta localities, respectively. However, other ore leads from the Oslo Region investigated by the same authors yielded anomalous (negative) model ages, suggesting progressive contamination of possible Permian lead by different amounts of a single radiogenic lead during passage of the ore-forming solutions through the country rocks to the site of deposition (Moorbath & Vokes 1963, pp. 315–317). Assuming that the deposits were indeed of a Permian age (250 m.y.), Moorbath & Vokes (1963) calculated that the age of the rocks that supplied the excessive radiogenic component was 1100 ± 200 m.y., an age which is not inconsistent with radiometric age determinations for the Sveconorwegian orogeny in southern Norway.

Recently, Ineson et al. (1975) have employed K/Ar dating methods on the clay minerals which appear to be the product of wall-rock alteration associated with the ore mineral deposition. Although this is patently an indirect method of dating the minerals of the actual deposits, the results achieved so far give ages consistent with those generally accepted for the ore deposition in the area and have allowed certain proposals to be made concerning the sequence of deposition in the region as a whole. They show that hydrothermal events leading to the formation of clay mineral assemblages spatially connected with the deposits, ranged in time from about 300 m.y. to about 190 m.y. B.P. Of these, 86 per cent fell in the time interval 280–210 m.y., and 67 per cent within the interval 270–230 m.y. Two distinct peaks occur, at roughly 265 m.y. and 235 m.y., though the geological significance of these is not yet apparent.

Table 1 shows, schematically, the relations of the recently determined clay-alteration ages to the main events of the Oslo Rift system.

Table 1. Schematic presentation of rock and mineral age dates from the Oslo Region and surroundings. The 'older plutons' include those in Vestfold, the biotite granites (including Drammen granite) and monzonites in Nordmarka. The 'younger plutons' comprise syenites/granites in Nordmarka–Hurdal. (B. Sundvoll, pers. comm. 1976). Superscripts; 1. Neumann (1960), 2. Moorbath and Vokes (1963), 3. Moorbath (1962)



Genetic considerations

The vast majority of the Oslo Region mineral deposits are demonstrably of an epigenetic character, clearly younger than their wall rocks. These relations are best seen in the classical contact metasomatic (skarn) deposits, in the magma-near, dyke-related deposits and in the quartz-breccia and other vein types in Lower Paleozoic and Precambrian areas at some distance from the igneous rocks. Even in the case of the endomagmatic, Mo-bearing, quartz veins of the Drammen area, there seems to be little doubt regarding the epigenetic character of the veins and their accompanying wall-rock alteration (silicification, argillization).

In the southern districts of the Oslo Region, in Vestfold, there occur certain deposits of a general orthomagmatic character where a difference in age between wall-rock and mineral deposit formation is less obvious. These have been interpreted as dyke-like injections or syngenetic magmatic segregations.

The weak and sporadic occurrences of copper minerals (especially native Cu) in the lower Permian basalt lavas of the Oslo Region may well be of a syngenetic origin, though insufficient information is available on which to base a judgement.

Within the central part of the magmatic province itself, the majority of deposits appears to be spatially related (see Plate 4) to outcrops of the biotite granite ('Drammen granite'), originally thought to be one of the younger rocks in the Oslo Region but now shown to belong to the earlier intrusive phases of the area (see Table 1). Recent work by one of us (P.M.I.) in the northern part of the Oslo Region indicates, however, that also other felsic intrusive rocks, in particular the alkali granites (ekerites, etc.), must be considered as having a closer spatial relationship to many of the deposits than do the biotite granites.

Even allowing that the Oslo Region's epigenetic mineral deposits show a close spatial and temporal relationship to its deep-seated igneous rocks and that this association may be regarded as a genetic one, it is not possible at the present state of knowledge to decide whether the ore-forming fluids were juvenile magmatic or connate/meteoric, or perhaps derived from both these sources.

