NGU rapport nr: 85.131

RECONNAISSANCE STUDY OF REGIONAL GEOLOGY AND MINERALIZATION IN THE BAMBLE REGION SOUTHERN NORWAY

Norges geologiske undersøkelse

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Rapport nr. 85.131	ISSN 0800–3416	Åpen/~~Fortrolig til~~ XXXXXXXX

Tittel:
Reconnaissance study of regional geology and mineralization in the Bamble region, southern Norway

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Fylke: Aust-Agder, Vest-Agder, Telemark	**Kommune:** Diverse
Kartbladnavn (M. 1:250 000) Arendal, del av Skien	**Kartbladnr. og -navn (M. 1:50 000)** 1511.1,1511.2,1511.3,1611.1,1611.4, 1512.2,1612.1,1612.2,1612.3,1612.4, 1712.1,1712.3,1712.4,1713.2,1713.3
Forekomstens navn og koordinater: Espelandsmyr Skyttemyr	**Sidetall:** **Pris:** kr.100.oo **Kartbilag:** 3

Feltarbeid utført:	Rapportdato:	Prosjektnr.:	Prosjektleder:
1983-1984	3. juli 1985		

Sammendrag:

Rapporten omhandler Arco Norway Minerals A/S's Bamble-prosjekt fra årene 1983-85, de enkelte bergartstypene og deres opprinnelse. Spesiell vekt er lagt på de ekshalitive bergarter og tilknyttet mineralisering, bl.a. gull. Forslag til videre prospektering finnes i eget kapittel. Som vedlegg finnes en kartsammenstilling i M 1:100 000. Den bygger på nedfotograferinger av sammenstillinger i M 1:50 000, basert hovedsakelig på publiserte data.

Emneord		
	Berggrunnsgeologi	Prospektering
	Malmgeologi	
	Geologisk beskrivelse	

DISTRIBUSJONSLISTE FOR NGU RAPPORT NR. 85.131

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Introductory remarks

In the years 1983-1985 Anaconda Minerals Company, USA, carried out significiant ore prospecting programmes in Norway through its Norwegian subsidiary Arco Norway Minerals A/S. One of its major projects was an investigation of the Bamble area - in geological terms the wellknown zone of Proterozoic rocks between Kristiansand and Porsgrunn, S. Norway. Investigations, however, came up to an abrupt halt in 1985 as a result of a decision by the parent company to discontinue all mineral prospecting. The Bamble project was duly terminated in July 1985. However, the amount of of data generated by the project was considerable and covered the fields of geological mapping, geochemical sampling and geophysical surveying. Arco (Oslo) accepted NGU´s offer to take responsibility for archiving them. The present report is a summary of the geology of the area as seen by the Arco team in July 1985. While not claiming to be exhaustive it describes important features of the geology and introduces some new ideas. These include:

- lithological subdivision of the rocks
- origin of certain gneissic rocks, and identification of exhalative types
- types of mineralization and their classification
- the possible occurrence of gold
- suggestions for future prospecting.

The geological map is mainly a compilation of existing published data, but also includes annotations made by the Arco team, particularly as regards the many rust zones in the area. Detailed geological mapping at 1:5000 scale using new topographic maps was also carried out in selected areas as follow-up work for certain ore geological targets. These data are not yet fully evaluated, but will be incorporated in map compilations now in progress at NGU. Geochemical and geophysical data are currently being studied at NGU, and can be seen on request.

NGU has pleasure in publishing this information in their report series, and would point out that the views and opinions expressed in the report are those of the Arco team, unabridged by NGU.

In conclusion, NGU would like to record their thanks to Arco for the cooperative spirit shown by the company at all stages of the programme culminating in transfer of this valuable material to NGUś archives for use by future workers in the area.

Berggrunnsavdelingen
05.09.86

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Reconnaissance Study of Regional Geology and Mineralization
in the
Bamble Region, Southern Norway

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Text to accompany the 1:100.000 scale geological map submitted to the Geological Survey of Norway, Postboks 3006, 7001 Trondheim.

ABSTRACT

The Bamble area of southeast Norway covers about 4.500 square kilometers along the Skagerak coast. Rocks of Proterozoic age include highgrade gneiss, mafic plutonic intrusions, granitic intrusions and metamorphosed assemblages of volcanic-sedimentary rocks in amphibolite to granulite facies. The rocks occur in a NNE-trending synclinorium with cascade-type folding along its western limbs. Mixed felsic and mafic volcanic rocks and sediments dominate the northwestern limb, while sediments dominate the southeastern limb. Elongate, lens like units of exhalite-bearing strata containing cherts, albitites and marbles occur in the transition zone from mixed volcanic-sedimentary strata to dominantly sedimentary strata.

Mineralization in the area is of three general types: 1) ores associated with mafic plutonic intrusions, 2) magnetite mineralization in the exhalite-bearing strata, and 3) sulphide mineralization in the exhalite-bearing strata. Exploration by ARCO Norway, Inc. indicates that the greatest potential lies in the third type. Significiant occurrences of gold mineralization have been located in areas underlain by exhalite-associated rocks where metamorphosed, synvolcanic alteration assemblages occur. Gold occurs both in epigenetic veins and in disseminations in synvolcanic strata. Some potential exists for copper-zinc and silver-lead-zinc massive sulfide deposits.

The most promising areas for prospecting appear to be in the vicinities of Sannidal, Skyttemyr, Bakkevatnet, Gjerstadvatn and Solvang. Localities and recommendations for further work are discussed.

INTRODUCTION

The Bamble area of southeast Norway includes about 4.500 km^2 along the coast between the towns of Porsgrunn and Kristiansand (Fig. 1)

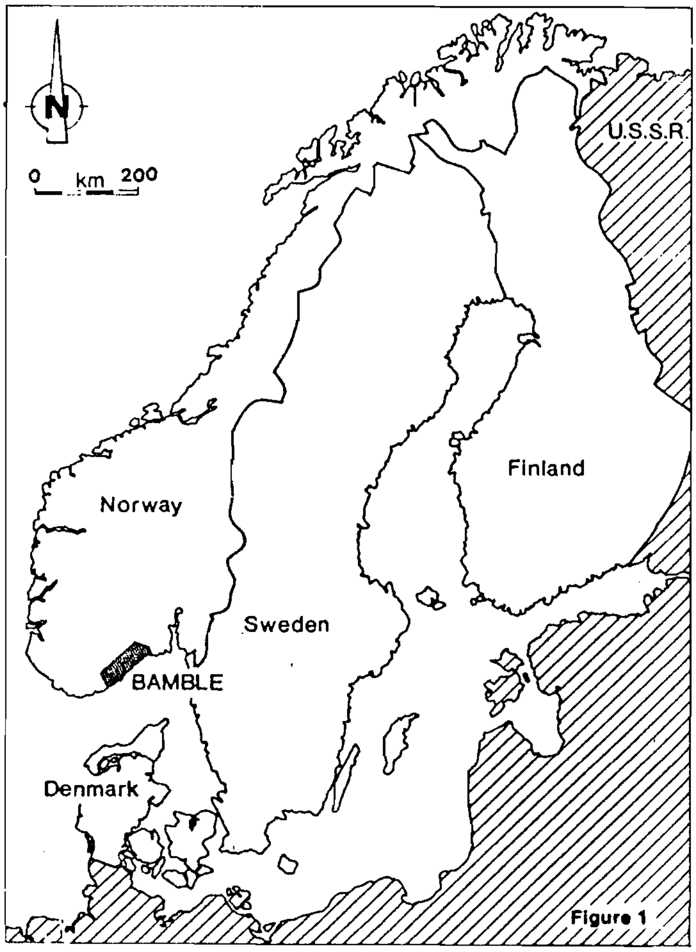


Figure 1

The Precambrian rocks of the Bamble region are truncated towards the north-northeast by the Oslo Graben and limited to the southeast by the Skagerak. To the northwest occur high grade Precambrian gneisses and granitoids of the Telemark suite.
The "Great Friction Breccia" separates the Telemark and Bamble areas.

Rock types in the Bamble area include high-grade gneiss, mafic plutonic intrusions, granitic intrusions and the metamorphic products of mixed volcanic-sedimentary rocks. Although the rocks have been metamorphosed and deformed several times, structures in the area tend to parallel the north-northeast trend of the Great Friction Breccia.

Strata generally dip 60^{o} to 90^{o} towards the south-southeast, and locally appear to be isoclinally folded. Shearing has been significant near the Great Friction Breccia. Metamorphic grades range from amphibolite facies in the northwestern part of the region (near the Great Friction Breccia) to granulite facies near the coast.

Radiometric age determinations by O´Nions et al. (1969), O´Nions and Baadsgaard (1971), and Neumann (1960) indicate the sequence may be composed of Upper Proterozoic rocks. It is also possible, however, that the K/Ar age determinations of 1125-975 m.y.b.p. merely reflect the Sveconorwegian Orogeny; true depositional ages may be much older.

During 1983, ARCO Norway Mineraler A/S (Anaconda Minerals Company) undertook a regional geological mapping program in the area in order to provide a basis for interpreting geochemical and geophysical data, and to highlight strata of particular interest with respect to mineralization. Previous geologic mapping had been too widely scattered to give a regional view of stratigraphic relations (see map 85.131-02).

The results of ARCO´s mapping are the subject of this article. The 1:50.000 scale geologic maps compiled by Pedersen in 1983 are compiled at 1:100.000 scale for the purpose of this report (see map 85.131-01 A,B). The reader should keep in mind that while the work has clarified several aspects of the region´s geology, there are many unanswered questions and problems.

Also, because there are rapid lateral and vertical facies variations within the area the map units shown are an amalgamation of several rock types. There is, however, a significant regional continuity of the dominant map units.

The most significant aspect of ARCO´s work in the Bamble region is that it has delineated a mixed, volcanic-sedimentary terrane within deformed Proterozoic rocks that contains potential for synvolcanic gold deposits in three areas, epigenetic gold deposits in three areas, and synvolcanic base metals deposits in two areas. Additional work should be done in these areas, which are described below.

DESCRIPTION OF MAP UNITS

The following descriptions of map units are based primarily on field descriptions and limited petrographic work. No major or minor element chemical data are available to assist in classifying the rocks.

