Takk for hjelpen A—

BIDJOVAGGE COPPER-GOLD DEPOSIT IN FINNMARK, NORTHERN NORWAY

by

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Abstract

The Bidjovagge copper-gold deposit is located 40 km northwest of Kautokeino in Finnmark, Northern Norway. The deposit occurs in the Lower Proterozoic Kautokeino Greenstone Belt, and consists of four ore deposits in albitic felsite and graphitic albitic felsite over a strike length of 2.5 km. The ore bodies occur on the eastern limb of a north-south-striking anticline. The albitic felsite may represent strongly altered tuffite and diabase or partly metamorphosed chemical sediment. The alteration of the metadiabase in the footwall sequence is complex. Carbonatization is very extensive, but there are also zones with biotite, scapolite and hematite alteration.

The main ore is stratabound and occurs as veins, breccias and low grade disseminated mineralization of a more stratiform character. High gold values are usually related to late quartz-carbonate veins containing tellurides and are often associated with weak uranium mineralization. The ore minerals of economic significance are chalcopyrite and native gold. Other common metallic minerals are pyrite and pyrrhotite. Marcasite, magnetite, ilmenite, hematite, tellurides, rutile, sphalerite, galena, davidite and pentlandite occur in accessory amounts. Preliminary isotopic analyses show that the lead isotope composition is markedly radiogenic ($^{206}Pb/^{204}Pb = 22.2 - 23.8$).

The association of ore deposits with albitic felsites is also known to the north, in the Kvænangen tectonic window, where similar copper deposits with, however, low gold values, occur in the Bergmark area and to the east near Masi in Big'geluobbal where U-V-Ti-REE mineralization has recently been found. Bidjovagge is similar in its depositional environment to the Viscaria deposit in Sweden and the Pahtavuoma deposit in Finland.

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INTRODUCTION

Sevetal ore deposits and prospects occur in Lower Proterozoic Greenstone Belts in the northern parts of Norway, Sweden and Finland. Best known are the Viscaria Cu deposit at Kiruna, Northern Sweden (Godin) and Pahtavouma Cu, Zn and U deposit in the Kittila area of Northern Finland (Inkinen 1979). Recently a small deposit with Sc and LREE has been found near Masi in Northern Norway (Bjørlykke et al., 1985). All of these deposits are associated with strong sodium metasomatism, but the style of mineralization and the metal composition differ from deposit to deposit.

The Bidjovagge copper-gold deposit is situated 40 km northwest of Kautokeino in the Caskias mountains of Finnmark, Northern Norway. Claims were first staked in 1952 by Boliden Mining Company (Hollander, 1979). Exploration was later taken over by a committee under the Norwegian Government. By 1966 they had found four separate deposits over a strike length of 2.5 km with total ore reserves of approximately 3 million metric tons averaging 1.8 % Cu and 0.5 ppm Au.

Bleikvassli Mining Company leased the property in 1967 and production started in 1970 with a yearly production of 100,000 tons. The mine closed in 1975 due to low copper prices and technical problems.

New and more detailed data on gold distribution made it possible for Outokumpu Oy to reopen the mine in 1985 with reserves of 1 mill.tons of ore averaging 2 g/t Au and 1.2 % Cu.

Previous work includes regional mapping by Holmsen et al. (1959), Mathiesen (1970a), (1970b), and Sandstad (1983).

A more comprehensive description of the ore body was published by Hollander (1979), and Hagen (1982) has investigated the mineralogical composition of the ore body, particularly the gold rich paragenesis.

Geological setting

The Precambrian of Finnmark (Fig. 1) consists of Archean gneisses and amphibolites separated by three north-south trending Proterozoic Greenstone Belts; Kautokeino, Karasjok and Pasvik-Polmak.

The Archean gneisses consist mainly of felsic orthogneisses and paragneisses, and they constitute domal structures, which are pierced by Proterozoic plutonic rocks. Together with the gneisses occur amphibolites (Gåldenvarri Formation; Solli, 1983), which can be classified chemically as tholeiitic basalts. Characteristic is low TiO_2 (mean 0.5%) and high Mg content (mean 12.3%).

The precise relationship between the Greenstone Belts is a subject of controversy, but they are all three probably of similar Early Proterozoic age (Krill et al., 1985). Based on structural and metamorphic studies and age determinations, Krill (1985) has adopted a plate tectonic model and described a complete "Wilson orogenic cycle" for the Karasjok Greenstone Belt. The supracrustal rocks of the Kautokeino Greenstone Belt can be followed on magnetic maps to the north under the Caledonian cover into the Alta-Kvenangen, Altenes and Repparfjord-Komagfjord tectonic windows. The rocks consist of fluvial and shallow marine sediments and volcanites and are intruded by gabbroic sills. Both a continental rift setting (Torske, 1978) and an ensialic back-arc basin (Pharaoh & Pearce, 1984), have been suggested as depositional environments for the greenstones in the Kautokeino Greenstone Belt. The best preserved example of rift sediments is exposed in the Komagfjord-Repparfjord window where the 3 km thick Saltvann Group is deposited in a horst-and-graben tectonic environment.

The Early Proterozoic rocks in the Bidjovagge area (western part of the Kautokeino Greenstone Belt), are divided into the Cas'kejas Formation, Bik'kacåkka Formation and the Caravarri Formation (Siedlecka et al., 1985). There are no depositional contacts between the Cas'kejas Formation and the Archean basement in the area due to the Middle Proterozoic granitic intrusion to the west.

The Cas'kejas Formation consists of dolomites, schists, metatuffites and metavolcanics, which mainly in the lower part, are intruded by synvolcanic diabase sills. Albitic felsite occurs often in contact with the sills, and is the host-rock for the copper-gold mineralizations.

The sequence is metamorphosed in greenschists facies to the east and in amphibolite facies in the west, near the granitic intrusion. Total thickness is approximately 4 km.

The Bik'kajokka Formation consists of a Lower Member of fine to medium grained sandstone with thin beds of limestone. The Upper Member consists of brown to green shales and argillites with intercalations of siltstones (Siedlecka et al., 1985). It is metamorphosed in very low to low grade facies, and the thickness is approximately 1 km.

The Carravarri Formation is the youngest in the Greenstone Belt and consists of grey to reddish feltspathic sandstones. The formation has been interpreted as alluvial, consisting mainly of braided stream deposits (Torske & Bergh, 1984).

GEOLOGY OF THE BIDJOVAGGE AREA

A generalized geological map of the Bidjovagge area is shown in Figure 2. The map is mainly based on work by Sandstad (1983), with minor contributions from unpublished company reports by K.I. Olsen, I.G. Hultin and R. Hagen. The map (Fig. 2) covers the north-western part of the Cas'kejas Greenstone Formation already mentioned. Towards the north the Precambrian rocks are overlain by the Late Precambrian Dividal Group. The Dividal Group consists of autochtonous shale and sandstone with a basal conglomerate.

The main structure of the Bidjovagge area, first recognised by Gjelsvik (1958), is a north-south striking anticline, which can be followed over an axial length of 8.5 km. The lower parts of the Cas'kejas Formation with the ore bearing units of albitic and graphitic felsite are exposed in this anticline. The same stratigraphic level occurs presumably in the small western anticline (Fig. 2) and in three anticlines more than 7 km to the east and northeast (outside the map area). From the main anticline and westwards, the rocks are folded isoclinally and dip steeply. East of the main anticline the folds gradually become more open. A large, complex synclinal structure with argillites is found in the north-eastern part of the map area.

Metamorphism and deformation increase gradually from lower grade in the east to middle grade in the west (Sandstad, 1983). Based on a study of regional aeromagnetic and gravimetric maps, Olesen et al. (1985) have proposed that the general deformation of the Kautokeino greenstone belt is a result of gravity tectonics.

Stratigraphy and petrography

The general stratigraphy of the Cas'kejas Formation is shown in Figure 3. The lowermost beds outcropping in the Bidjovagge area consist mainly of carbonates. Then follow argillites, often carbonaceous and usually altered to albitic felsites in the mining area. The uppermost beds in the Bidjovagge area consist of tuffites and amphibolites. This primary sequence has been intruded by diabase sills.

Carbonates

The lowermost units are carbonate rocks with tuffites in the core of the Bidjovagge anticline. The carbonate rocks are partly fine-grained dolomites, though massive amphibole-bearing coarser grained dolomite is more common. The coarse-grained amphibole-bearing dolomite is interpreted as dolomite intermixed with tuff material. Rocks underlying these units are not exposed and the nature of the contact with the basement of the greenstones is not known. The white to grey, fine grained (grain size 0.01-0.1 mm) dolomite has a fine lamination similar to the algal mat lamination seen in less deformed carbonates in the Kvenangen area (Fig. 1). It is often albitized and in some thin-sections most of the dolomite is replaced by albite. Albitization of carbonates has been reported by Vik (1985) from the Kvenangen area. Elvebakk et al. describe tidal sediments from the Karasjokk area with sedimentary macrostructures preserved, but all microtextures show a complete recrystallization with albite and no evidence of primary grains.