Recent work on the scheelite deposition in the Mistberget area (Ihlen, unpublished results) indicates that considerable movement of elements has taken place within the sedimentary rocks of the metamorphic aureole, apparently under the influence of heat (and, perhaps, solutions?) from the intruding alkali granite magma, and that juvenile additions from this magma have been almost negligible. It is not yet apparent, however, whether such conclusions also can be said to apply to the far more abundant and important base metal sulphide and iron oxide deposits of the contact-metasomatic type in the area.

Relation of the ore deposition to the rifting

In recent years, several authors have considered the rifting of the Oslo Region and adjacent areas in terms of modern plate tectonic notions (Ramberg 1972, Vokes 1973, Burke 1973, Burke & Dewey 1973, Whiteman et al. 1975, Vokes & Gale 1976). This aspect of the geology of the Oslo Region is also dealt with elsewhere in the present volume and a detailed discussion of the available evidence will not be entered into here.

In summary, the present authors consider that the rifting, igneous activity and associated mineralization in this region of south-western Scandinavia is ascribable to the incomplete or abortive break-up of the Laurasian continental mass prior to the separation of America from Eurasia. It is considered that the rifting activity was controlled by fracturing along two main trends (NE–SW and NW–SE to NNW–SSE); these are parallel to the trends of the fractures along which the separation of the continents later took place (cf. Vokes 1973, fig. 2).

The fracturing can thus be regarded in terms of a 'failed rift' situation, in that the main continental rifting subsequently occurred elsewhere. The stage of rifting that was reached thus seems to correspond to what has been termed the 'initial stage' of continental drift by Blissenbach (1972). Blissenbach did not envisage any metallogenetic activity, at the surface of the crust at least, during this initial stage. He relates the formation of metalliferous brines of the Red Sea type to a later, mature stage of rifting when new oceanic crust has been established. This is in keeping with the known facts of the Oslo Region metallogeny; the mineral deposits were formed at some depth (2 – 3 km) below the surface and are now exposed as the result of subsequent erosion. One might possibly speculate that the native Cu and other Cu minerals occurring in the Lower Permian basalts in the Oslofjord area are an exception to the general rule. Such metal-rich basalt could perhaps have contributed, by brine leaching, to the metalliferous muds which might have formed at the mature stage of rifting, had the process not 'failed' prior to this.

The fact that the Oslo rifting was discontinued at the initial stage, and that the subsequent erosion has exposed the deeper levels of the rift system and its accompanying magmatic rocks, enables us to study the metallogenic processes which had occurred by that time. This situation, while perhaps not unique, is a very unusual one, and one which makes the study of the region so rewarding from a metallogenist's point of view.

Review of deposit-types present

In the following, the main characteristics of the deposit-types related to the tectonomagmatic evolution of the Oslo Region are reviewed from information contained in the publications cited elsewhere in this volume and from the authors' own recent investigations in the region. Several different morphological types may be distinguished among the deposits, each bearing a distinct spatial relationship to the supposed parent magmatic rocks. In all, five different classes (A–E) will be outlined below, based on this relationship, beginning with the intramagmatic deposits and moving successively outwards from the exposed igneous rocks.

A. Magmatic segregation deposits

Deposits apparently originating through processes of differentiation and segregation within magmas are not at all frequent in the Oslo Region, though one representative of this class would appear to be the economically most significant deposit yet found there. This is the P–Ti–Fe-bearing *jacupirangitic body* at Kodal in Vestfold, just north of Larvik. This potential ore body is located within the northern sector of a large larvikite massif in this southern part of the region. Recent investigations of the jacupirangite have shown that it has a dyke-like form, 20 – 35 m wide and about 2 km long. It strikes approximately E–W and has a general dip of 80°S. It has an average modal composition of 17–18% apatite, 40% ilmenomagnetite, 9% ilmenite, 30% pyroxene and 5% amphibole and biotite. The iron-titanium oxides and apatite cement the pyroxene in a typical igneous texture.

Along the borders of the main ore body, the larvikite shows lenses and patches of jacupirangite. This 'impregnation ore' is especially well developed on the footwall side, where it reaches a width of 100 metres. At its west end the jacupirangite has been modified by later nordmarkite intrusions.