I. Volcanic-Sedimentary Rocks:

There are 3 general classes of volcanic-sedimentary rocks:

- Type 1. The volcanic-sedimentary rocks of southern Bamble area.
- Type 2. The volcanic-sedimentary rocks of northern Bamble area.
- Type 3. The exhalite-bearing, volcanic-sedimentary rocks of northern Bamble area.

Type 1. The volcanic-sedimentary rocks of southern Bamble:

Type 1 rocks occur south of the Herefoss granite and include gneiss, mafic rocks, and minor biotite schist and quartzite. The gneisses are more common here than to the north, and range in composition from very silicic to felsic. They are medium to fine grained, thin bedded and characterized by a typical "sugary" weathering that may appear rusty due to oxidation of minor disseminated pyrite and pyrrhotite. These gneisses are interpreted to be metamorphosed, waterlain sediments which were derived from source rocks occurring to the west (Telemark) and north (Bamble).

The "amphibolites" of the southern Bamble area are not strictly amphibolites. They are black, "sugary" textured, and exhibit pillow-shaped weathering surfaces which are characteristic of the unit. The rock contains 20-30% quartz, 30-40% plagioclase, 30% hornblende and 10% biotite with accessory K-feldspar and iron sulphides. This suite changes laterally to the north into a conglomeratic rock containing chert clasts in a matrix of calc-silicates, quartz, minor feldspar and hematite. The orientation of chert clasts is suggestive of cross-bedding.

Type 2. The volcanic-sedimentary rocks of northern Bamble:

Type 2 volcanic-sedimentary rocks consist of two main lithologies: gray, diffusely-banded, felsic gneiss and homogeneous amphibolite. On the geological map these volcanic-sedimentary rocks are grouped into units with more than 70% amphibolite and units with less than 70% amphibolite. In addition to felsic gneiss and amphibolite, the volcanic-sedimentary rock unit contains minor amounts of dark biotite gneiss, biotite schist, gneiss with a granitic composition (type 5, see below) and quartzite. Larger quartzite bodies are shown separately on the map, and where these look cherty (see description below), it is separately mentioned. All the rock types are strongly intercalated, and thicknesses of layers range from 1 cm to several hundred meters, 2 to 6 meters being average. Rapid lithological changes occur both across and along strike. The borders of the individual rock types within the unit are usually gradational, but may be sharp.

The gray felsic gneisses are diffusely grey-white banded and contain 40% plagioclase, 30% quartz, 10% K-feldspar, 10% mica (biotite, phlogopite and muscovite) and 10% accessory minerals including garnet, hornblende, sphene, apatite and opaques. Towards the Type 3 exhalite-bearing volcanic-sedimentary rocks the mineralogy becomes more complex and minerals such as sillimanite, garnet, cordierite, and carbonates become important. Beeson (1975) reports petrographic and geochemical details on metasedimentary gneisses from the Gjerstad area.

The amphibolites exhibit a speckled, gray and white texture, and are homogeneous, massive and thick bedded. The average mineral content is 40% plagioclase, 10-20% quartz, 30-40% hornblende and 10% biotite. Important accessories are apatite, sphene and opaques (magnetite, pyrite and pyrrhotite). In all investigated thin sections a fairly high quartz content is seen, and thin quartz layers are common.

Type 3. The exhalite-bearing volcanic-sedimentary rocks of the northern Bamble area:

These rocks occur in elongate, lens-like units, here termed "trends" which contain cherts, albitites and marbles inferred to be of exhalative origin. Other rock types include: calc-silicate rocks; amphibolite; and sillimanite, garnet or cordierite gneiss and quartzite. The chert, albitite and marble are distinctive rock types in the trend, and the amphibolite and felsic gneiss appear to be enriched in Al, Mn and Fe as indicated by their enrichment in garnet, sillimanite, corderite, and magnetite or iron sulfides. These types of metamorphic rocks can be formed from several original rock types, e.g., ancient regoliths or pelitic sediments, or by alteration during metamorphism. However, field evidence indicates that the abundant occurrence of these minerals within particular areas is related to metamorphism of hydrothermally altered rocks, with the alteration having occurred during late stages of volcanism. Thus, the exhalite-bearing trends are hosted in metamorphosed, hydrothermally-altered strata. Rapid changes in lithology, intimate interlayering of the rock-types, and sharp internal contacts between units are characteristic of the trends. Most of the sulphide and magnetite mineralization of the Bamble area is within these trends. The exhalite-bearing trends are characterized by a lithologic and mineralogical complexity that is not found outside the trends.

Chert and albitite units

Quartzite with a cherty appearance occurs within the quartzite units and as thin layers in the felsic gneisses, very often with sulphide or magnetite mineralization. The albitite occurs, as cm to 20 meter thick horizons interbedded with felsic gneiss in areas near sulphide or magnetite mineralization, e.g. between Solvang and Gjerstad. There is a complete gradation between chert and albitite and they often grade into each other.

The cherts are weakly mica-foliated, dm-thick bedded, and often have a pitted surface due to oxidation of mm-sized blebs of ankerite. Single, isolated mm-sized grains of K-feldspar and diopside are common. The color is whitish-grey with gray shades parallel to bedding.

The albitites are often very garnetiferous, and coarse intergrowths of albite and quartz are common. In some places the albitites grade into a K-feldspar - bearing variety. Thin layers of chert and albitite are commonly interbedded in felsic gneisses and were preferentially mobilized during metamorphism, so that minor cross-cutting veins occur.

The cherts and albitites are interpreted to have formed from gels produced by exhalations onto the sea-floor.

Marbles

Marble is easily weathered and it has been noted only in road-cuts. The marbles may therefore be more widespread than recognized. Calcite-ankerite marble occurs north of Skyttemyr/Bøylestad mine. Ankerite marble is seen in 5 places along highway E18.

Three types have been seen. One is an equigranoblastic, medium-grained calcite-ankerite marble with accessory ore minerals and pseudomorphs after scapolite (indicates a Na-rich brine). The second type is massive, green ankerite marble with accessory pyrrhotite, graphite or thin mica-layers. On fresh surfaces the ankerite is green but on weathered surfaces it is brown to rusty. The thicknesses of the marble horizons range from 0.5 to 8 meters and their lateral extent appears to be limited. Marble and calc-silicate horizons are present in significant amounts in strata in the Skyttemyr and Sannidal trends.

These carbonates occur near areas mapped as volcanic centers and are interpreted to have formed as chemical precipitates from solutions exhaled onto the sea-floor. The apparently smaller lateral extent of the marbles compared to the chert/quartzites may indicate that the marbles occur very close to vents.

A third, distinctly different, dirty, well-layered dolomitic marble hosts the Espelandsmyr mine Pb-Zn-Ag ore. This thin carbonate horizon can be traced for at least 7 kilometers along strike and is represented by varying amounts of dolomite, calcite and calc-silicate.

Calc-silicate rocks

Calc-silicate rich horizons are wide-spread within the exhalite-bearing, volcanic-sedimentary trend. The minerals present are amphibole (tremolite-actinolite), diopside, garnet and minor glaucophane. Mineralization is often associated with the calc-silicate - bearing rocks, and the magnetite ores of the Arendal area are hosted in coarse-grained, banded diopside-garnet rock.

Amphibolites

Many, but not all, of the amphibolites within the exhalite-bearing trend are noted for a high garnet content, the garnets being as large as 30 cm. Other amphibolites are noted for a minor magnetite content. Garnet contents within amphibolite increase with proximity to exhalites, an observation that indicates deposition of exhalites and alteration of surrounding (and overlying) strata were concurrent. An examination of thin sections from selected amphibolite units shows that they all have a high quartz content (10-20%). Quartz occurs both disseminated and in mm- to cm-thick quartz lenses.

Some of the amphibolites of the trend are characterized by thin quartz layers and biotite foliations. An examination of a thin section from one of these amphibolites shows that it contains free carbonate, and it is probably a sedimentary-derived amphibolite. In some outcrops, the amphibolite exhibits pitted surfaces 1-3 meters wide and parallel to bedding which are the result of bedded carbonate being preferentially weathered out.

Garnet, sillimanite or cordierite gneiss and quartzite

The garnet-bearing felsic and siliceous gneisses are often diffusely banded like their equivalents outside the trend, but are characterized by up to 40% mm-sized red-violet garnets.

The sillimanite-bearing gneisses are characterized by a very typical weathering, where nodules of fibrous sillimanite and quartz stand out. The content of sillimanite is normally between 5 and 15%, but percentages as high as 50% are not unusual. A typical example has grain size ranging 0.5-3 mm, with the grain sizes generally bimodal. Coarse quartz-garnet layers occur within a finer-grained matrix. Minerals present are 20% fibrous sillimanite, 20% K-feldspar, 30% quartz, 10% garnet, 10% plagioclase, 10% biotite and accessory opaques.

Cordierite occurs in quartzite sampled south of Sannidal along E18. The cordierite is seen in the field as 2 - 4 mm sized, rounded, dark-grey porphyroblasts (ca. 10%) in a cordierite quartzite. In thin section, large rounded cordierite porphyroblasts occur in a matrix of equigranoblastic quartz-biotite-feldspar matrix. Phenocryst proportions average 40% quartz, 40% cordierite, 10% biotite, 10% K-feldspar and accessory sillimanite. The cordierite quartzites are apparently not very wide-spread and were only seen in the Søndeled-Sannidal area.

II. Granitic Gneiss and Augen Gneiss:

Due to the many metamorphic and structural events in the Bamble area the grouping and interpretation of the various types of granitic gneiss, augen gneiss, granulite facies gneiss (Arendalite and others) is very complex. Table 1 shows a general division into 5 types based on lithological and structural evidence. The division leads to an interpretation of how the various types were formed. Future work is likely to alter the model, due to the lack of details recorded during this reconnaissance field-work.

TABLE 1.

Type	Criteria
Type 1. Augen gneiss	sharp contacts, homogeneous composition, marker horizon in surrounding rocks parallels the contact, cross-cutting contacts (intrusive).
Type 2. Augen gneiss	gradational contacts, contains relicts of surrounding rocks (granitization) and feldspar augens.
Type 3. Granitic gneiss	gradational contacts, contains relicts of surrounding rocks (granitization).
Type 4. Granitic gneiss	sharp contacts, but with thin concordant layers of granitic gneiss in surrounding rocks (meta-arkoses, metasiltstones or metarhyolites).
Type 5. Granitic gneiss	homogeneous composition, sharp contacts, igneous-textured in center, gneissic along borders. Orthogneiss.