Albitized argillites

Above the carbonate beds follows a 20-50 meter thick sequence of albitized argillites interbedded with thin limestones and tuffites. When it is completely albitized the rock is called albitic felsite or graphitic felsite. The graphitic felsite is altered carbonaceous argillite and it can contain up to 40% C as very fine grained graphite.
There are both sharp contacts and continuous transitions from albitic felsite to graphitic felsite. Near the ore bodies the contacts between the two types of felsite are often discordant with the primary bedding.

Tuffites and amphibolites

The Bidjovagge level is succeeded by a mixed sequence of diabase sills, metatuffites and amphibolites. Units of carbonate rocks also occur in this part of the sequence. The tuffites are the most dominant rock type. The most common variety is mapped as "banded amphibolites" and consists of light and dark bands alternating on a cm to dm scale. The dark bands are coarse grained and consist mainly of hornblende, while light bands are fine grained and contain mainly quartz and plagioclase.

Massive amphibolites with thicknesses of a few meters occur with metatuffites. They are medium to fine grained without any primary structures and may be interpreted as metavolcanic rocks.

The upper part of the Cas'kejas Formation consists of argillite units with carbonate rocks and graphitic schists. These rocks are found in the syncline in the north-eastern part of the map in Figure 2.

Intrusive rocks

Diabase occurs both stratigraphically above and below the ore-body. The diabase is folded and must have been intruded as early sills. Individual units can be up to 100 meters thick. Ophitic textures and chilled margins are locally present. The diabase is a fine to medium grained green rock with a subophitic texture, consisting of albite,amphibole, epidote, chlorite, biotite, calcite, magnetite, pyrrhotite and pyrite. It shows different degrees of alteration; the diabase below the ore body is strongly altered.

Recently an albitite dyke has also been found in the B deposit. The dyke is a reddish, coarse grained albitite with minor amounts of pyrite and calcite, up to 5 meters thick and eith sharp contacts to its albitic felsite host rock.

Alteration

Sodic alteration, producing albitic felsites, graphitic felsites and secondary albite in diabase, is the most important alteration type associated with the mineralization at Bidjovagge. The felsites are mainly an alteration product of argillites, but occur also in carbonates, diabase and tuffites. The albitic felsite and graphitic felsite of the Bidjovagge stratigraphic level are associated with diabase sills. These rocks are stratigraphic units and can be followed over a strike length of 8.5 km in the Bidjovagge anticline. The normal stratigraphy is a graphitic unit with albitic felsite on both sides. The lower contact of the lower albitic felsite is usualy sharp against a diabase, while the upper albitic felsite gradually turns into a tuffite upwards.

The albitic felsite consists mainly of albite with small amounts of quartz and carbonate. Amphibole and micas also occur. The rock is granular and very fine grained (0.01 mm). Near the contact to the diabase it is usually massive, without internal primary structures. Near the contact to metatuffites the albitic felsite is laminated with 3-8mm thick layers.

The alteration of diabase sills is very complex, resulting zones enriched in albite, biotite, calcite, scapolite and hematite. Albitization is the most common alteration; large phenocrysts of albite replacing amphibole can be seen frequently in thin-section (Fig. 4). The albitization can be complete in limited zones, resulting in a coarse grained albitite called leucodiabase by earlier authors (Hollander, 1979). A gradual change from diabase to fine grained albitic felsite has been observed in some drill cores. The albitization is often associated with carbonatization. Calcite occurs both disseminated, replacing mostly amphibole, and as thin veins. Hematite occurs often together with secondary calcite. Scapolitization can be fairly extensive with 30-50% of the rock consisting of scapolite in the form of 5-10mm large poikiloblasts formed at the expense of mainly albite. Scapolitization is also a regional feature in the Kautokeino Greenstone belt. Biotite occurs in restricted zones together with albite, some amphiboles and carbonate. Biotite rich zones are more schistose and may represent metamorphosed clay-mineral alterations.

GEOLOGY OF THE ORE DEPOSITS

The Bidjovagge mine encompasses four oredeposits bodies, which are situated on the eastern limb of the Bidjovagge anticline over a strike length of 2.5 km (Fig. 2). The deposits are generally tabular with an individual strike length between 100 m and 200 m. The thickness varies from less than 5 up to 35 m. Original ore reserves and ore reserves in 1986 are shown in Table 1. Copper and gold are the only metals of economic importance, with average grades of about 1% copper and 2-3 ppm gold. The geochemistry of the ores is not known in detail. The silver content is of the order of 2-3 ppm. The mean zinc contents in the different ores range from tens to hundreds of ppm, as do the lead contents. The mean nickel contents range from about 300 to 600 ppm, the cobalt-contents from 80 to about 300 ppm.

All economic ore is hosted by albitic felsite, but the graphitic felsite is often mineralized close to its contact with the albitic felsite. Since the felsites occur within certain stratigraphic units, the mineralization can be classified as stratabound.

Three types of chalcopyrite mineralization in albitic felsite can be distinguished, but there are gradual transitions between each of them:

1. Most of the chalcopyrite occurs in veins with ankerite, actinolite and some pyrite and pyrrhotite. The veins are usually 2-10 cm thick and form a brecciated texture in the cherty looking albitic felsite (Fig. 5). A few wider veins, each several meters thick, are folded and boudinaged.

2. Chalcopyrite with minor gangue minerals (ankerite and actinolite) is found in veinlets in a stockwork like texture. In some areas the veinlets occur parallel to the bedding.

3. Disseminated chalcopyrite is usually observed in association with the vein mineralization.

There is always some gold in the copper mineralization, but a positive correlation between copper and gold has only been reported from the southernmost ore body (Hagen, 1977). The highest gold grades are always found in zones with low sulphide contents.

The chalcopyrite in the graphitic felsite forms very irregular veins with small amounts of gangue minerals. Copper grades are sometimes high, but low gold grades and poor recovery make mineralization in graphitic felsite uneconomic.

The four deposits are known as A, B, C and D. During the first mining period, from 1970 to 1975, 400 000 tons of ore were mined from A and C deposits. These two deposits have earlier been described by Hollander (1979) and Hagen (1977, 1982, 1983a) and will only be briefly described here. New information has been gained about the B and D deposits through recent diamond drilling, removal of glacial overburden and production in the second mining period. The B and D deposits will therefore be described in some detail:

The B deposit

The B deposit is the northernmost of the Bidjovagge deposits (Fig. 2). It comprises three ore bodies, the main, the east and the west ones (Fig. 6). The main and west ore bodies occur as northerly continuations of a graphitic felsite, while the east ore body occurs on the western flank of another graphitic unit. A typical section through the B deposit is shown in Figure 7.

The main orebody continues to a depth of a least 100 m, and contains some 440 000 tons with 1.1% copper and 3.56 ppm gold. The east ore dies out at a depth of 20 to 30 m, and contains on the order of 76 000 tons, carrying 0.67% copper and 2.0 ppm gold. The west ore is a small gold ore in the footwall of the main ore and close to the graphitic felsite (Fig. 6). This ore has not yet been delineated, but the size is on the order of 5 000 tons, the copper grade is about 0.1% and the gold grade is 2-5 ppm.

The albitic felsite at the B deposit can be divided into three units. On top of the mineralized felsite is a mixed series with alternating felsite and laminated carbonate layers. The mineralized unit is a light homogeneous felsite. The felsite hosting the east ore contains 1-2 m thick albite carbonate sills. The host rock of the west ore is reddish due to hematite and in some parts greenish due to chlorite. The footwall felsite unit is often chloritized and hematitized. The graphitic felsite in the south interfingers with the albitic felsite, and a "finger" of graphitic felsite penetrates into the main ore for at least 50 m at a depth of 15 m to 50 m in the north.

The D deposit

The D deposit is situated between the A and C deposits (Fig. 2). A geological map of the D deposit is shown in Figure 8. Diamond drilling in 1985 converted previously known low grade copper mineralization into a mineable gold-copper ore.

The deposit occurs as a northerly continuation of a graphitic felsite, a feature which is shared with the main and west ore bodies of the B deposit; see description above. The length of the D deposit is about 100 m, and the thickness is up to 35 m. The ore changes into a thin mineralized zone towards the north, and at depths of 50 to 60 m below surface. The body dips 70^{o} to the east in the north and 50^{o} to the east in the south and contains 208 000 tons of ore, grading 0.94% copper and 2.36 ppm gold. A section of the D deposit is shown in Figure 9.