Bergstøl (1972) considered that the Kodal ore formed as an immiscible melt in a monzonitic magma and was injected into the larvikite host rock while this was still in a semi-molten condition.

More recent work on the area is said to indicate that the jacupirangite body at Kodal is a true segregation deposit, situated along the margin of a former larvikite magma chamber. Less important ore bodies of similar origin are also encountered other places within the larvikite and lardalite massifs to the south–west (J. S. Petersen and P. Lindberg, pers. comm. 1976).

The intrusive bodies of the so-called Oslo-essexites, which comprise rocks ranging in composition from ultramafic to monzonitic, in places include pyroxenitic members containing considerable amounts of ilmenite and magnetite. Several now abandoned mines and prospects have been located on such deposits, the main interest being in the magnetite present. Among these may be mentioned the Husebye, Bjørnstad, Filtvedt and Knalstad mines located within the Huseby and Vestby Oslo-essexite necks (Ramberg 1970), which penetrate the Precambrian rocks on either side of the central part of the Oslofjord.

In the northern part of the Oslo igneous complex at Østre Toten some small mines, the Kultum mines, have been worked within a pyroxenite body, constituting part of a larger monzonite massif. The ultramafic body shows magmatic layering with concentration of ilmenite, magnetite and some iron sulphides.

B. *Vein deposits within the Oslo Region proper*

Vein deposits, mainly carrying sulphides of Mo, Cu, Pb and Zn, occur scattered in most rock-types encountered within the Oslo Region proper.

Among the *intramagmatic* vein deposits are the molybdenite-bearing quartz veins in the biotite granite near Drammen. These are usually associated with irregular areas of quartz–porphyry and aplitic granite in possibly apical positions with regard to the main intrusive body. Some of the molybdenite also occurs in granitic pegmatite veins and segregations, and along fissures with clay gouge (Bugge 1963). Disseminations are usually absent from the wallrocks which, however, show alteration in the form of silicification. The ore paragenesis is molybdenite and pyrite, with fluorite, scheelite and chalcopyrite as minor constituents.

In the past several of these molybdenite mineralizations have been mined along steeply dipping E–W or N–S striking vein systems rarely exceeding 2 m in width. Similar mineralizations are found inside the Finnemarka and Holterkollen granites.

Other intramagmatic vein deposits that can be briefly mentioned are the sulphide mineralizations within the ekerite massif south of Drammen. These occur along a N–S trending breccia zone with small, transverse, quartz veins carrying galena, sphalerite, chalcopyrite and fluorite (J. Olsen 1976, unpubl. results).

Perimagmatic vein deposits are especially numerous in the Alunsjø area. These mineralized veins are situated mainly along the contact between quartz–porphyry dykes and volcanic rocks. The ore minerals are associated with small quartz veins and, more rarely, occur as impregnations and veinlets in the wallrocks. They are dominated by bornite, chalcocite and chalcopyrite. Other perimagmatic deposits dominated by Cu sulphides have been reported from the Skien area (Segalstad 1975).

At Byrud along the southwest shore of lake Mjøsa, several small mines, now abandoned, were worked for emeralds in the past. They are situated in a flat-lying, discordant pegmatite; beryl (occasionally as emerald), topaz and fluorite occurring along its contact with silicified Cambrian alum shales and a Permian mænaite (syenite) sill. The pegmatite is possibly a differentiation product of the nearby alkali–granite of the area.

At Jeløya and in the Horten–Holmestrand area, several small occurrences of native copper have been recognized, among these the Gullholmen and Løvøya occurrences. (See also excursion No. 3). This mineralization type is connected with fissures and amygdales within basaltic lava flows (B_1). These are filled with native copper and some chalcocite and have calcite and prehnite as gangue minerals.

C. *Porphyry-type molybdenum mineralization*

A possible porphyry-type molybdenum mineralization has been recognised during recent investigations in the *Glitrevann cauldron* north of Drammen (A. Geyti and H. K. Schønwandt 1976, unpubl. results).