Type 1. Augen gneiss

Examples of this type of gneiss are seen west of Espelandsmyr mine and south of Herefoss granite. The augen gneisses are homogeneous, K-feldspar porphyroblastic; single porphyroblasts are up to 10 cm in size, and the gneisses in general appear to be of potassium-rich granitic composition.

The augen gneiss south of Herefoss granite is characterized by a very homogeneous composition and knife-sharp contacts with the country rock. The Espelandsmyr augen gneiss is somewhat more complex. The eastern, northern and southern contacts are very sharp, whereas the contact towards the west and the Great Friction Breccia is more complex and gradational, probably because of the influence of the shear zone found there.

The bedding in the country rock parallels the contacts with the augen gneisses, and near Espelandsmyr mine a marker horizon can be followed for several kilometers at a constant distance from the contact. At the northerly end of the Espelandsmyr gneiss body, cross-cutting and discordant contacts with surrounding rocks are observed (Grahl-Madsen and Bech, 1984). Moreover, thin layers of gneiss become conformable with surrounding strata. These contact relationships, combined with the homogeneity of the augen gneiss and the absence of fragments of gneiss in the surrounding sediments, indicate that it represents an intrusion.

Touret (1961) argues that the Espelandsmyr augen gneiss could be a granitized metasediment. This is unlikely because of the contact relationships described above and the fact that layers with similar composition 50 meters above the contact are not affected by the inferred granitization.

Type 2. Augen gneiss

This type is especially frequent along the coastline, where higher metamorphic grades occur, and also near the Great Friction Breccia.

This augen gneiss is characterized by common relicts of un-granitized felsic gneiss, amphibolite and quartzite, and by gradational contacts where a gradual development of K-feldspar porphyroblasts occurs over 200 to 800 meter wide zones. A good example is seen by Solumåsen, on map-sheet 1511 II, SW corner.

Near the Great Friction Breccia this augen gneiss type is clearly developed postkinematically. Development of postkinematic K-feldspar porphyroblasts and augen gneisses is one of the most characteristic features in the shear-zone near the Great Friction Breccia.

This type of augen gneiss was formed by granitization.

Type 3. Granitic gneiss

This type is seen in many places, as for example near Akland, at the SE-corner of the Nelaug map-sheet, near the Levang granite (old name), east of Kragerø, and in the coastal area from Arendal to Risør.

The contacts with surrounding rocks are gradual. Up to the arbitrary limits to the granitic gneiss, increasing amounts of granitic and granodioritic gneiss occur, as well as relicts of felsic gneiss, amphibolite and quartzite which are common within the granitic gneiss. Generally they are metamorphosed to upper amphibolite facies. However, in the coastal area between Arendal and Risør granulite facies is reached and a hypersthene-bearing gneiss known as "Arendalite" is found (Starmer, 1972A; Bugge, 1943).

Like the above described type 2 augen gneiss, these granitic gneisses were clearly formed by granitization.

Type 4. Granitic gneiss

This type is seen as thin layers in many places and the large Farsjø "granite" belongs to this type.

Internal compositional variations, well-bedded nature and interlayered amphibolite characterize this granitic gneiss. It is also characteristic in this type to find a sharp contact with the surrounding rocks, and also to find thin concordant granitic gneiss layers within the gneiss.

Due to the layered nature, the compositional variations and the sharp contacts, this type of granitic gneiss is interpreted as being derived from meta-arkoses, metasiltstones or metarhyolite.

Type 5. Granitic gneiss

This type of granitic gneiss is known in two places: south of Akland and the Helle granite (old name) west of Kragerø.

The two granitic gneisses have a granitic core and a gneissic rim. The contacts to the surrounding rocks are sharp, but somewhat obscured by many pegmatites which surround the two granitic gneisses. The composition is homogeneous and granitic. The two granitic gneisses are interpreted as being old granitic intrusions, now partly metamorphosed.

Parts of the Levang granite (old name) may also be of this type.

III. Mafic Plutonic Intrusions and Albite Pegmatites:

The mafic plutonic intrusions of the Bamble area are widespread but are particularly abundant in two centers. The major center is located in the Kragerø-Bamble region and the minor center is found in the Risør-Søndeled area. The areal extent of individual intrusions ranges from 0.5 to 8 km^2.

Morphologically, the intrusions stand out as topographic highs. The hyperites/gabbros are intruded semi-concordantly; the foliation of the surrounding rocks tends to bend around the intrusions and only minor discordant relationships are found.

The rims of the individual intrusions are often metamorphosed into homogeneous amphibolite and it is suggested by Starmer (1969B) that the plutons were intruded between two major episodes of metamorphism and deformation.

The intrusions have a mafic to ultramafic composition and later metamorphism has changed some of the olivine into hypersthene and amphibole - thus producing the hyperites, which is the normal term applied to the intrusions in the area (Bugge, 1943 and others). For details about the composition of the intrusions see Starmer (1969B).

Albite pegmatites are often found close to the mafic plutonic intrusions and have been given the local name Kragerøite (Green, 1956). The Kragerøites are found as meter-thick cross-cutting pegmatites and as major intrusions south of Kragerø. The minerals are mainly albite, some quartz and diopside, and accessory sphene, rutile and Ti-magnetite. Rutile was mined from Kragerøite in various places; the largest of the ancient mines occurs just south of Kragerø.

IV. The Herefoss and Grimstad granites

The huge Herefoss granite and the minor Grimstad granite are situated north of Birkeland and around Grimstad town respectively. The granites, especially the Herefoss granite, occur as distinct hills.

The granites are younger than the rest of the rocks seen in the Bamble area and have ages, based on K/Ar determinations, which range from 956 to 850 million years, although some data indicate slightly older ages (Starmer, 1972B).

The contacts of the granites with the surrounding rocks are sharp, irregular and cut general bedding in the host rock. Up to 5 kilometers from the borders of the granites there is a large number of cross-cutting pegmatites and in some places manganese oxides on joint surfaces.

The granites appear to be homogeneous in composition and are unfoliated. K-feldspar porphyries occur locally, but in general the granites are medium-grained and equigranular.

STRUCTURES

The Bamble area is often called the Bamble linear belt due to the strong NNE-trending lineaments seen in the area. This linearity is seen in the morphology, the aeromagnetic maps and in the geological maps. The NNE strike of the rocks parallels the Great Friction Breccia. In areas nearest the Great Friction Breccia this parallelism is strongest.

Towards the coast the rapid changes across strike decrease and the geology becomes complex due to the many intrusions in the coastal area. These intrusions mainly occur in two regional centers located in Kragerø-Bamble region and in Risør-Søndeled region. Below is a summary of some of the structural elements of the area.

I. The Great Friction Breccia:

The Great Friction Breccia is a zone of weakness that has been reactivated several times. The most prominent features are a 0.5 to 4 kilometer wide shear zone and a later fault (the Porsgrunn-Kristiansand fault) expressed by mylonites. The initial opening of the basin, in which the rocks of the Bamble area were deposited, is likely to have occurred along a marginal fault with the same location as the Great Friction Breccia. However, shearing has obscured evidence of this possible relationship.

The shear zone is widest in the area between the Herefoss granite and Kristiansand in the south, and in the area between Nelaug and Porsgrunn in the north. Here the rocks are characterized by blastomylonites, chloritization and development of late postkinematic K-feldspar porphyroblasts. The bedding is characteristically very sharp, thin and almost schistose in places, but still determinable as bedding. Within the Herefoss granite the shear zone is not seen, and in the area between the Herefoss granite and Nelaug the shear zone is very narrow and mainly expressed as numerous subconcordant pegmatite intrusions in a 1 to 3 kilometers wide zone.

Based on gravimetric surveys and the orientation of the shearing, the Great Friction Breccia has been estimated to have a NNE strike with a steep 80° easterly dip (Morton et al., 1970). This orientation is, however, not seen in the orientation of the blastomylonites of the shear-zone, due to later compressional folds with a typical wave-length of 50 to

150 meters and flat-dipping, NNE-orientated fold axes. This is best seen along the road from Gjerstad railway station towards the west and in the area south of the Herefoss granite. This is in contrast to the steep dips found in the rest of the Bamble area.

The later Porsgrunn-Kristiansand fault occurs as a 1- to 50-meter thick zone of mylonite with a steep easterly dip. In the northern part of Bamble, the fault is found along the western margin of the shear zone, and just north of the Herefoss granite the fault splits into two arms. The westernmost of the two goes west of the Herefoss granite and dies out 10-20 kilometers south of this. The other arm divides the Herefoss granite and follows the trend of the shear zone south of the Herefoss granite. It is likely that the Herefoss granite operated as a strong plug in an old zone of weakness. The fault first went west of the Herefoss granite, and later transected it. The rock types between the two arms are distinctly different from those of the Bamble area and they probably belong to the Agder complex (Falkum, 1982).

The movements associated with the fault were mainly vertical and the downward displacement of the eastern side has been estimated to be at least 500 meters (Morton et al, 1970).

II. Structures outside the Great Friction Breccia:

Near the Great Friction Breccia a belt of NNE-striking and generally steeply-dipping rocks occurs. The belt hosts the exhalite-bearing, volcanic-sedimentary trend. On air photos some indications of isoclinal folding within the belt are seen. Mapping along traverses and roads indicates that isoclinal folding is apparently not as common as inferred from air photos. Facies variations along strike appear as lens-like bodies and seem to be the cause of some of the patterns. Also, "cascade-type" folds with tight isoclinal limbs occur along the limbs of a major synform (Figure 2) and also account for some of the patterns seen in the air photos.