The host rock is a light albitic felsite with varying carbonate and actinolite contents. Coarse grained carbonate-albite sills are common. These are folded and boudinaged, showing clearly a predeformational origin. As in the B deposit the mineralized unit is overlain by a mixed series with albitic felsite alternating with laminated carbonate layers and material of probably tuffitic origin. The footwall felsite is chloritized and hematitized. The graphitic felsite in the south interfingers with the mineralized albitic felsite. Close to the contact the albitic felsite is bleached and contains inclusions of graphitic felsite.

The northern part of the deposit is mainly a copper ore, dominated by vein mineralization, with ore types 1 and 2. In the central parts ore type 3 becomes more abundant, and unmineralized layers of flinty albitic felsite alternate with high grade layers, often characterized by ankerite and actinolite. To the south the ore gradually changes into a gold ore characterized by minor sulphides and quartz veinlets with tellurides in a reddish albitic felsite. This development from north to south is demonstrated by a map showing the gold to copper ratio (Fig. 10).

In the D deposit there is a positive correlation between gold and redioactivity. In Figure 9, gold and radioactivity values are shown in a profile over the geological section. High radioactivity values are related to the occurence of davidite as a weak dissemination in the albitic felsite. The correlation between davidite and reddish to brownish albitic felsite with quartz veinlets and gold mineralization is confirmed from the west ore of the B deposit, the footwall of the A deposit (Hagen, 1983a) and from the gold ore in the footwall of the C deposit (Hagen, 1983b).

A very gold rich zone occurs directly below the mixed series in the hangingwall of the D deposit. The thickness of the zone is between 3 and 7 m, and the average gold grades recorded vary between 18-65 ppm. The zone is thin and weak at surface, and does not show on the gold-copper ratio map of Figure 10. This gold ore is hosted by a carbonate-albite rock with zoned hastingsite porphyroblasts. The rock may represent an altered carbonate bed. Also in this gold zone there is a positive radioactive anomaly.

The A and C deposits

The A and C deposits are more copper-rich than the B and D deposits. The copper grade of the A deposit is 2.10% (Table 1), and that of the C deposit 1.84% (Hollander, 1979). In other respects the A deposit is similar to the B deposit. The ore of the A deposit is mostly of types 1 and 2, and the periphery of the ore is richer in gold than the central copper rich part. In the footwall the ore gradually changes into a gold ore with tellurides, davidite, quartz veinlets and minor sulphides in a cherty looking albitic felsite. Below the ore the albitic felsite is often rich in pyrite, and chloritized and hematitized zones occur.

The C ore contains more iron sulphides than the other deposits. As a whole the C deposit is also richer in zinc, lead, nickel and cobalt. In the footwall of the C ore occurs a small gold-copper ore, designated "gold" in Table 1. This ore is hosted by an albitic felsite with the same features as described from the gold-rich zones in the other orebodies.

Compared to the other orebodies the tonnage of the C deposit is large (Table 1), but at present the main C ore is not considered mineable; the gold grade is low (0.5 to 1.0 ppm), the ore is partly hosted by graphitic felsite and the deposit is only suitable for underground mining.

Ore mineralogy

The main ore mineral in the copper ore bodies is chalcopyrite. Its typical mode of occurrence is as coarse grained anhedral aggregates, though individual anhedral grains of chalcopyrite are also common.
Pyrite and pyrrhotite commonly occur with the chalcopyrite, but the distribution of the iron sulphides is irregular and they seldom make up more than 10 percent of the ore. Grains of chalcopyrite and pyrrhotite show mutually interpenetrating grain boundaries.

In pyrite rich ore chalcopyrite occurs as inclusions and fracture fillings in the pyrite. Replacement of pyrite by chalcopyrite along fractures and grain boundaries is common (Fig. 11).
Microprobe analyses of pyrite have recorded up to 6.9 percent nickel (Hagen, 1977) and 0.9 percent cobalt (Sotka and Hanninen, 1983). However, the majority of the pyrite grains contains undetectable amounts of nickel and cobalt.
Gold occurs mainly as native metal. In the copper mineralization gold is commonly associated with pyrite, as inclusions and fracture fillings. A positive correlation between gold and copper has, however, been proved in the C ore body (Hagen, 1977). Gold has also been observed as inclusions in chalcopyrite and in pyrrhotite.
In the zones of high gold and low copper, gold is found in an assemblage with tellurides (Fig. 12). Melonite, tellurobismuthite and altaite are the most common tellurides, but frohbergite, native tellurium and calaverite have also been identified (Hagen, 1982). The assemblage is found in quartz-carbonate veinlets, with minor sulphides. Tellurides also occur in the copper ore, usually as inclusions in pyrite (Fig. 13). Most of the gold at Bidjovagge has a grain size of less than 0.1 mm (Hagen, 1981), but larger grains occur and the tellurides can often be seen with the naked eye.
Microprobe analyses of native gold show a marked difference in the composition of native gold, in copper ore and in gold ore (Table 2). The gold in the copper ore contains more than 9 percent silver while the gold from the gold ore has a fineness of more than 99 percent.

Marcasite is a common accessory mineral. It occurs as subhedral grains, usually associated with pyrite. The mode of occurence of the marcasite indicates a hypogene formation (Hagen, 1977).

Other accessory sulphides in the ore are: sphalerite, galena, pentlandite, violarite, mackinawite and molybdenite (Hagen, 1977). Sphalerite mainly occurs as anhedral inclusions in chalcopyrite and may itself contain tiny inclusions of chalcopyrite. A few observations of galena as fissure fillings in pyrite have been made. In one sample galena and chalcopyrite form lamellae in sphalerite (Fig. 14).

Bornite, chalcocite, covellite and native copper have been observed in near surface samples and are interpreted as products of supergene processes.

Magnetite, ilmenite, hematite and rutile are all common accessory minerals. Magnetite often occurs as euhedral inclusions in sulphides. Larger magnetite grains are usually cataclastically deformed. In hand specimens magnetite can be seen, having a "blade-like" appearance which may represent a pseudomorph after hematite. Ilmenite is found as subhedral and anhedral grains both in the ore bodies and in the unmineralized albitic felsite. Ilmenite grains often contain hematite lamellae in an exsolution texture. Disseminated rutile occurs in the albitic felsite and sporadically in the graphitic felsite.

Mathiesen (1969) investigated a complex titanium mineral from the A ore body. The mineral has later been identified as davidite (T. Sverdrup, pers. comm.). In addition to the davidite, Mathiesen identified thortveitite, vanadio-rutile, a vanadiochrome spinel, gadolinite and euxenite. The titanium - vanadium - uranium - REE mineralization has later also been found in the other ore bodies, and may be spatially related to gold mineralization.

Geochemistry

The Early Proterozoic volcanites of the Baltic Shield have recently been investigated by several authors. In a regional survey of the Lappland area, Pharaoh and Pearce (1984) concluded that the metavolcanic greenstones in Finnmark are tholeiitic basalts which range from MORB to WPB in their content of elements of high ionic potential. The association with shallow marine sediments deposited on an Archean continental basement, indicates a depositional environment connected with the initial phase of opening of an ocean or a back-arc basin. A rift environment has also been suggested by Torske (1978). The volcanites and the diabase sills of the Cas'kejas Formation have been studied by Sandstad (1983) in the Bidjovagge-Kautokeino region; they are chemically similar. They also pre-date deformation, and the diabase may therefore be formed early, in association with volcanicity in Cas'kejas Formation.

In the Bidjovagge mining area the diabase sills are altered to varying degrees. In order to illustrate the chemical changes due to alteration of the diabases in the mining area, they have been compared with less altered diabases from the regional study of Sandstad (1983) in Table 3. The altered diabases can be separated into two main groups. One group is enriched in sodium and one in potassium. Sodium enriched diabase occurs often near albitic felsite and the contact is usually transitional. The sodium enriched diabase has a plagioclase with An_{0-10} and the occurence of authigenic albite can be observed in thin sections. The calcium content is similar to that in weakly altered diabase in the region, but calcite has been formed at the expense of the mafic minerals. This is also shown in the high loss on ignition in the sodium enriched samples, and it explains the reductions in the iron and magnesium contents. The potassium enriched diabase sills are characterized in the field by an increased content of biotite and sometimes scapolite or hematite. The biotite altered diabase has a lower calcium content than the regionally weakly altered diabase, but the calcite content is higher, indicating a replacement of amphibole by calcite and biotite. The plagioclase is sometimes replaced by scapolite. The same alterations are also observed in the Kvenangen area (Vik, 1985).