The central part of the cauldron consists of late, stock-shaped, multiple intrusions of aplitic granite and quartz-feldspar porphyries (Oftedahl 1953). The main molybdenite mineralizations, with associated alteration assemblages, are situated within the porphyries along the western and southern shore of lake Glitrevann. The main features of this mineralization are described later in this volume (p. 127).

D. *Contact-metasomatic deposits*

The contact-metasomatic deposits are situated along the exocontact at the immediate junction between mainly granites and adjacent sedimentary rocks or a short distance away, rarely exceeding a few hundred metres. The metasomatic alteration and accompanying ore mineralization are commonly located within limestones, often spatially related to igneous dykes. Some, however, also occur in altered hornfelses and in the igneous dykes.

The predominant skarn minerals are grossular–andradite, diopside–hedenbergite, epidote–clinozoisite, amphibole and chlorite associated with varying amounts of vesuvianite and wollastonite. The skarn bodies have massive and banded appearances.

In addition to wall-rock lithology, a very important control on the local distribution of the metasomatic alteration and ore deposition has been the faults and other fracture zones developed during the emplacement and later contraction of the crystallizing magma. These tectonic zones have served as conduits for both the skarn- and the ore-forming solutions. They have also been of great importance for the escape of surplus CO_2 and Ca released from the limestones as a result of the skarnification processes.

The deposition of the ore minerals (sulphides, oxides, etc.) can often be seen to be separated in time and space from the formation of the skarn. This is especially seen in the sulphide deposits and would also appear to explain the large number of barren skarns which are observed.

The major ore minerals are magnetite, hematite, scheelite, sphalerite, galena, chalcopyrite, pyrite, bismuthinite and pyrrhotite. Deposits dominated by bornite, chalcocite, molybdenite, arsenopyrite and Mn-oxides are less important. Accessories are fahlore, cobaltite, idaite, native copper, bismuthite, millerite, pentlandite, linnaeite-minerals and gold.

The ores form irregular concentrations within the skarn bodies, comprising disseminations, veinlets, irregular pods and larger massive bodies. They can be classified as oxide- or sulphide-dominated ores. The former contain mainly magnetite, hematite and scheelite, and the latter mainly sphalerite with varying amounts of galena and chalcopyrite. Some sulphide deposits are, however, dominated by bismuthinite, arsenopyrite, pyrrhotite and pyrite.

During recent years numerous *tungsten mineralizations* have been discovered inside the thermal aureoles. Scheelite is connected with metasomatic veins and irregular skarn bodies in different types of hornfelses and more rarely in skarn-altered limestones. The wallrocks are argillitic, calcareous and quartzitic hornfelses, some containing layers with nodular limestone. These deposits are especially numerous in the Mistberget and Hørtekollen areas and in the Korsegård–Dammyr areas near Drammen, where other metallic deposits are sparse.

The scheelite-bearing veins and bodies can be divided into early clinopyroxene–plagioclase skarns and late grossular–clinopyroxene skarns. Both are transected by younger scapolite veins giving rise to scapolitization of the plagioclase in the early skarns and in the hornfelsed calcareous wall rocks.

Along these veins argillitic hornfels (biotite hornfels) is bleached to a light green clinopyroxene–alkali feldspar hornfels. The largest concentrations of scheelite (usually high in molybdenum) are associated with the grossular stage. The mineralization consists of monomineralic aggregates of scheelite. Only accessory amounts of sphalerite, galena, chalcopyrite, pyrite and magnetite are associated with the skarn, but these minerals belong to a younger phase together with quartz, calcite and fluorite.

This mineralization type is clearly different from most other contact-metasomatic deposits in the Oslo Region in that the limestones present, including those bordering the mineralized hornfelses, show no signs of metasomatic alteration.

Subordinate concentrations of scheelite are also encountered in other oxide and sulphide ores, such as those at the Skjerpemyr and Nyseter mines in the Grua district, in several iron mines in the Skreia area and at Glomsrudkollen mine and Korsegårdseter prospect near Drammen.

Minor amounts of scheelite have also been recognised along epidote and quartz veins in the Cambro–Silurian and Precambrian rocks along the exocontacts.