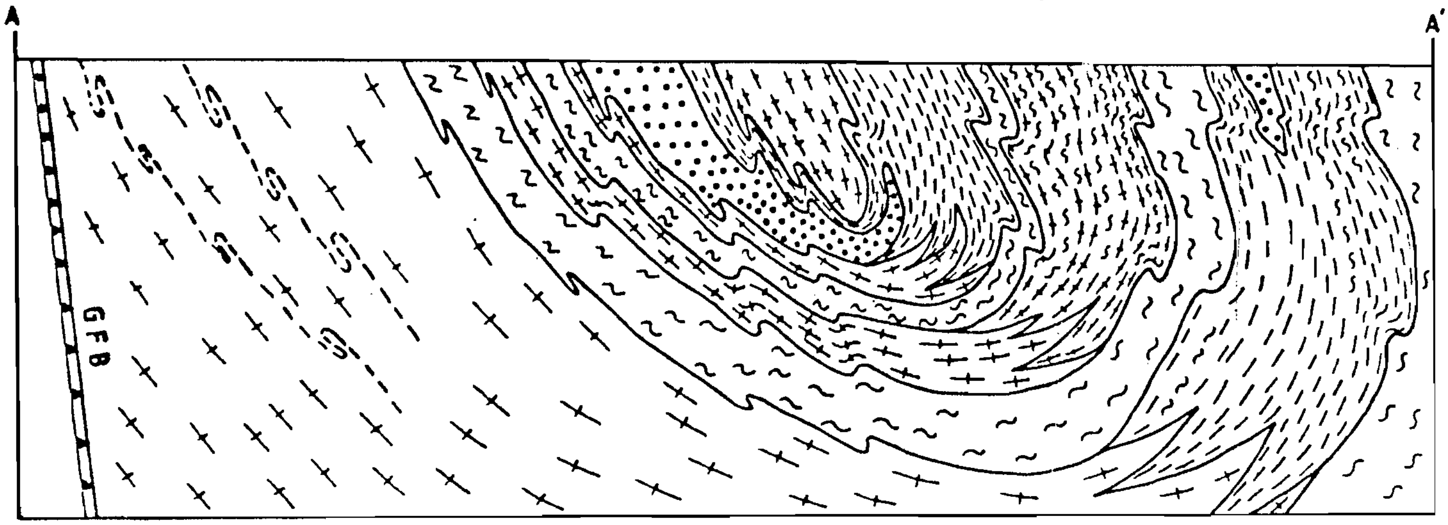


FIGURE 2

Generalized geologic cross section from the vicinity of Åmli to Tvedestrand area showing a simplified interpretation of geologic relationships. Facing evidence has been observed only rarely. The mixed volcanic-sedimentary sequence near the Great Friction Breccia (GFB) is inferred to change laterally southeastwards (stratigraphically laterally) to distal sediments. The higher metamorphic grades observed nearer the Skagerak may be the result of deeper erosion of the southeastern limb of an overturned synclinorium. Intraformational isoclinal folding occurs locally, with tighter folding nearer the GFB and more open folding towards the coast. Not to scale. Legend see map 85.131-01 A,B.

Open to tight folding becomes more obvious in the coastal area, and numerous igneous intrusions occur. The coastal area is also characterized by high-grade metamorphism between Kragerø and Arendal, and just south of Lillesand.

Primary, cross cutting contacts occur south of Sannidal on a scale of 500 meters. These rocks resemble the pipe of an extrusive center and strongly indicate that shearing parallel to bedding did not occur in this area (Pedersen, 1984). Although similar relationships have not been observed elsewhere, it is reasonable to assume that shearing parallel to bedding is not a prevalent phenomenon in the rest of the region.

Brecciated rocks are not very widespread, apart from the area near the Great Friction Breccia. An exception is the area west of the Helle granite (by Auråa) where brecciation is quite common (see next paragraph).

III. Fault and joint-patterns

Looking at the topographic maps of the area, a striking NW trend is evident in the pattern of rivers and lakes. Morton et al. (1970) have made a fault-pattern study of the northern Bamble area, and Røsholt (1967) made a joint-pattern study in the Tråk area. The fault-pattern study revealed two maxima. The one with a NE direction was interpreted by these workers as being old faults sub-parallel to bedding and perhaps associated with shear stress created by formation of the Great Friction Breccia. The other direction is NW and probably related to the opening of the Permian Oslo Graben. In the northwestern part of the Bamble region, numerous NW-trending narrow valleys are cut along breccia fillings consisting of carbonates and idiomorphic to drusy quartz (Pedersen, 1984).

The joint pattern has two maxima with orientation ESE and SSE. The ESE orientation was interpreted as being due to tensional joints associated with the Great Friction Breccia. The other is probably related to the opening of the Oslo Graben.

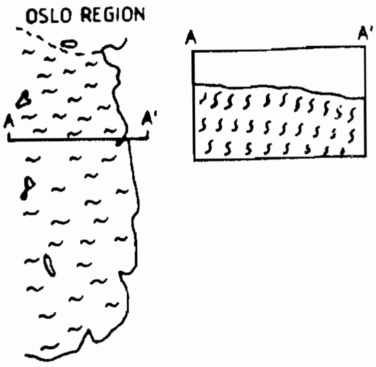
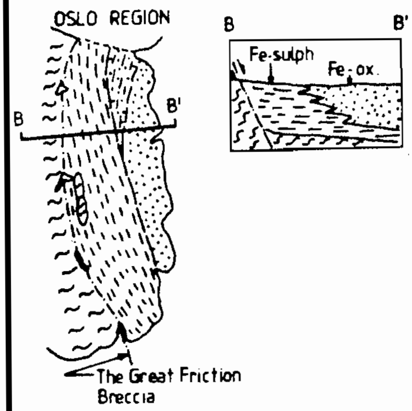
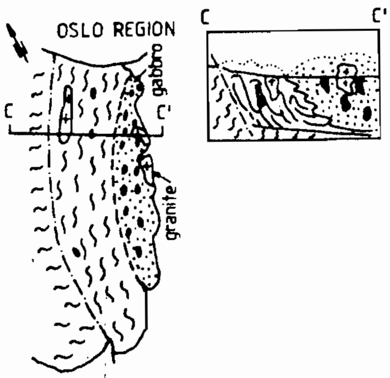
The stratigraphic younging in the sequence of rocks seen in the Bamble area is not known, but we infer that the package is generally younging from the Great Friction Breccia (Nelaug vicinity) to about 15 kilometers towards the southeast. This inference is based on rare observations of graded bedding, and the change from a mixed volcanic-sedimentary sequence in the northwestern part of the area to a dominantly sedimentary sequence to the southeast. This change occurs both stratigraphically upwards and laterally to the southeast. From the vicinity of Klubben to the Skagerak the rocks may be progressively older (see Figure 2).

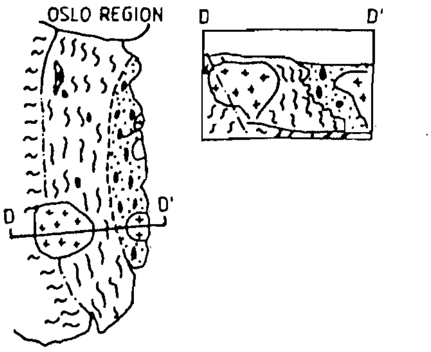
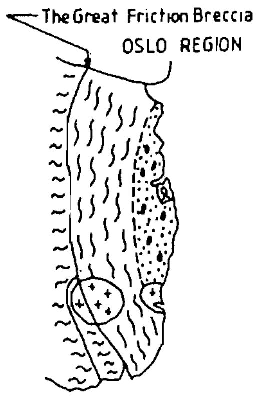
GEOLOGIC HISTORY AND TIMING OF EVENTS

A generalized geologic history is shown in Table 2. While this geologic interpretation is consistent with present data, further work will no doubt refine the model. The absolute ages of events are very uncertain, and the dates shown in the Table are speculative.

Deposition of the Bamble sediments and volcanites began during development of a major basin, the northwestern margin of which was close to the Great Friction Breccia. Near the Friction Breccia a sequence of interlayered mafic and felsic volcanite, arkose, sedimentary quartzite, siltstone and minor carbonate and exhalite was deposited. Towards the southeast this sequence changed laterally to mixed arkose, siltstone, turbidite and other felsic clastic material. Late in this period, mafic igneous rocks were emplaced in these distal sediments. Lateral facies variations parallel to the Friction Breccia indicate that volcanic centers occurred at intervals along the basin margin. One inferred center is near Nelaug and another near Gjerstad. It is interesting to note that both of these inferred centers lie near the intersection of the Friction Breccia and prominent NW-trending linears. Two other centers of smaller scale (satellite volcanoes?) were mapped by Pedersen (1984); one occurs near Sannidal and one near Auråa. Data reported by Morton (1971) indicate that volcanic centers, probably of a similar scale to those reported by Pedersen (1984), occur near the coast in the area dominantly underlain by metasediments.

TABLE 2

Phase	Time mybp	Mineralizatn	Horizontal Sections (not to scale)	Events, Localities
Basement	>2,000?	Pb, Zn by Kristian-sand?		Basement, on which the Bamble sediments rest. A. Rock types from the Telemark area seen west of the Great Friction Breccia: Migmatites, granites, banded gneisses.
Faulting and formation of the Bamble sedimentation basin.	1,500-1,300?	Pb, Zn, Cu, Ag mineralization; Fe-ores		A normal fault opens up with a location close to the Great Friction Breccia. Sedimentation and infilling of basin with a seawards direction approximately ESE (towards Denmark). A. Near the Friction Breccia (the ancient shore-line) occur amphibolite (mafic volcanic rocks), quartzites, cherts, albitites, sillimanite-siliceous gneiss, scattered carbonate-rich horizons (the exhalative package), biotite-schists (clay), grey albitite-rich banded gneisses (tuffs), and biotite-gneisses (silt-stones?). Sulfide-type BIF's located nearest the Friction Breccia in the exhalative package and oxide-type BIF's located to the east (sea-wards) near the contact between the exhalite package and the eastern "clastic package" (see below). B. Along the present coast line occurs a region of high-grade gneisses with a very uniform over-all appearance (meta-arkoses, turbidites or other homogeneous sediments with general granitic mineralogy, some may be old granitic intrusions). After this, mafic "volcanic" rocks are intruded sub-parallel to bedding near the present coast line (now homogeneous amphibolites with xenoliths of meta-sediments) (Starmer, 1972).
Regional meta-morphism. A. Isoclinal folding, shearing. B. Intrusions of gabbro, granite. C. The Bamble shear-zone forms.	 A. 1,300? B. C. 1,200?	Fe, Ni, Ti-ores connected to hyperites (gabbros). Rutile, sphene in albitites connected to hyperites.		Regional metamorphism reaching upper amphibolite facies (sillimanite, etc.) in the western part, and granulite facies and local granitization in eastern part near the present coast line. Metamorphic conditions prevail throughout the phase with two peaks contemporaneous with phase 3A and 3B. As temperature decreases the deformation turns into more ductile deformation (the Bamble shear belt forms - a 4-5 km wide shear-zone close to the Great Friction Breccia). A. Deformation. To the west isoclinal folds form with axial planes trending NNE-SSW and dipping about 80° towards the ESE. Fold axis dips about 5-15° SSW. To the east more open, but still tight, folds form. The general rule is more tight folds when moving towards WNW. B. Intrusions. A large number of gabbroic intrusions are emplaced, predominantly to the east, but are common throughout the Bamble area. A considerable amount of granite (the Levang granite/gneiss, the Helle granite/gneiss, the Farsjø granite/gneiss) is intruded, predominantly along the present coast line. C. Metamorphic temperature decreases and the deformation tends to concentrate near the Friction Breccia (possibly because the structures are interlocked by the present coast line due to the innumerable "stiff" gabbro intrusions) and the Bamble shear zone forms, a 4-5 km wide shear zone immediately east of the Great Friction Breccia. Mineral occurrences in this phase are mainly related to the gabbro intrusions. That is: Ni-pyrrhotite bodies, magnetite ores in skarn close to the gabbro (meta-morphosed into hyperite, amphibolite and pyroxenite), and in rutile-sphene ores in albite-dominated pegmatites.