The albitic felsites have an average sodium content of 7.5% Na_2O and a SiO_2 content of 66%. They consist mainly of albite with minor quartz and carbonate. They have been interpreted as being primary tuffites by Hollander (1979), but field observations point to a metasomatic and contact metamorphic alteration of shales, tuffites and carbonates.

REE-elements

The REE-content in the diabase sills and in the albite from the mining area has been analysed at the Imperial College Reactor Centre in England. REE-contents of unaltered diabase have also been published by Vik (1985) from the Kvenangen area. The diabase (gabbroic sills) in the Kvenangen area has a flat REE pattern with a weak Eu-depletion implying that the magma is derived by partial melting of a primitive mantle with little or no enrichment or depletion of the LREE or the HREE (Cullers & Graf, 1984). The potassium enriched diabase (Fig. 15, group II and Table 3) has a more irregular pattern compared with unaltered diabase, but has also a fairly

flat REE distribution and a weak Eu-depletion. One sample of biotite altered diabase, which is not included in group II, is enriched in LREE and has a REE distribution more similar to the albitic felsite.
The albitized diabase is characterized by a marked Ce-depletion (Fig. 15) and a lower La/Lu ratio compared with unaltered diabase and potassium enriched diabase. Seawater has also a marked Ce-depletion and basalt with a Ce-depletion is interpreted to be seawater altered, or to have been formed by partial melting of seawater altered rocks (Humphris, 1984).

The diabase sills were probably associated with the volcanites in the Cas'kejas Formation (Sandstad, 1983). The sills may have been intruded at very shallow depth partly into unconsolidated sediments, where a high water content would give a relatively high water/rock ratio. The temperature during alteration in unconsolidated sediments may have been higher than during alteration on the seafloor, due to a more restricted circulation of seawater. The Ce-depletion in Bidjovagge only occurs in the sodium enriched diabase and may relate this albitization to seawater alteration.
The albitic felsite has a totally different REE distribution with an enrichment of LREE. The same pattern for albitic felsite and for graphitic felsite has been published by Vik (1985) from the Kvenangen area. Sediments can have an enrichment in the LREE, and the REE pattern may therefore reflect a primary distribution of REE before albitization.

Field observations indicate that albitization of the diabase and sediments/tuffites was part of the same prosess. The low content of LREE in the albitized diabase favuors therefore a primary high content of LREE in the albitized sediments.
This preliminary study will be followed up by a more detailed analytical program where the REE content will be correlated with the content of U, Au and Cu.

Lead isotopes

Galena occurs mainly in the C deposit where the lead content can be up to 0.5% in induvidual analyse. The galena occurs late in the paragenetic sequence, often as fissure fillings in pyrite and chalcopyrite.
Five samples of galena from the C ore body were separated and the analyses

were performed by Geospec Consultants, Edmonton, Alberta, Canada.
All analytical data have been corrected for mass discrimination by comparison to NBS CRM-981 common lead standard. The 2G-error limits for the ratios $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{207}Pb$ are 0.87 o/oo, 1.95 o/oo and 1.44 o/oo respectively. The correlation coefficient between ratios is 0.82. Two of the samples were analysed in duplicate, because of the initial values obtained and the linearity of the plotted data. In one case the repeat analysis lies outside the expected error limits (Table 4, sample 65226), but the variation is not sufficient to alter the slope of the straight line array to any significant degree. The results are plotted in Figure 16.
The five galenas define a secondary isochron for which a calculated slope of 0.132 +/- 0.059 was obtained. The most radiogenic sample 65226 falls somewhat below the line defined by the four other samples (Fig. 17). If sample 65226 is excluded, a slope of 0.159 is obtained.
The slope and the $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{208}Pb$ ratios are similar to results published from sandstone-lead deposits along the Caledonian front in Scandinavia. In particular, a large variation in the data from one individual deposit has been found in the Osen deposit in SE Norway (Bjørlykke & Thorpe, 1981). Five samples from the Osen deposit define a secondary isochron with a slope of $0.1237^{+}/-0.056$.
A slope of 0.132 gives a t-max of approximately 2125 Ma and a t-min of 1290 Ma. If we use 530 Ma for the age of formation of the galena, similar to an age found at Osen (Bjørlykke & Thorpe, 1981) the age of the source rock will be 1850 Ma.
A slope of 0.159, using the four least radiogenic samples, will give a t-max of 2445 and a t-min of 1495. If one again uses 530 Ma as an age of mineralization, the source of the lead must be 2200 Ma.
Field evidence shows that the main mineralization was pre or syn deformation (1700-1900 Ma). The results from the lead isotope data gives a much younger age for the galena. Even if the secondary isochron is a mixing line, the 207/206 ratio shows that some of the radiogenic isotopes have been formed relatively recently. The galena must therefore partly be later than the main mineralization event.
The Bidjovagge mine is situated just below the Cambrian-Precambrian unconformity. Many occurences of galena are known from this unconformity in Finnmark (Bjørlykke et al., 1985) and radiogenic lead could have been contributed to the C deposit during the peneplanization.
The source of the lead would then be rocks of the Cas'kejas Formation and

this is in agreement with a t_1 between 1800 and 2200 Ma and a t_2 of 500-600 Ma. Also the relatively large variation in the isotopic ratios support this model.

SUMMARY AND CONCLUSIONS

The Bidjovagge copper-gold deposit occurs in an Early Proterozoic rift or back arc environment. Several occurences of Bidjovagge-type mineralization have been found in the Kautokeino Greenstone Belt, and they are all related to diabase sills and associated albitic felsite. The main mineralization occurs in the lower part of the Cas'kejas Formation above a thick dolomite unit, but mineralizations stratigraphically higher up in the Cas'kejas Formation are also known.

At Bidjovagge, the diabase sills occur in a sequence of primary shallow marine sediments with dolomites, black shales, grey/green shales and limestones, tuffites and thin greenstones.

The albitization of the diabase and the surrounding sediments may be related to the diabase intrusion; the REE distribution indicates that the alteration may have been caused by seawater circulation or by a sodium rich brine of seawater origin.

Gradual transitions to albitic felsite can be observed in the diabase and in the sediments. Black shales are also albitized in graphitic felsites. Limestone beds are less albitized than the shale beds. Preliminary results of the REE-distribution in the albitic felsite indicate an enrichment in LREE in these beds before albitization.

Along the Bidjovagge anticline the ore bodies are situated at discontinuities in the self potential anomalies and in low magnetic anomalies (Mathiesen, 1972). Field observations suggest that the main mineralizations are restricted to the oxidized part of the albitic felsite, where hematite deposition has occured in the foot wall rocks. This suggests an ore forming solution within the stability field of hematite. The SP and EM anomalies are displaced at the A, B and D deposits (Mathiesen, 1972). This indicates the possibility that small scale faults acted as channelways for the ore forming solutions. Within an ore deposit there are three main zones of mineralization (see Fig. 17). Zone A consists mainly of chalcopyrite and occurs in the centre of the light albitic felsite. Zone B contains gold, some copper, minor U and occurs in light albitic felsite near the border of graphitic fels. Zone C, contains pyrite and chalcopyrite in graphitic felsite near the border of light albitic felsite.

The most important copper mineralization event seems to be related to brecciation of the host rock (in zone A), formation of ankerite-actinolite veins and oxidation of the graphitic felsite. The relation between the albitite dykes and the mineralization is still uncertain but dissemination of chalcopyrite occurs also in albitite dykes, and the dykes are sometimes cut by late carbonate veins.

The ankerite-actinolite veins with chalcopyrite are clearly folded and boudinaged, and the main mineralization seems therefore to have occured between the period of diabase intrusion and the Svekokarelian deformation (1900-1750 Ma).

The intense brecciation and the precipitation of carbonates indicate that boiling of the ore forming solution could have been an important factor in ore genesis. Actinolite occurs as disseminations, in thin veins and along the border between ankerite and albitic felsite in the larger veins. Actinolite may therefore be formed by alteration of albitic felsite by the ore forming solution.

The gold rich mineralization (in zone B) is hosted in grey and reddish albitic felsite, often near the contact to graphitic felsite. In zone B the host rock is less brecciated, the carbonate actinolite veins are thinner and not so frequent as in zone A. The mineralization occurs partly in the veins and partly in veinlets and disseminations near these veins. The gold content is often correlated with the uranium content and davidite, tellurides and chalcopyrite are parts of the same paragenesis. The gold rich zones in the footwall of the mineralization are often associated with an actinolite-chlorite-hematite alteration.