The tungsten mineralizations can thus be subdivided into an early and a late stage. The latter deposition occurred more or less simultaneously with other ore minerals.

The *iron deposits* are mainly associated with skarns consisting of andradite together with minor clinopyroxene. Magnetite is the predominant ore mineral. All the deposits are situated within altered limestones, except some small occurrences of mineralized diopside hornfels in the Skreia area.

The Fe-oxides have partly crystallised simultaneously with the andradite and partly as somewhat later fissure and replacement veins. In the Hørtekollen area the magnetite-bearing skarns contain considerable amounts of helvine. This mineral has also been observed as an accessory mineral in the sulphide deposits. Near the ekerite contact at Andorsrud, near Drammen and at Tangen, near Lake Hurdalen, small occurrences of *manganese ores* have been found. This mineralization contains a mixture of different Mn-oxides, rhodonite, rhodochrosite and calc-silicates. The mineralization is probably of hypogene origin although it has apparently been modified by supergene alteration.

The largest *base-metal deposits* are associated with skarns dominated by clinopyroxene, epidote, amphibole and/or chlorite in altered limestones. In addition, small occurrences of sphalerite, pyrrhotite and pyrite are encountered in most contact aureoles, usually as skarn breccia veins in hornfelses.

The sulphide mineralizations are often associated with abundant fluorite, quartz and calcite deposited contemporaneously with the base metals or as later fissure and cavity fillings. This stage has in many cases succeeded brecciation of earlier-formed skarns. Introduction of sulphur- and/or fluorine-rich solutions into magnetite-bearing skarns to form mixed oxide–sulphide deposits, often led to a breakdown or retrograde alteration of early-formed calc-silicates (garnet–clinopyroxene) and formation of minerals such as actinolite, chlorite, biotite, epidote, hematite, quartz and calcite. Large fluorite-dominated veins occur at Andorsrud, Mistberget and Berg near Hakedal. They are probably related to a late, possibly truly hydrothermal, event.

On morphological criteria the pyrometasomatic deposits can be further subdivided into the following groups: 1) True contact-metasomatic deposits; 2) fault-controlled deposits; and 3) deposits spatially related to igneous dykes.

1) To this group belong deposits situated at the immediate junction between sediments and granites. Among these are the Narverud Fe, Krambodalen Fe and the Kjenner Bi deposits near Drammen, the Nyseter Zn deposit at Grua and the Paulshaugen Fe deposit at Skreia.

2) Several deposits with a more distant relation to the plutonic contacts can be included in this group. The major deposit among these are the scheelite mineralizations of the hornfels type, the Nikkerud Fe mines near Drammen and the *Glomsrudkollen* Zn mine. (See p. 129).

3) The most conspicuous deposits within the Oslo Region proper are the pyrometasomatic deposits spatially related to igneous dykes (diabase, quartz–porphyry and/or porphyritic syenite). The ore appears as veins and replacements along the contacts of the dykes, while replacement may occur for distances of up to several metres from the veins, especially in carbonate rocks. Examples of this type are found especially among the deposits in the Konnerudkollen–Åserud area south of Drammen. In the Konnerudkollen Zn–Pb deposit, the ore is situated partly along a system of diabase dykes and partly within these. Some of the dykes carry a central core of quartz porphyry that downwards gradually changes to coarse biotite–granite.

In the nearby Dalen mine such quartz–porphyries contain skarn veins with Pb, Zn and Mo mineralization. In the Mutta (Grua) Pb–Zn mine and the Bekke mine, the ore deposition and accompanying metasomatic alteration has affected the igneous dykes, while at the Skreikampen Fe mines both quartz–porphyry dykes and quartzite hornfelses situated outside the ore zone have undergone alteration to garnet skarn along cross-cutting fractures. Some of the ore bodies at the Nyseter mine are transected by late dykes that have been partly altered to epidote and scapolite.