Intrusion of Herefoss and Grimstad granites.	900	Cu, Fe by Skiftenes. Magnetite concentrations within granite		Intrusion of the Herefoss and Grimstad granites. Mushroom shaped intrusions of coarse-grained K-feldspar porphyritic granites.
The Friction Breccia is reactivated	Between 900 and 600	None		The Friction Breccia is reactivated in a basically vertical movement. The down throw of the eastern side is estimated to be at least 500 meters. Due to the presence of the huge Herefoss granite the fault trend goes W of the granite, but finally breaks through along the old trend. In this way some of the Telemark area rocks are included within the Bamble sequence.
The Oslo Graben opens.	300?	Pb,Zn,Cu veins by Tråk, Northern Bamble?		Faults associated with the Oslo Graben trending NNW are mineralized with Pb-Zn-Cu sulfides in carbonate-quartz veins.

Metamorphism and deformation occurred some time after deposition, but the interval of time between deposition and metamorphism is uncertain. Dominant compressional forces were directed normal to the Friction Breccia, but minor, isoclinal folding seen near the Friction Breccia indicates some strike-slip movement along it. The increase in metamorphic grade from the Friction Breccia to Skagerak indicates that a deeper stratigraphic level is exposed along the coast. The relatively high grade of metamorphism throughout the area indicates that published radiometric age determinations reflect timing of metamorphism. Methods such as Sm-Nd determinations would be necessary to ascertain ages of deposition and emplacement.

MINERALIZATION

The Bamble area has a long history as a mining district, and 160 different small mines, trenches and workings are listed in the Bergmesters File although no mines are active now. However, not more than 5 are base-metal deposits and only a few of the 160 occurrences are located within the exhalite-bearing, mixed volcanic-sedimentary trend (hereafter shortened to the exhalite-bearing trend) which, as determined from ARCO's rock chip assays, contains the region's highest concentrations of Au, Ag, Pb, Cu and Zn. The majority of the mines produced magnetite, nickelifereous pyrrhotite-chalcopyrite, rutile or apatite ores and they are found predominantly in the coastal area. This may be due to the fact that a very active industry and shipping environment was centered around the harbors, while the less populated forests, where the exhalite-bearing trend is found, received less attention in the 19th and beginning of the 20th centuries. Moreover, the strata with higher sulphide concentrations weather easily and tend to form topographically low areas such as bogs.

The ores and mineralization can be grouped into mineralization associated with the mafic plutonic intrusions, magnetite mineralization in the exhalite-bearing trend, and sulphide mineralization in the exhalite-bearing trend.

Mineralization associated with mafic plutonic intrusions

Associated with the mafic plutonic intrusions are rutile mineralization, apatite mineralization and mixed magnetite, nickelifereous pyrrhotite and chalcopyrite mineralization.

The rutile mineralization is found in albite-rich rocks, usually aplitic to medium grained. No anomalies for Au, Ag, Pb, Cu or Zn were detected in samples from rutile mineralization. No assays were made for platinum group metals.

The apatite ores of Ødegårdens Verk (1712 IV, NE corner) are very rich in apatite and occur in cross-cutting apatite-diopside-biotite-enstatite pegmatites. The pegmatites are described in detail by Bugge (1965), and they are probably related to nearby hyperites. Two samples from the ore show detectable Au (0.005 ppm) but no anomalies for Cu, Zn, Pb or Ag are detected.

The mixed magnetite, pyrrhotite and chalcopyrite mineralization generally occurs along the margins of mafic plutonic intrusions, where these are partly amphibolitized. The typical ore is either: 1. brecciated coarse-grained magnetite, amphibole, hypersthene and plagioclase cemented by nickelifereous pyrrhotite and chalcopyrite, or 2. hyperite/gabbro with disseminated pyrrhotite and chalcopyrite. No samples taken from these ores show any anomalous Au, Ag, Pb or Zn except for samples from Vissestadt mine (0.389 ppm Au, no other major anomalies) and Skibrekka mine. If these sulfides are relict magmatic sulfides, the rocks should be examined for possible platinum group metals mineralization.

Apart from the mineralization in the E18 trend, the above mineralization types are believed to be of no importance for base-metals exploration. However, they do indicate centers of igneous activity which may have been accompanied by other mineralizing processes that are of regional importance to an exploration program.

Magnetite mineralization in the exhalite-bearing trend

Magnetite mineralization is found mainly along the southwestern margin of the exhalite-bearing trend with concentrations around Arendal, Søndeled and Kilsfjorden (west and southeast of Kragerø). Another important magnetite-bearing trend occurs near the Great Friction Breccia, from Nelaug to Gjerstad. Magnetite-bearing rocks tend to parallel sulphide mineralization on another stratigraphic level which occurs to the northwest. A rapid evaluation of the extent and location of the magnetite mineralization is possible from inspection of NGU aeromagnetic maps.

The magnetite is normally found as layers in gray felsic gneiss interbedded with amphibolite and calc-silicate horizons. Ore material in the larger magnetite mines of the Arendal district is interbedded, coarse-grained diopside-garnet-magnetite. Thin amphibolite layers interbedded with gray felsic gneisses are also magnetite-bearing but not of ore grade. In other places the massive magnetite ore bands are found in cherty quartzites with thin amphibolite layers adjacent to the magnetite. Calcite veins are quite commonly associated with the magnetite ores.

The magnetite ores are thus banded and associated with amphibolites in a package of felsic gneisses with chert, albitite, calc-silicate and enrichments of garnet, and are interpreted as oxide-facies banded iron-formations (BIFs) clearly associated with exhalites.

Sulphide mineralization in the exhalite-bearing trend

Many occurrences of sulphide mineralization were described and sampled during ARCO's field-work. As a general rule, all roadcuts displaying evidence of iron staining in the Bamble area were sampled, and it was found that only mineralization from the exhalite-bearing trend showed elevated concentrations of Au, Ag, Cu, Pb or Zn.

The individual areas are described below, after a short summary of general trends in the sulphide mineralization.

The sulphide mineralization generally occurs within gray felsic gneiss and biotite-schist which locally are enriched in disseminated sulphides. The gneiss hosting the sulphides is associated with calc-silicates, and is either very siliceous or enriched in garnet, sillimanite or cordierite. There does not appear to be a consistent or even common hanging or foot-wall rock type to the mineralization. The presence of garnet, sillimanite, cordierite, chert, albitite or marble is a guide to where the mineralization occurs.

The units containing the disseminated sulphides range from centimeters to several meters in thickness. Many of the mineralized units can be followed for several kilometers along strike within the same stratigraphic position.

The sulphides normally occurring in rusty roadcuts are pyrite and pyrrhotite. Graphite almost invariably accompanies the sulphides, and cm to dm-thick horizons containing up to 50% graphite are not uncommon. In some mineralized areas galena, chalcopyrite, sphalerite, arsenopyrite or tennantite-tetrahedrite occur in trace amounts. Chalcopyrite is by far the most common ore mineral, sphalerite occurs frequently, but the other mentioned sulphides are rare. Assay results show that Au is correlated with Cu, Zn and As, whereas Ag is correlated with Pb.

In a few rusty outcrops, massive pyrrhotite-chalcopyrite lenses and cross-cutting veins are found. These are sometimes accompanied by sphalerite and many of them assay high in Au (0.3 to 2.0 ppm). All the higher Au values are found in samples of massive pyrrhotite and chalcopyrite, which occur both stratabound or in veins.

Table 3 shows a list of selected analytical results from representative rock chip samples taken across the width of mineralization.

TABLE 3.

Sample Location	No.	Au ppm	Ag ppm	Pb %	Zn %	Cu %
Skyttemyr						
	3200	2.94	38.8	.0060	.0503	1.13
	3210	0.75	70.0	.0041	.0850	3.94
	3211	2.48	7.0	.0204	1.39	0.70
	3244	1.73	9.4	.0051	2.01	1.15
Espelandsmyr						
	RB17	0.05	496	8.2	4.37	.0313
	RB18	1.85	641	8.0	4.40	.62
	3017	0.01	30.2	0.16	6.21	.0150
	3018	0.06	31.6	0.15	6.46	.0140
	1329	0.39	d.l.	.0013	.009	.0137
	1046	0.73	3.0	.0023	.004	0.5
Gjerstad						
	1170	7.4	d.l.	d.l.	.0055	.0781
Kragerø						
Auråa	3151	0.23	1.8	n.d.	.0260	.17
Auråa	3176	0.12	3.7	n.d.	.0120	.63
Skogen	3156	0.34	n.d.	.0026	.0078	.0181
Grøtvn.	3139	0.06	n.d.	.0013	.0141	.0193

n.d. indicates not determined, d.l. indicates below detection limit

The Skyttemyr area

The Skyttemyr area was mapped in detail by Beck (1983) and a short summary is given here.