The spatial separation of mineralization in zones A and B, and the poor correlation between gold and copper, indicate that the precipitation of the two metals was controlled by different factors. Boiling and a drop in temperature may have been an important factor for the formation of copper mineralization, some gold being precipitated together with the sulphides. Some of the reduced sulphur may have been in the felsite before the mineralization. The increased gold content near the oxidation front of the graphitic felsite indicates that changes in oxygen fugacity or pH may have been responsible for the gold rich paragenesis. A study including stable isotopes is now in progress and it will hopefully give some answers to these questions.

The lead isotope composition is markedly radiogenic and the $^{207}Pb/^{206}Pb$ gives a maximum age for the galena of approximately 1500 Ma. Radiogenic lead must therefore have been added either continously by decay of uranium and thorium in the mineralization and/or by an episodic contribution; for example during the Cambrian peneplanation.

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FIGURES

Fig. 14 Lamellae of chalcopyrite (cp) and galena (gn) in sphalerite (sl). Reflected, plane polarized light.

Fig. 15 Chondrite-normalized REE contents of unaltered diabase (I), potassium enriched diabase II, albitized diabase II and albitic felsite IV. Chondrite values are from Evensen et al., 1978.

Fig. 16 Lead isotope composition of galena from Bidjovagge compared with samples from caledonian sandstone-lead deposit. (L - Laisvall, V - Vassbo and O - Osen, Bjørlykke and Thorpe, 1981).

Fig. 17 A schematic map of the D-deposit with the main zones of mineralizations.

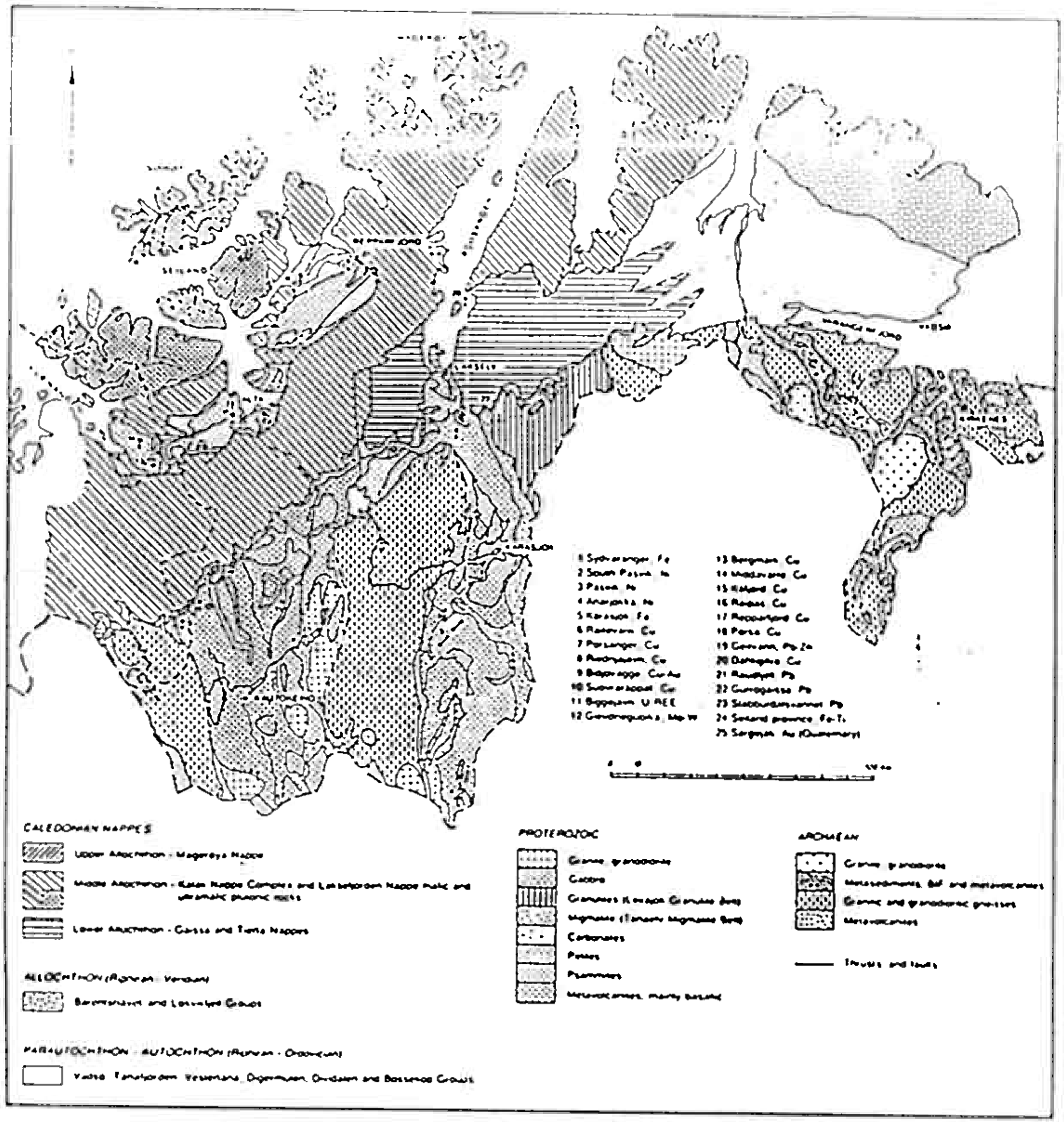
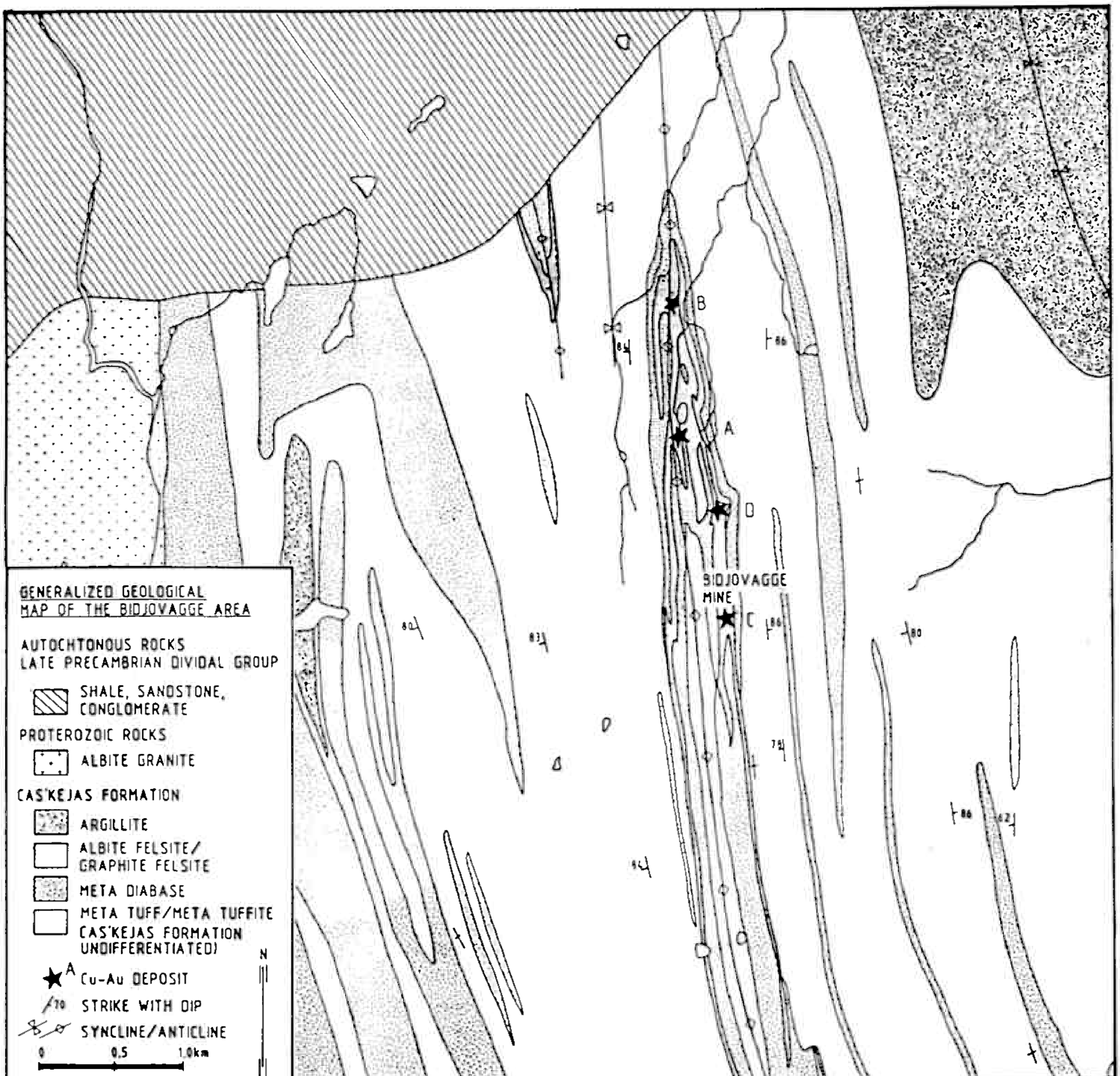

CALEDONIAN NAPPES
PROTEROZOIC
ARCHAEAN
Gabbro
Carbonates
Pelites
Psammites
Metavolcanites
Thrusts and faults
1 Sydvaranger Fe
2 South Pasvik Fe
5 Karasjok Fe
13 Bergmann Cu
18 Porsa Cu
19 Gimvann Pb Zn
24 Seiland province Fe-Ti

Fig 1.