The above observations would seem to indicate that the contact-metasomatic mineralization in the Oslo area is of both pre-, syn- and post-dyke age. This evidence is consistent with that described elsewhere in this report regarding the ages of dykes and vein deposits in the Precambrian areas outside the contact zones. Moreover, just as is the case with the latter dykes and veins the contact-near dykes and mineralizations seem relatable to common, large-scale, regional tectonic structures in the region. One may thus conclude that both the dykes and the ore deposits are related to common processes and have common sources, viz. the tectonic, magmatic and hydrothermal activity of the Oslo province rifting. It is thus perhaps of interest and worth noting here that the assumed parent igneous rocks themselves show, on the whole, very few signs of this ore-depositing activity, e.g., hydrothermal alteration.

Endocontact alterations have been observed in connection with some of the true contact-metasomatic deposits. Small areas within the intrusion show silicification and/or enrichment of fluorite, hematite, magnetite and epidote. Only at Bremsa mines, along the ekerite contact south of Drammen has a sphalerite – galena – chalcopyrite mineralization been observed both within the intrusive rock and in the adjacent skarn-altered country rocks (J. Olsen 1976, unpubl. results).

In the Skreia area autometasomatic sericitization and argillization have been observed, both in the ore bodies and the adjacent intrusion. Similar clay alteration can also be recognised in other ore deposits and along large-scale tectonic structures within the central parts of the intrusives, possibly caused by the latest hydrothermal solutions emanating from lower levels of the plutons.

E. Vein-type deposits in the Precambrian basement and overlying Cambrian sediments

Numerous vein deposits of varying mineralogy occur within a 20 – 25 km wide aureole around the Permian plutonics in the Oslo Region, and in connection with the larger rift structures along the Skagerrak and Kattegat coasts. Similar vein deposits are also identified in the northern thrust sheets. Among these may be possibly included the Krækkjeheia, Etnedalen and Tufsingdal occurrences.

Around the Oslo Region proper the vein direction is dominantly N–S and E–W similar to the intramagmatic veins earlier described from the Drammen area. Local deviations from this trend are observed in the Gjerpen area where the veins have a more NW–SE direction, i.e. parallel to the border of the Oslo Region. The veins show both cross-cutting and concordant relationships with the foliation and layering in the wallrocks. Concordant relationships are common among the N–S striking veins in the Kongsberg–Fiskum district.

The vein deposits can be separated into early quartz-breccia veins carrying base metal sulphides, and late calcite veins carrying native silver and Co–Ni-arsenides. They have been interpreted by C. Bugge (1917) as veins of first and second generations, respectively.

Veins of the first category are the most widespread. They consist mainly of quartz, with usually subordinate amounts of fluorite and calcite, and contain unaltered fragments of wallrock. They are usually 0.1–1 m wide, rarely exceeding 10 metres, and have a nearly vertical dip. They show repeated brecciation and fracturing with introduction and probably redistribution of both ore and gangue minerals, leading to recognition of several mineralizing stages. This is one of the main difficulties in establishing a clear-cut division between early and late vein deposits.

Ore minerals associated with the quartz veins are pyrite, sphalerite, galena and chalcopyrite. Some veins are dominated by fluorite, others by a magnetite–andradite paragenesis. The quartz-breccia veins can be traced for several kilometres but the concentrations ('ore shoots') have in most cases an erratic distribution along the structures. The veins appear to be closely related spatially to diabase and other dykes of the Oslo Region type. This is especially seen among the vein deposits in the southern and southwestern areas. The dykes show cross-cutting relationships with the veins at several localities indicating a pre-diabase age for the mineralization. Similar dykes are missing in the north-eastern areas around Eidsvoll.

Some of the quartz veins occurring in Cambrian sediments and mænaite sills just above the Precambrian basement and near the plutonic contacts are undoubtedly related to Permian activity. Deposits among this group are the Zn–Pb-veins in Mistberget, one of the andradite-bearing quartz–fluorite veins at Gjerpen, the Feiring Cu-veins and possibly the Pb–Zn-veins at Bø near Slemmestad. Recent work in the Mistberget and Feiring areas has shown that the ores contain accessory minerals such as Ag–Bi–Pb–tellurides, gold and Ag–Bi–sulphides (P. M. Ihlen 1976, unpubl. results). Many of the veins in the Gjerpen and Kongsberg districts carry considerable quantities of fluorite and only subordinate amounts of sulphides. Among these are the Lassedalen deposit south of Kongsberg and the Stulen deposit in the Gjerpen area.