The Skyttemyr occurrence was mined during the late 19th century at two locations, Skyttemyr and Bøylestad. The mines were in production for about 10 years, and then abandoned due to technical and financial problems. The mines produced Cu and Zn concentrate, and at the time the mines were in operation the potential gold credit to the ore was not recognized.

The ore is stratiform, 0.5 to 2 meters thick at the surface, and can be followed for about 2-3 kilometers in scattered outcrop. The strike and dip of the orebody is 032°/70° SE. The ore comprises massive pyrrhotite, chalcopyrite and sphalerite with minor arsenopyrite, galena, tennantite-tetrahedrite, and graphite. Rounded quartz eyes, small lenses of felsic gneiss and minor cross-cutting calcite veins are common within the ore. The footwall to the ore is mafic biotite gneiss and amphibolite. From the Great Friction Breccia to the ore zone, the footwall rock sequence consists of normal mixed volcanic-sedimentary rocks and granitic gneiss with very few exhalite horizons. In contrast, the hanging-wall sequence consists of a mixed sequence of sillimanite-garnet-bearing felsic gneiss, garnet amphibolite, cherts, etc. The ore thus marks the northwestern margin (base?) of the exhalite-bearing trend hosted in altered rocks.

Southwest of Skyttemyr, on the Arendal 1:50.000 scale map sheet, is a very large area dominated by quartzite which often exhibits a cherty appearance and which is interbedded with amphibolite. This appears to be a favorable setting for more mineralization, and two minor gold occurrences were located in this area. Representative samples are 3057 and 3058, with 0.108 ppm and 0.142 ppm Au respectively (located near Rise); and samples 3360 to 3363 with values between 0.024 and 0.045 ppm Au (east of Syndles Øya). Northeast of Skyttemyr, several sulphide occurrences anomalous in base metals and a thin carbonate horizon are found in the exhalite bearing rocks (Figure 3). It should be emphasized that many more occurrences are probably hosted in the area, which has not been mapped in sufficient detail to locate them.

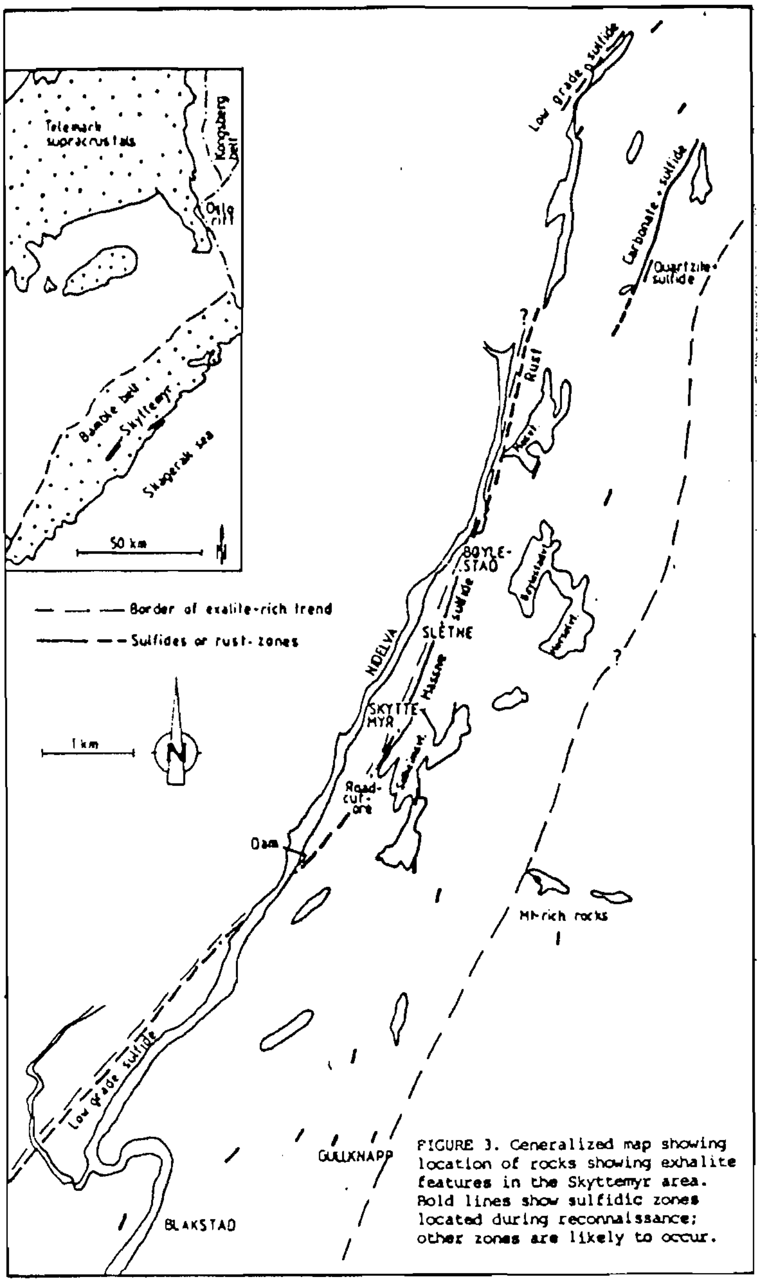


FIGURE 3. Generalized map showing location of rocks showing exhalite features in the Skyttemyr area. Bold lines show sulfidic zones located during reconnaissance; other zones are likely to occur.

The Espelandsmyr area

The Espelandsmyr ore is hosted by felsic gneiss 50 meters stratigraphically above (?) the contact with a coarse-grained K-feldspar, porphyroblastic, augen gneiss (type 1). The contact between the augen gneiss and the felsic gneiss is sharp, and the package of felsic gneisses can be followed to the southwest where it bends around the augen gneiss. A marker horizon of garnet-biotite-calcite rock has been followed for several kilometers in the same stratigraphic position (Grahl-Madsen and Beck, 1984).

The ore is a stratiform, layered sphalerite-galena ore poor in Fe-sulphides and with minor chalcopyrite and is hosted in banded, dirty dolomitic marble and garnetifereous, gray felsic gneiss. Assay results show that the sphalerite-galena ore has a high silver concentration (up to 650 ppm) and a potential gold credit (see selected analytical results shown in Table 3). The relatively high concentration of silver in the ore indicates it may be a stratabound vein, rather than stratabound syngenetic mineralization. The orientation of the orebody is $052^{O}/75^{O}$ SE and the footwall to the ore is gray felsic gneiss and amphibolite. The hanging-wall sequence is gray felsic gneiss and interlayered magnetite-bearing amphibolite and pink granitic gneiss (type 5).

Northeast of the mine, the rusty zone hosting the ore can be observed sporadically for about 5-6 kilometers along strike at the same stratigraphic position. Just southwest of the mine is a very large bog. Airborne magnetic/electromagnetic and ground IP surveys traced the ore horizon which occurs sporadically over several kilometers to the southwest. Two drill holes tested the horizon and penetrated pyritic-graphitic zones but failed to locate significant galena or sphalerite. However, only two holes along a trend of such length is not a realistic test of the trend´s potential.

A distinct magnetic high located southeast of the ore zone parallels the horizon hosting the ore. The magnetic maximum is at Solvang, 8 kilometers southwest of Espelandsmyr.
The high continues to the southwest and does not bend around the augen gneiss. The package which bends around the augen gneiss is, however, found to be magnetite-bearing like the hanging wall of the Espelandsmyr ore.

Near Solvang, there occurs an approximately 800 meter thick sequence of interbedded garnetifereous felsic gneiss, chert and ± magnetite-bearing amphibolite overlain by normal diffusely banded, gray, felsic gneiss and amphibolite.
Some of the magnetite-bearing amphobolites contain low, but anomalous, concentrations of gold. Between Solvang and Espelandsmyr mines, for example, samples taken were anomalous in gold and the sample, taken approximately 4 kilometers southwest of Espelandsmyr mine, assayed 0.821 ppm Au, 30 ppm Ag, 1.13% Cu and low Pb and Zn.

To summarize, a thick package of exhalites and magnetite-bearing amphibolites, partly anomalous in Au, occurs near Solvang.
The package thins out about 8 kilometers towards the northeast; at the mid-way point, near Bakke, a Au-Cu-Ag-bearing Fe-sulphide sample was taken, and near Espelandsmyr a thin carbonate horizon containing Ag-Zn-Pb (Au) and poor Fe mineralization occurs.
This can be viewed as one system; the thick Solvang exhalite/ magnetite sequence being the proximal center with an intermediate Au-Cu-Fe sulphide mineralization (perhaps a Skyttemyr "type") north of Bakke, and distal Ag-Zn-Pb, Au-bearing and Fe-poor mineralization at Espelandsmyr.

The stream-sediment sample anomaly pattern from Espelandsmyr area outlines an anomalous trend in the area. The anomaly pattern does not bend around the augen gneiss, but tends to follow the trend of the magnetic high.
Higher gold values are located in the Espelandsmyr mine area and in an area south of Solvang, and the entire trend between these two areas is anomalous. High silver contents accompany the two gold

highs, and higher lead and zinc values are scattered throughout the anomalous trend. No significant anomalous area occurs outside the trend.

The Gjerstad area

The Gjerstad area (Grahl-Madsen and Bech, 1984) is characterized by innumerable rusty road cuts. The typical rusty road cut is mineralized with small amounts of disseminated pyrrhotite and mm-thick pyrite layers on joint surfaces - thus giving a more rusty appearance than the amount of sulphides justifies.

Albitite, chert, garnetifereous gray felsic gneiss and calc-silicate horizons are widespread and very common within the area.

The Gjerstad section includes three exhalite-bearing horizons separated by normal gray felsic gneiss and granitic gneiss (type 5). The two marginal exhalite-bearing horizons are mineralized with magnetite and the central exhalite-bearing horizon with iron sulphides. Ground and airborne magnetic surveys clearly outlined the iron-sulphide and magnetite-bearing horizons. Assay results show that all three exhalite-bearing horizons contain anomalous Au, but only the central, sulfide-bearing horizon is also anomalous in Cu, Pb and Zn.

A 14 meter long and maximum 0.5 meter wide quartz-arsenopyrite-chalcopyrite vein containing up to 7 ppm Au and 5% As was found

1.5 kilometers south of Gjerstadvatn. The vein crosscuts an amphibolite that locally shows intense silicification and sericitization, and which contains sillimanite, garnet, tremolite and disseminated sulfides. This occurrence lies near the contact between the central, iron-sulfide horizon and the southeastern, marginal magnetite-bearing horizon.