Fig. 2


GENERALIZED GEOLOGICAL MAP OF THE BIDJOVAGGE AREA
AUTOCHTONOUS ROCKS
LATE PRECAMBRIAN DIVIDAL GROUP
SHALE, SANDSTONE, CONGLOMERATE
PROTEROZOIC ROCKS
ALBITE GRANITE
CAS'KEJAS FORMATION
ARGILLITE
ALBITE FELSITE/ GRAPHITE FELSITE
META DIABASE
META TUFF/META TUFFITE CAS'KEJAS FORMATION UNDIFFERENTIATED)
A Cu-Au DEPOSIT
70 STRIKE WITH DIP
SYNCLINE/ANTICLINE
0 0,5 1,0km
N
BIDJOVAGGE MINE
A
B
C
D

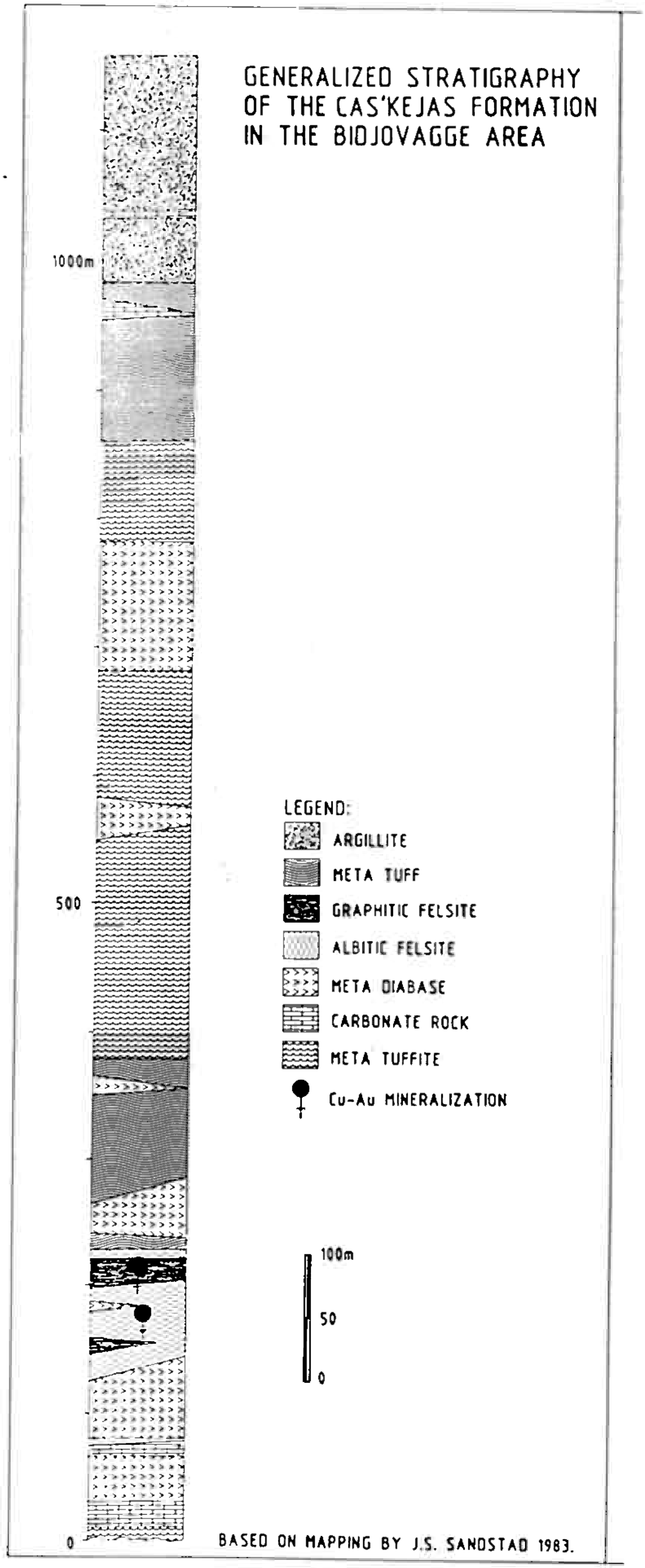

GENERALIZED STRATIGRAPHY OF THE CAS'KEJAS FORMATION IN THE BIDJOVAGGE AREA
1000m
500
0
LEGEND:
ARGILLITE
META TUFF
GRAPHITIC FELSITE
ALBITIC FELSITE
META DIABASE
CARBONATE ROCK
META TUFFITE
Cu-Au MINERALIZATION
100m
50
0
BASED ON MAPPING BY J.S. SANDSTAD 1983.