The *Lassedalen deposit* is described in some detail below (p. 133). In the Gjerpen mining area there occur several parallel, steeply dipping, breccia zones having widths rarely exceeding 5 m. The largest of these, the Stulen breccia zone, actually forms the boundary between the Precambrian basement and the Cambro-Silurian sediments within the Oslo Region proper (Kaspersen 1976). The fluorite veins in this area are characterized by abundant andradite, magnetite and hematite that crystallized prior to the major influx of sulphide- and fluorine-rich solutions. The different paragenetic stages recognised in the Stulen area have a great similarity with the deposition trend found among the contact-metasomatic deposits. Some of the iron deposits within the Precambrian basement east of the Oslo Region are possibly similar to the Gjerpen vein type, although fluorite is probably missing in these deposits.

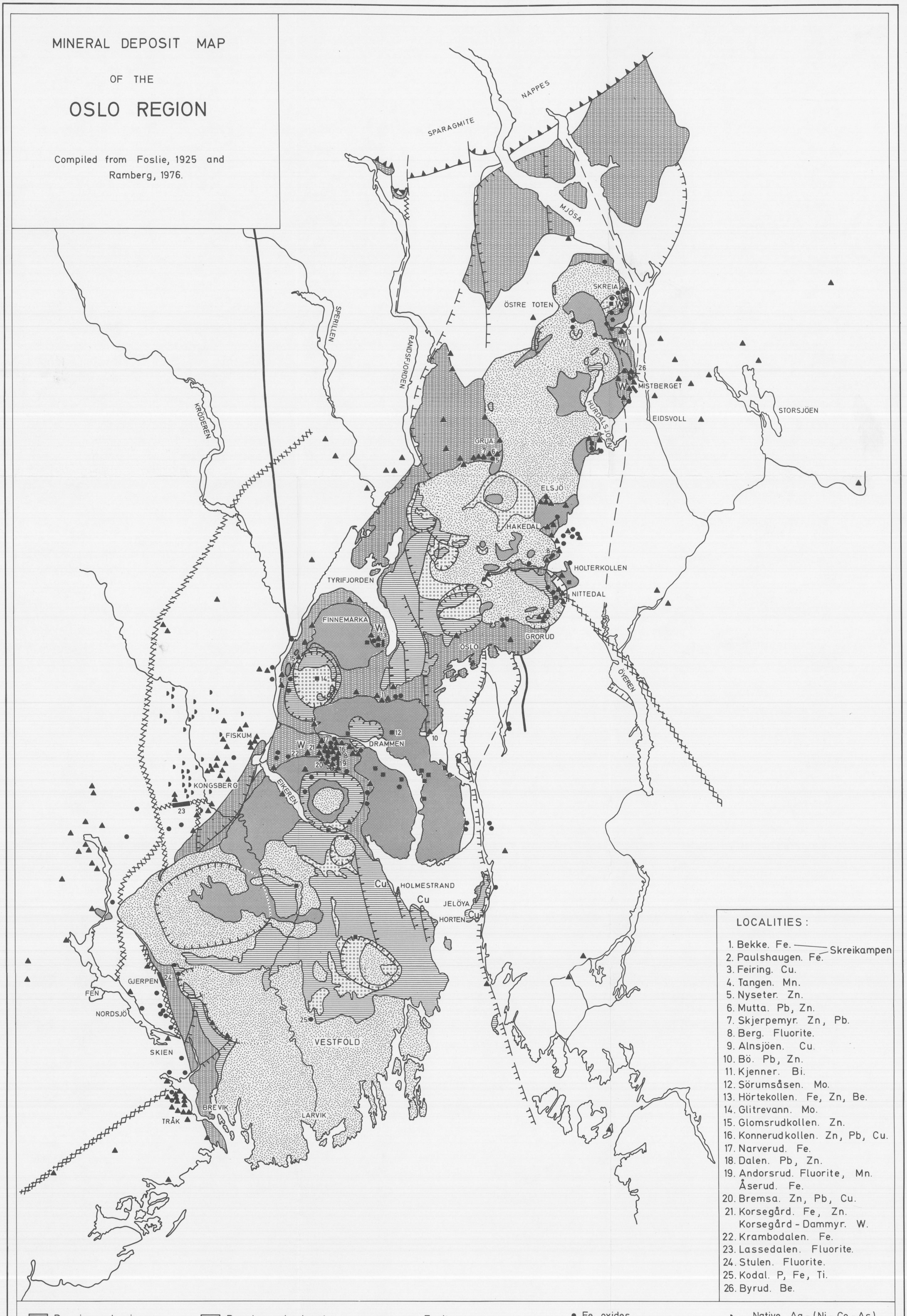
The youngest vein generation occurs mainly within the Kongsberg area as E-W striking calcite veins of 0.1–30 cm width. These well-known veins were worked until 1958 for their content of native silver. Neumann (1944) described in detail the minerals of the veins, comprising native silver, sphalerite, chalcopyrite, galena, argentite and Co-Ni arsenides. Besides calcite, the gangue minerals are fluorite, barite, chalcedony, zeolites, adularia, coalblende and other types of carbon. A more detailed account of the *Kongsberg silver veins* is given in the description of the excursion No. 4.