The E18 area

The E18 trend is very long, complex and situated close to the igneous center found in the Kragerø-Bamble area. Details are given by Pedersen (1984).

The southern end of the trend by Sannidal is characterized by at least seven thick iron sulfide-bearing horizons with traces of chalcopyrite, which are stacked on top of each other (between Sannidal South and Sannidal North), and a very complex mineralogy and lithology. The sulfide-bearing horizons occur in interbedded biotite schist and quartzite, garnet-rich amphibolite, ankerite marble, and biotite quartzite. The sulphide-bearing package has the form of a wedge, being thickest at the southern end and thinning out along strike towards the northeast and Auråa (the igneous center).

Near the igneous center (west of the Helle granite and by Auråa) are found complex interlayerings of sillimanite gneiss, garnet amphibolite, magnetite amphibolite, sedimentary amphibolite, and chert and ankerite marble, that are often brecciated. Sulphides here are found as disseminations and as massive pyrrhotite-chalcopyrite layers, lenses or cross-cutting veins.

RECOMMENDATIONS FOR FURTHER WORK

In April, 1985, Atlantic Richfield Co. eliminated its minerals exploration program world-wide. As a result, ARCO's minerals exploration program in the Bamble region was terminated. The results of work done in 1983 and 1984 indicate that certain types of deposits can be expected to occur in the area. As a guide to exploration, our data indicate that the highest gold values occur in areas anomalous in arsenic where chalcopyrite appears in addition to iron sulfides. In areas covered by ARCO's DIGHEM III survey, careful examination of resistivity data presented as stacked profiles may indicate favorable areas because the presence of elevated, but non-massive, sulphide concentrations will exhibit lower resistivity (see Corbett and Abildgaard, this report). An area with a coincidence of low resistivity, favorable geology and elevated gold concentrations in rock samples would be worth careful examination. The presence of bedded carbonate (e.g., ankerite) in the section is an additional favorable criterion (R.P. Foster, personal comm.).

The expected deposit types are:

A) Epigenetic gold: Three areas exhibit characteristics favorable for this type of mineralization.

1. A 3 to 5 km^2 area located between Auråa and Bakkevatnet comprises amphibolite that has been silicified and carbonatized, and which contains sulphide minerals that have replaced ferromagnesian minerals.

Pyrrhotite, accompanied by intense carbonatization, is frequently observed, usually in the lower 0.5 to 10 meters of individual amphibolite units. The overlying gneiss and amphibolite are enriched in garnet, sillimanite, chert, albitite and calc-silicates. The highest gold values (up to 0.6 ppm) occur in small veins and lenses of mobilized sulfides. Mapping of alteration patterns could indicate areas most likely to contain abundant veining (stockwork breccias) or stratabound, disseminated gold mineralization.

2. An area of 6-10 km^2 located southwest of Gjerstadvatn includes exhalite-bearing horizons separated by gray, felsic gneiss and Type 5 gneiss. A central sulphide-bearing exhalite sequence lies between 2 magnetite-bearing exhalite sequences. The Vekselmyr Au-As vein occurrence (7 ppm Au, 5% As) lies in the eastern part of this area. Stream sediments in the area tend to be anomalous in Au and As. A structural analysis of the Vekselmyr area might provide a guide to controls on the vein occurrence, and indicate areas where larger veins could occur. Also, the occurrence is near a trend of low resistivity strata as shown by the DIGHEM III data. The trend lies within the central, sulfide-bearing zone. This trend should be carefully examined for stratabound, disseminated ("invisible") gold mineralization.

3. A narrow, elongate zone in the footwall of the Espelandsmyr trend. The presence of arsenopyrite and tourmaline combined with occasional elevated Au values (up to 0.8 ppm) associated with chalcopyrite indicate a potential for epigenetic gold mineralization in the trend. Unfortunately, the most favorable area is not well defined, and elevated Au concentrations apparently occur sporadically along a 10 kilometer trend. The vicinity of Solvang may be the most favorable locality, because a volcanic center may occur about 2-3 kilometers north to northwest of Solvang.

B) Syngenetic gold: Three broad areas exhibit characteristics favorable for syngenetic (i.e., synvolcanic) mineralization. During our work, the Agnico-Eagle deposit of Quebec (Barnett et al., 1982) was used as a general exploration guide. The Agnico-Eagle deposit is hosted by Archean rocks, while the Bamble rocks are probably of Middle Proterozoic age, or, at the oldest, of Early Proterozoic age. The difference in ages of host rocks may be significant, but both areas seem to have undergone similar processes of volcanism and mineralization and therefore can be expected to have similar deposit types. Elements which may be anomalous in the synvolcanic gold deposits include Ag, As, Ba, Cu, Zn, Mo, V, Sb and Hg, and one or more of these elements as well as gold may form detectable haloes over several hundred meters. In general, however, gold is the best pathfinder element for gold mineralization.

1. The Skyttemyr trend extends for several kilometers to the northeast and southwest of the Skyttemyr-Bøylestad deposits. The trend is defined by the exhalite features

described above as well as frequent concentrations of gold exceeding 0.1 ppm in rock-chip samples. In the ore zone of Skyttemyr, concentrations of 2 ppm Au are common and concentrations as high as 6 ppm Au have been determined but not reproduced. The Skyttemyr trend crops out over an area of 2 x 20 kilometers (see accompanying map) and should be examined in detail. At least three target types are possible: 1) gold in stratabound semi-massive to massive iron sulfides with accessory chalcopyrite and sphalerite; 2) gold associated with disseminated, stratabound iron-sulphide mineralization, probably hosted in pyritic chloritized/sericitized quartz schist; and 3) gold in stratabound epigenetic veins. Epigenetic veins would most likely be hosted in pervasive shear zones.

2. A thick exhalite sequence occurs in the Sannidal area overlying what appears to be silicified gneiss (felsic tuffs?). The exhalite package includes interlayered ankerite marble horizons and horizons enriched in pyrrhotite. Bedded carbonate is frequently observed. The mineral assemblages in and around the exhalite package indicate intense alteration of the original rocks. Assay results for gold are low (30-70 ppb) but the area should be carefully examined as ore-grade gold mineralization could occur over short strike lengths in near-vent environments. Mapping in this area, as well as Skyttemyr, should be focused on locating vents and higher-temperature alteration zones.

3. The rock package near Solvang described above may also be favorable for syngenetic gold mineralization. A likely

host rock would be pyritic, sericitic/chloritic quartz schist.

C) Stratabound, massive sulfides: The results of 1984's program indicate that there is little potential for this type of deposit in the area flown by the DIGHEM III survey. Some potential for this deposit type remains in the Skyttemyr trend and in the Sannidal area, although the results of stream sediment sampling indicate the potential is low. The stream sediment data are not definitive, however, because of the limitations imposed by glacial overburden and poor drainage in large parts of the area. This type of deposit would, however, be discovered in the course of exploration for synvolcanic gold deposits if assays for pathfinder elements are done. The presence of extensive, metamorphosed alteration patterns in these two areas supports the concept that massive sulfides may be present.

SUMMARY AND CONCLUSIONS

The Bamble region is underlain by a complex assemblage of mixed volcanic and sedimentary rocks metamorphosed to amphibolite and granulite grades. The assemblage was deposited in a basin the margin of which is defined by the Great Friction Breccia (GFB). Volcanic centers are located near the GFB where volcanic and volcanically-derived rocks are concentrated. To the southeast, sediment interfingers with the volcanic assemblage. The interface between the underlying volcanic/sedimentary assemblage and overlying sediment is defined by a sequence of rocks containing exhalite sequences. The exhalite units include chert, albitite and marble and are interbedded with felsic gneiss and amphibolite enriched in garnet, sillimanite and cordierite which we interpret to represent the metamorphic products of hydrothermally altered rocks.

Mineralization in the region is of two distinct types. The first includes mineralization associated with mafic plutonic intrusions, such as rutile, apatite or mixed magnetite-pyrrhotite-chalcopyrite mineralization. Most of the known deposits in the area belong to this group.

The second type includes mineralization occurring in exhalite-bearing rocks. Both magnetite mineralization (oxide-facies banded-iron formation) and sulphide mineralization associated with marbles, cherts and albitites (sulfide-carbonate-silicate facies banded-iron formation) are widespread. The Skyttemyr Au-Cu-Zn and Espelandsmyr Ag-Pb-Zn (Au-Cu) deposits occur in the sulfide-bearing exhalite sequences. Elevated gold concentrations in sulfide-bearing exhalites indicate potential in the area for both epigenetic (vein) and syngenetic (stratabound) gold mineralization.

ACKNOWLEDGEMENTS

We thank ARCO Norway, Inc. for permission to publish the results of work in the area. L. Bech, L. Grahl-Madsen and J. Bielak provided significant contributions to our understanding of the area. Jeanette Øverland typed the manuscript and Arild

Akselsen did the drafting. C. Bow, P. Padget and R.P. Foster kindly reviewed the manuscript.