Fig 4a

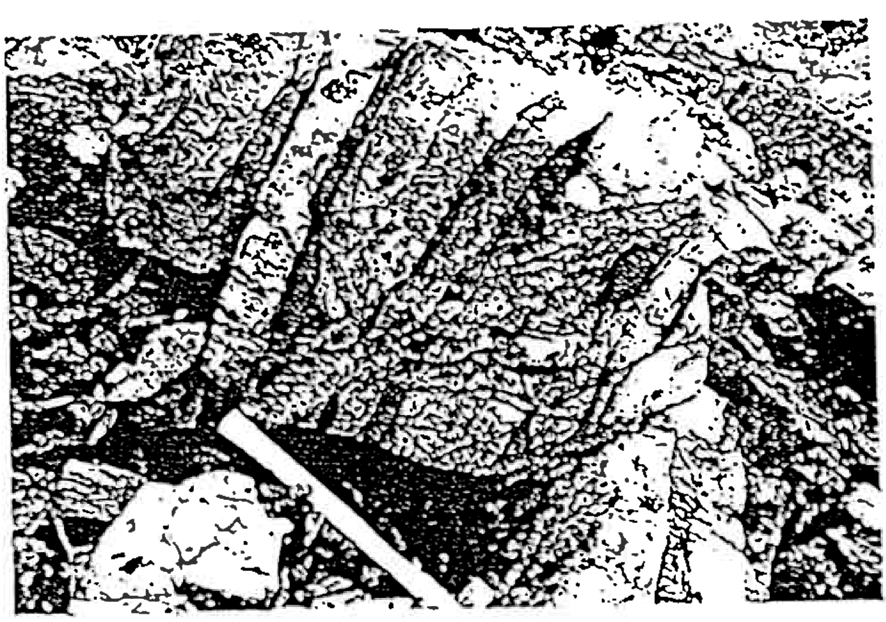


Fig 4b 5

BIDJOVAGGE
GEOLOGY OF THE B-DEPOSIT

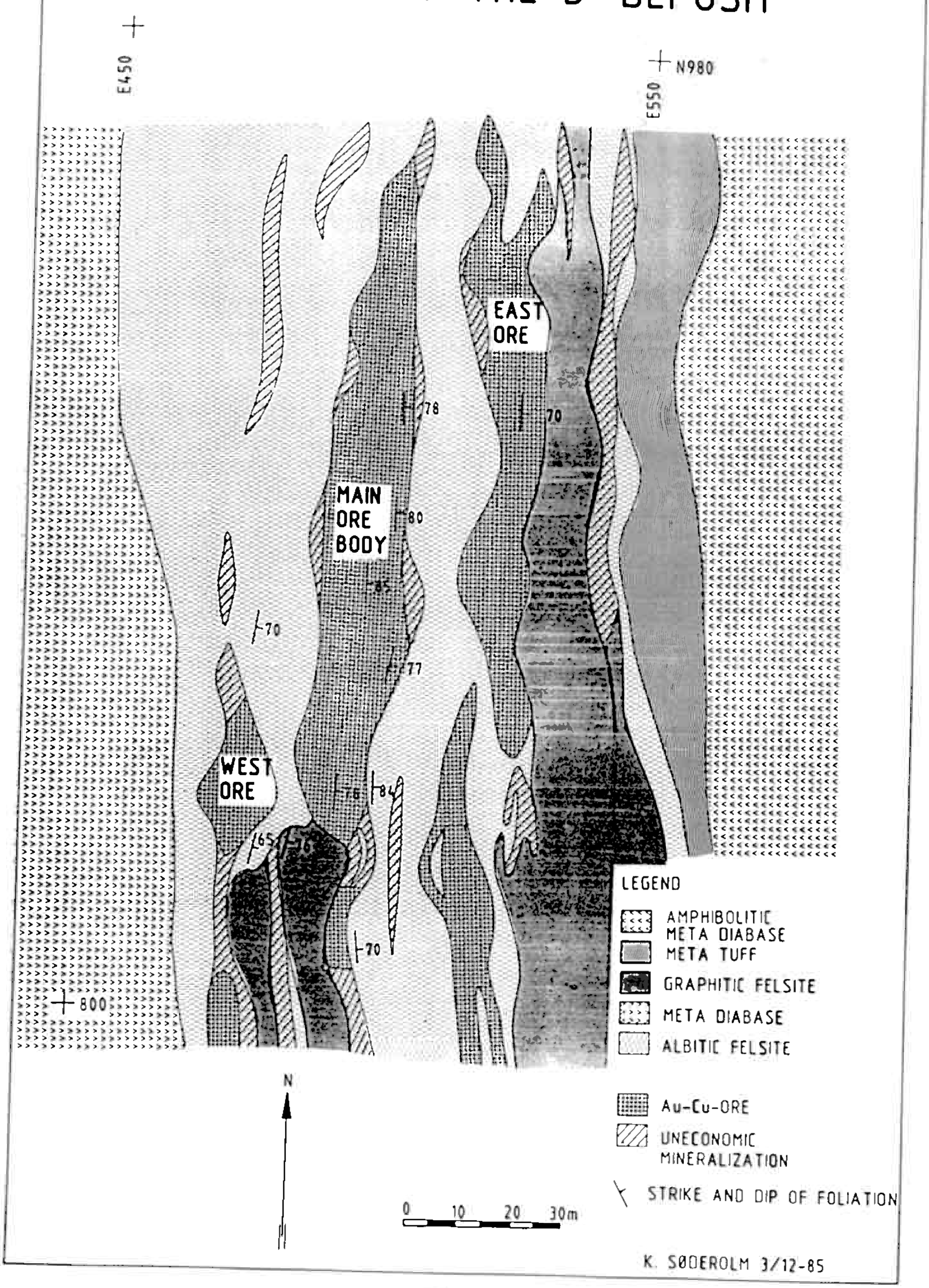


Fig 6

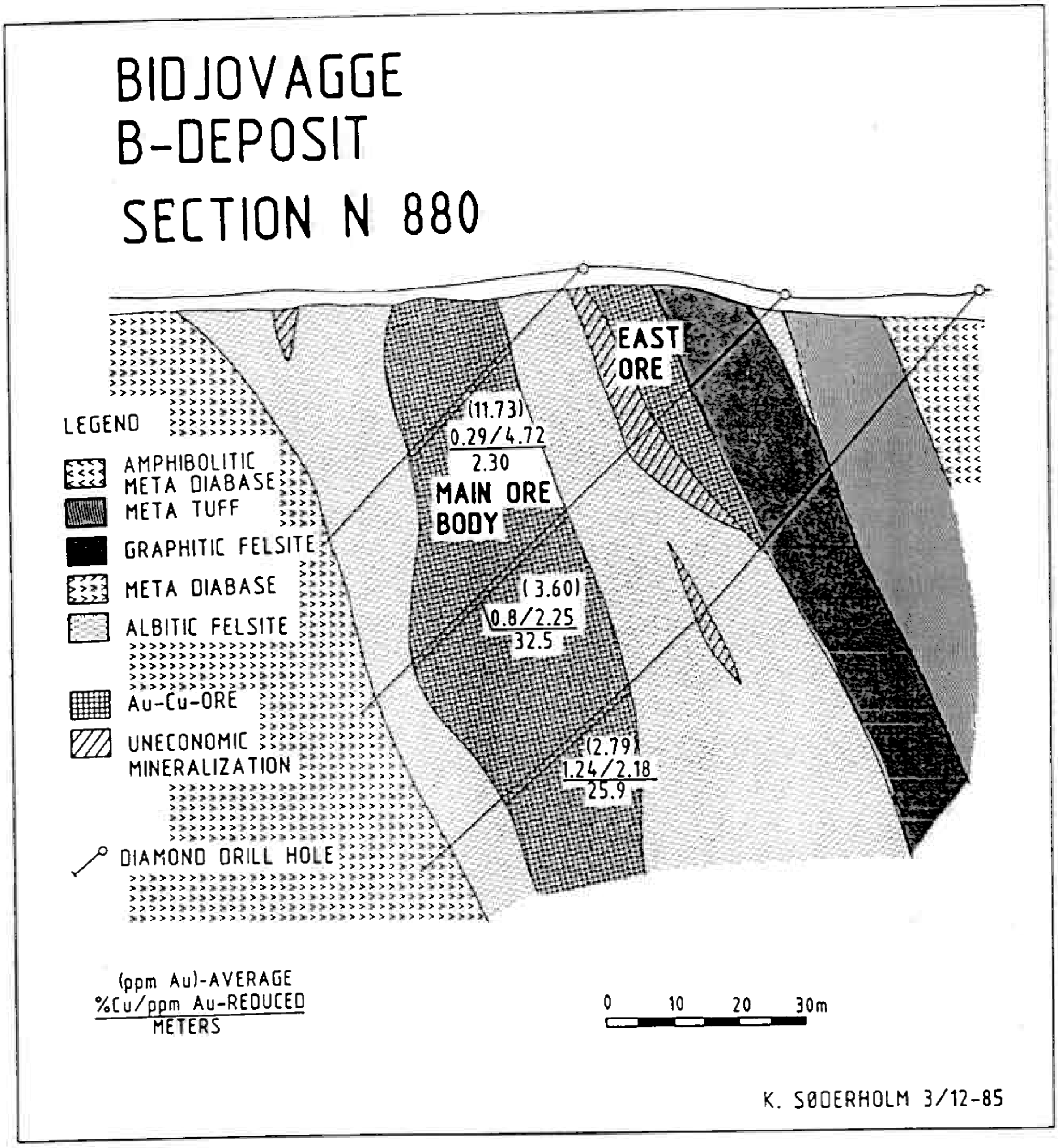

BIDJOVAGGE
B-DEPOSIT
SECTION N 880
EAST ORE
MAIN ORE BODY
(11.73)
0.29/4.72
2.30
(3.60)
0.8/2.25
32.5
(2.79)
1.24/2.18
25.9
LEGEND
AMPHIBOLITIC META DIABASE
META TUFF
GRAPHITIC FELSITE
META DIABASE
ALBITIC FELSITE
Au-Cu-ORE
UNECONOMIC MINERALIZATION
DIAMOND DRILL HOLE
(ppm Au)-AVERAGE
%Cu/ppm Au-REDUCED
METERS
0 10 20 30m
K. SØDERHOLM 3/12-85