Wallrock alteration is a conspicuous feature related to the formation of all these veins and comprises chloritization, sericitization and argillization. Similar alteration products are also encountered in the Lassedalen and Stulen fluorite deposits and in some of the early quartz vein deposits, possibly showing that these have been modified by a late hydrothermal event synchronous with the formation of the Ag-bearing calcite veins. It is not unreasonable to suppose that the main fluorite deposition is related to this late event, as are possibly also the barite-dominated veins at Tråk and Heskestad.

Liquid-inclusion studies on quartz and fluorite from the Tråk, Gjerpen and Kongsberg veins gave formation temperatures in the range 200°–400°C. (Birkeland & Bjørlykke 1972, Bjørlykke 1973, Kaspersen 1976).

MINERAL DEPOSIT MAP
OF THE
OSLO REGION

Compiled from Foslie, 1925 and
Ramberg, 1976.



LOCALITIES:

1. Bekke. Fe. — Skreikampen
2. Paulshaugen. Fe. — Skreikampen
3. Feiring. Cu.
4. Tangen. Mn.
5. Nyseter. Zn.
6. Mutta. Pb, Zn.
7. Skjerpemyr. Zn, Pb.
8. Berg. Fluorite.
9. Alnsjöen. Cu.
10. Bö. Pb, Zn.
11. Kjenner. Bi.
12. Sörumsåsen. Mo.
13. Hörtekollen. Fe, Zn, Be.
14. Glitrevann. Mo.
15. Glomsrudkollen. Zn.
16. Konnerudkollen. Zn, Pb, Cu.
17. Narverud. Fe.
18. Dalen. Pb, Zn.
19. Andorsrud. Fluorite, Mn.
    Åserud. Fe.
20. Bremsa. Zn, Pb, Cu.
21. Korsegård. Fe, Zn.
    Korsegård - Dammyr. W.
22. Krambodalen. Fe.
23. Lassedalen. Fluorite.
24. Stulen. Fluorite.
25. Kodal. P, Fe, Ti.
26. Byrud. Be.

▤ Permian extrusives

▩ Permian biotite granites and alkaligranites

▨ Permian monzonites, syenites and nordmarkites

▦ Permian subvolcanic porphyries

▩ Cambro-Silurian sedimentary rocks

☐ Precambrian rocks

— RP - dykes

Faults

Breccia zones

▲ ▲ ▲ ▲ Overthrusts

0 5 10 15 20 25 km

● Fe oxides

Mn oxides

▲ Pb - Zn - Cu sulphides

■ MoS_2

Native Ag - (Ni - Co - As)

▬ Fluorite + Beryl

W Tungsten

Cu Native copper