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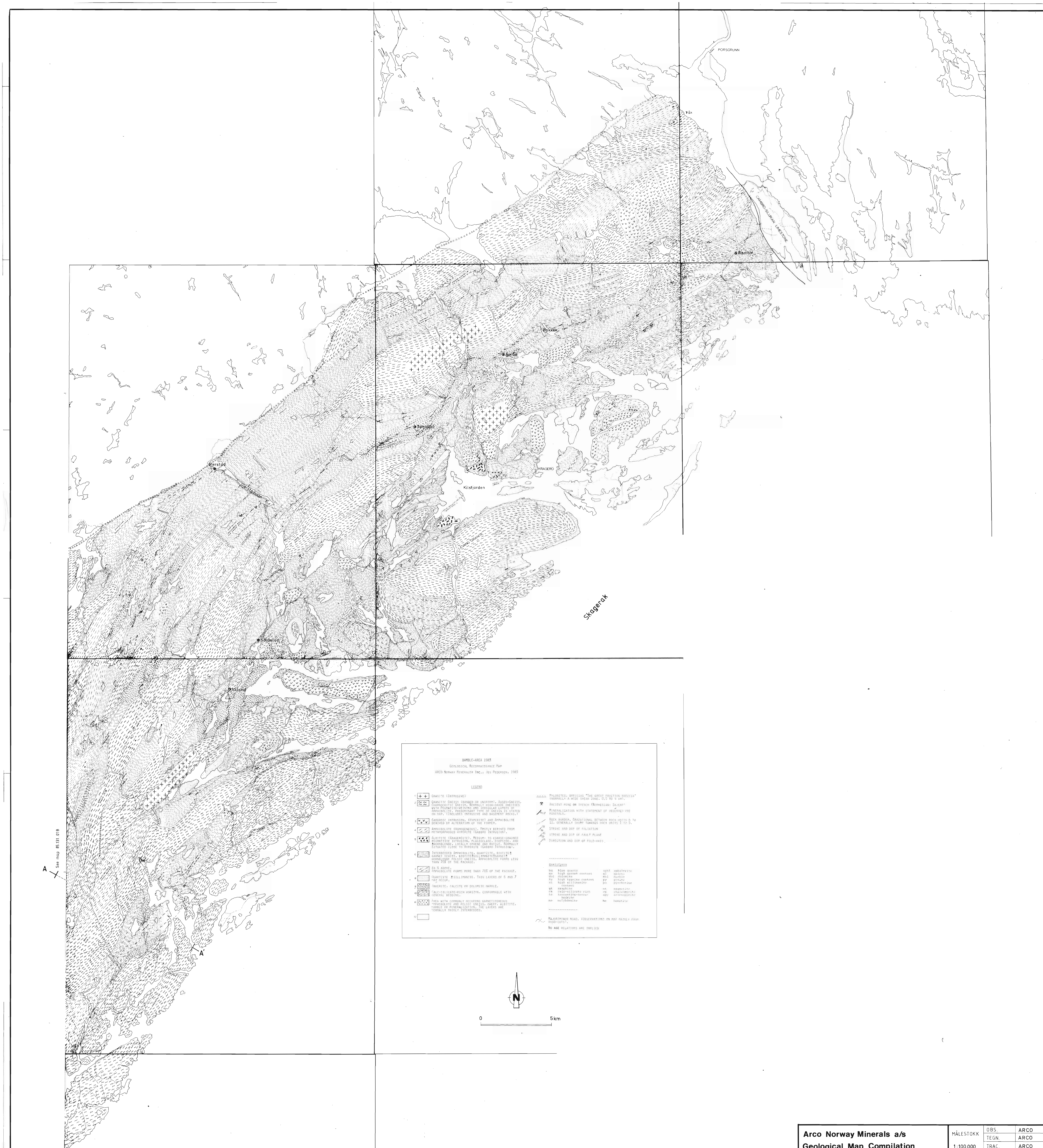

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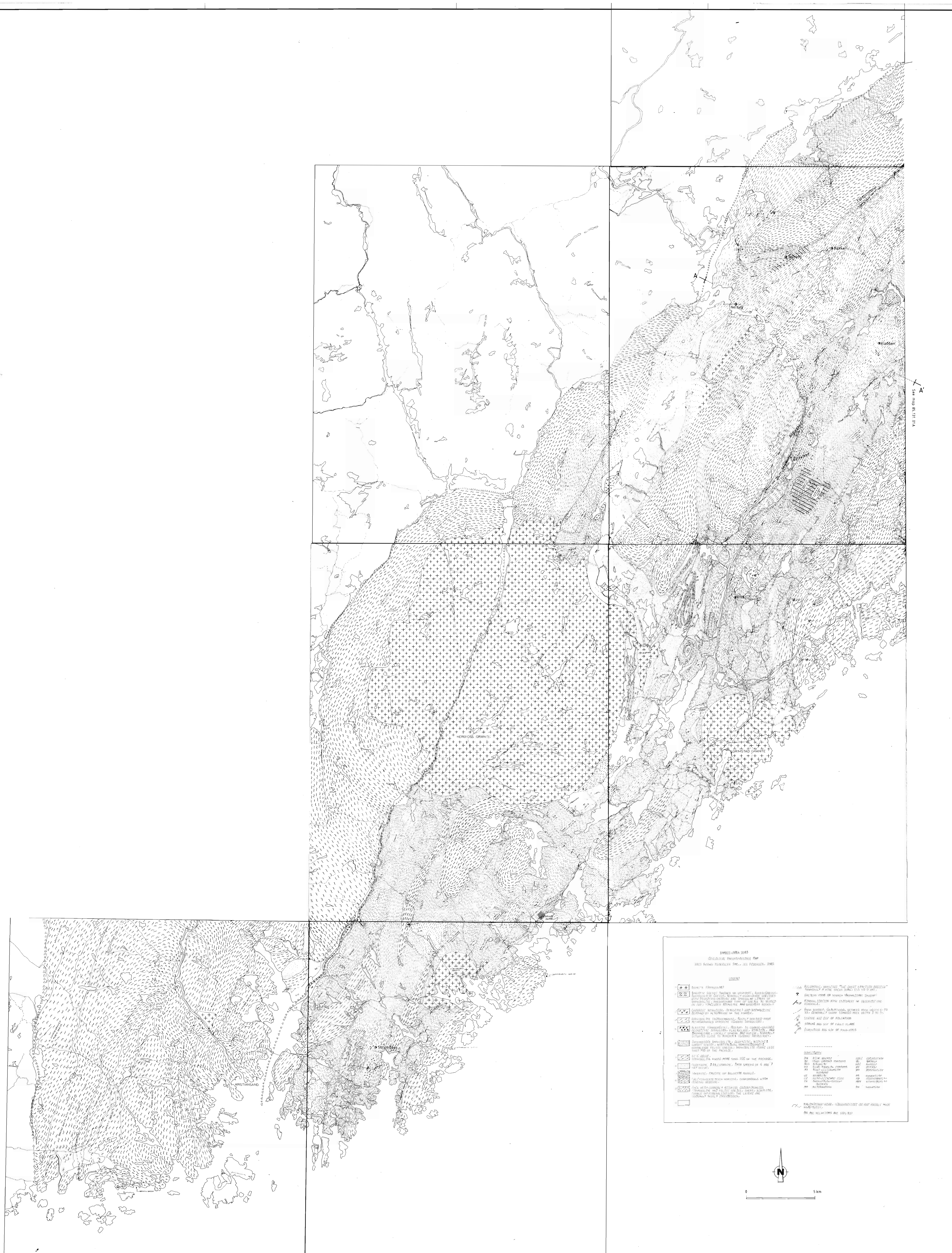

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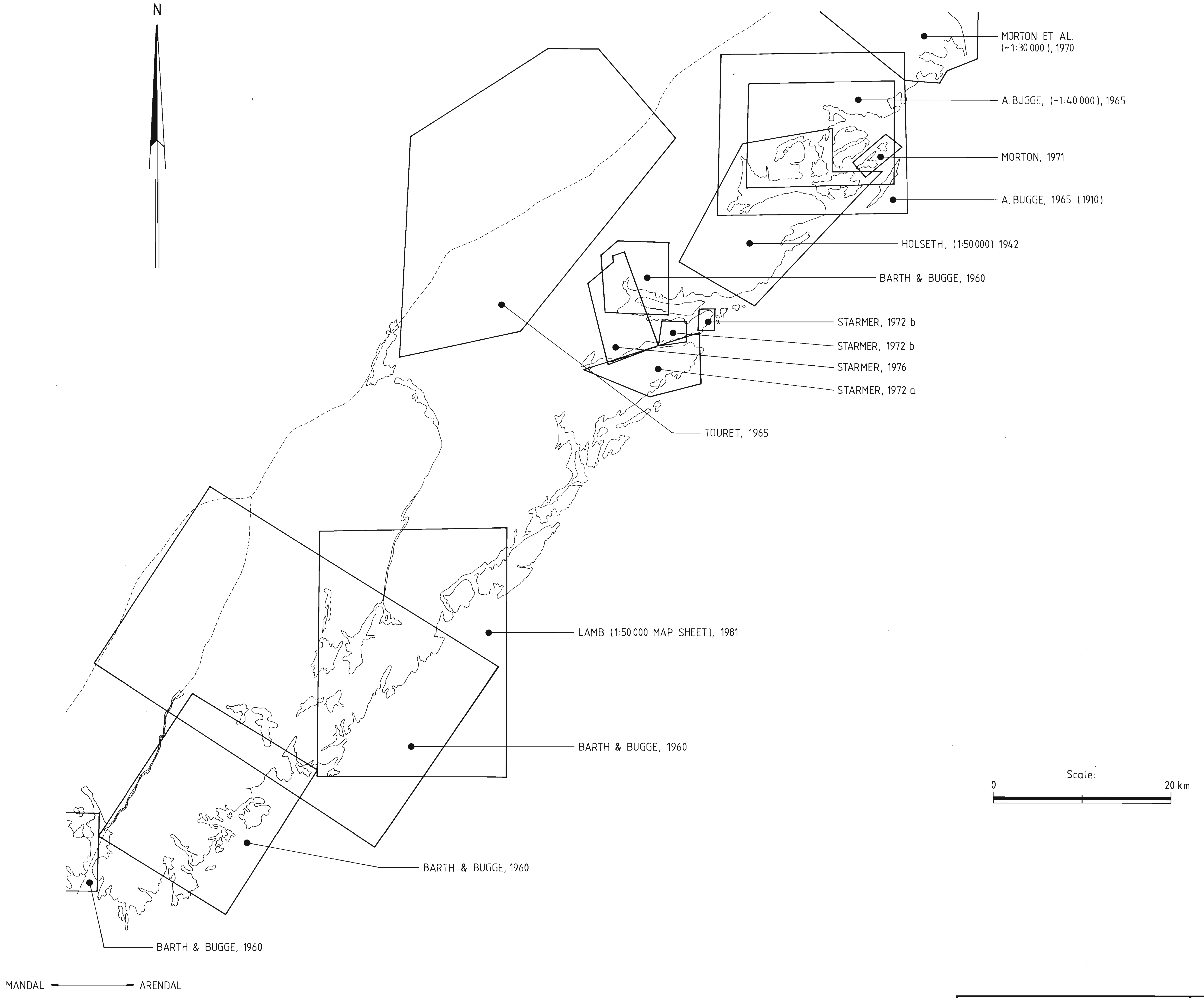

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Location of previous geological maps from the Bamble area

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