Fig. 7

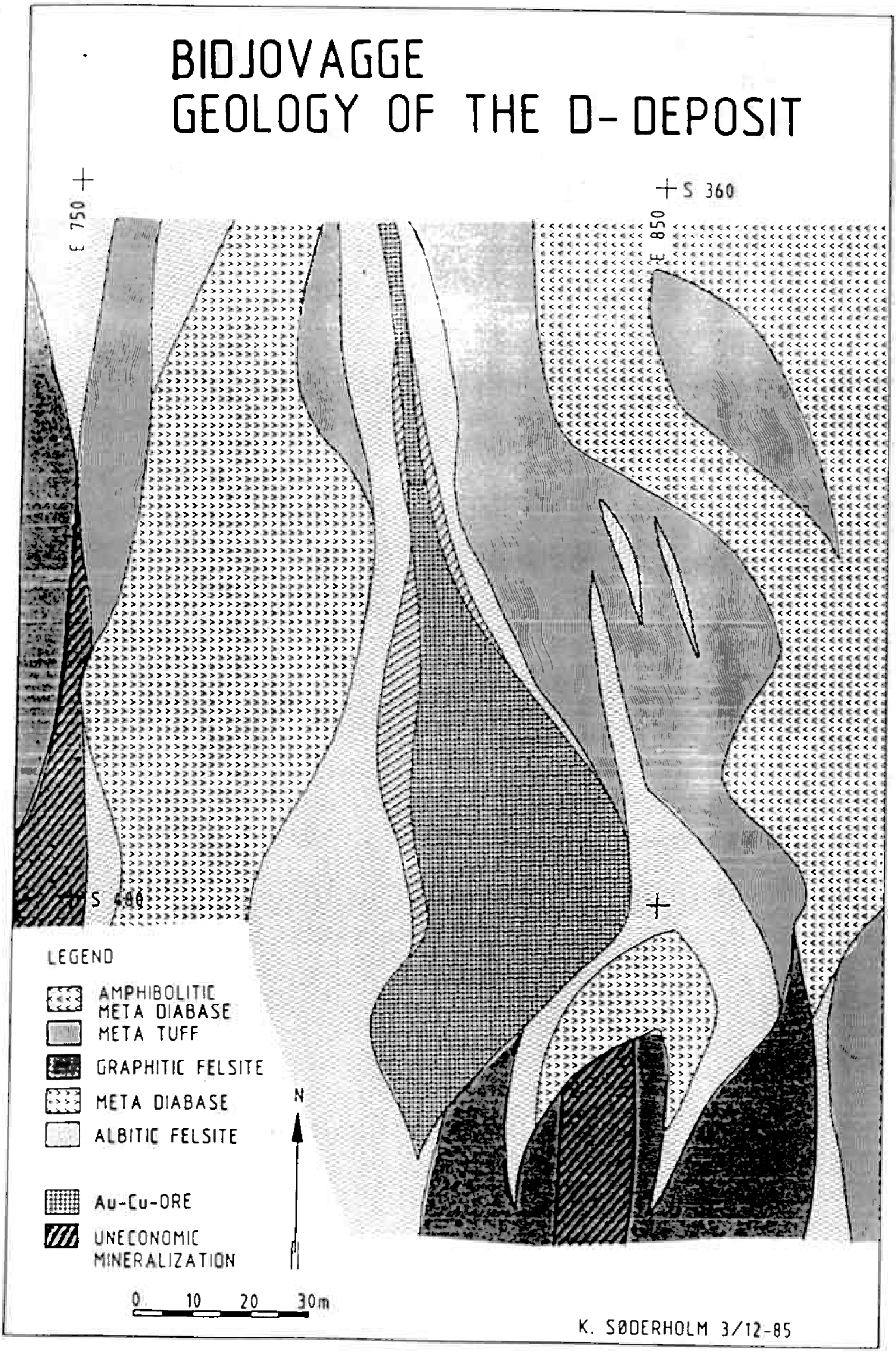
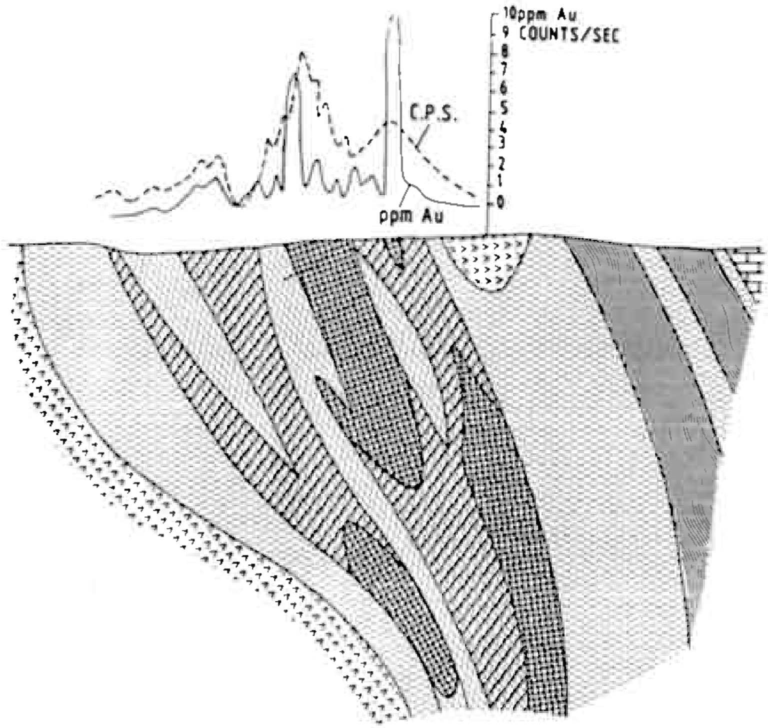

BIDJOVAGGE
GEOLOGY OF THE D-DEPOSIT
E 750
S 360
E 850
S 680
LEGEND
AMPHIBOLITIC META DIABASE
META TUFF
GRAPHITIC FELSITE
META DIABASE
ALBITIC FELSITE
Au-Cu-ORE
UNECONOMIC MINERALIZATION
N
0 10 20 30m
K. SØDERHOLM 3/12-85

Fig. 8

D-DEPOSIT
SECTION S490



CARBONATE ROCKS
META TUFF
ALBITIC FELSITE
META DIABASE

Au-Cu-ORE
WEAK MINERALIZATION

0 40m

Fig 9

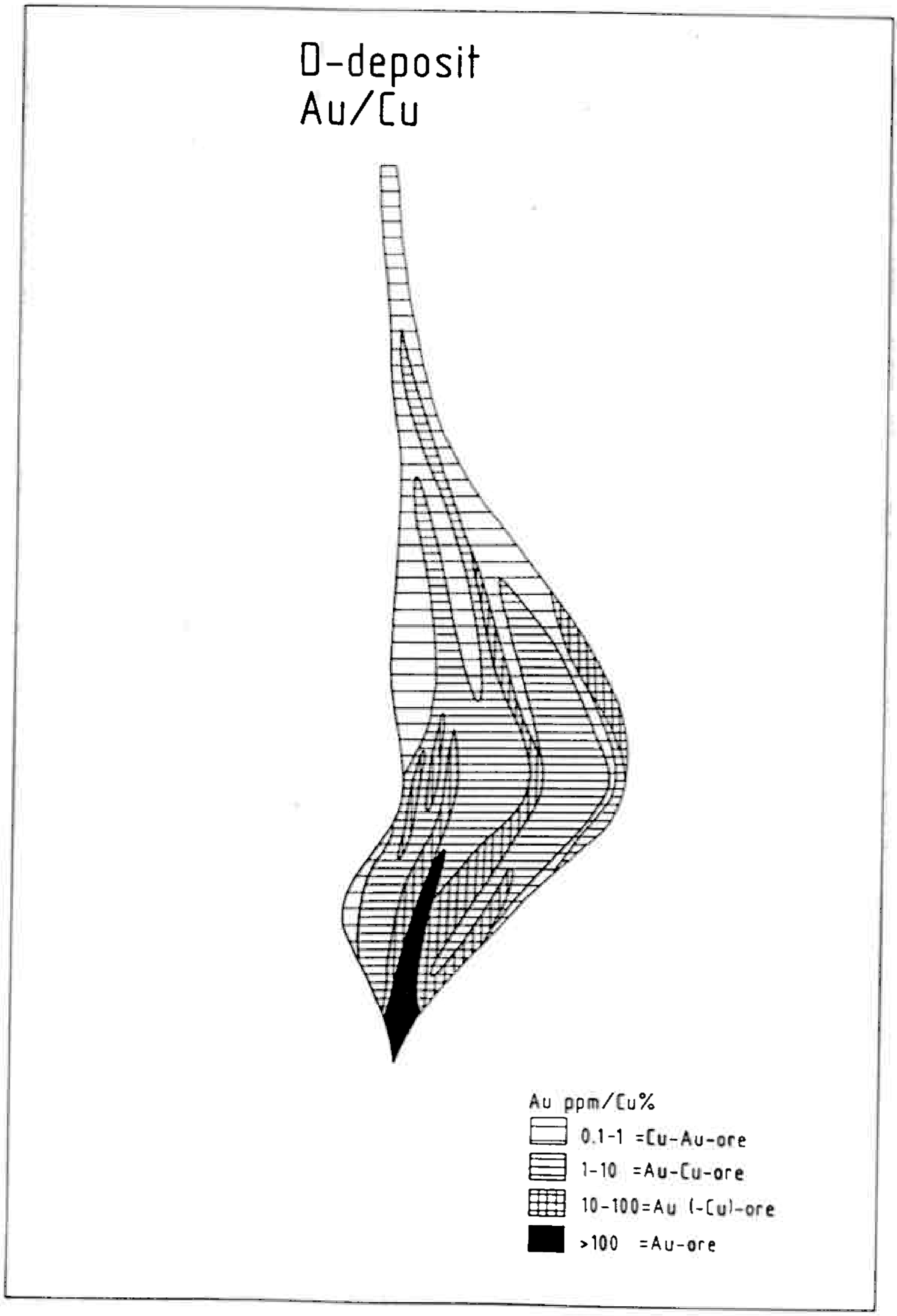
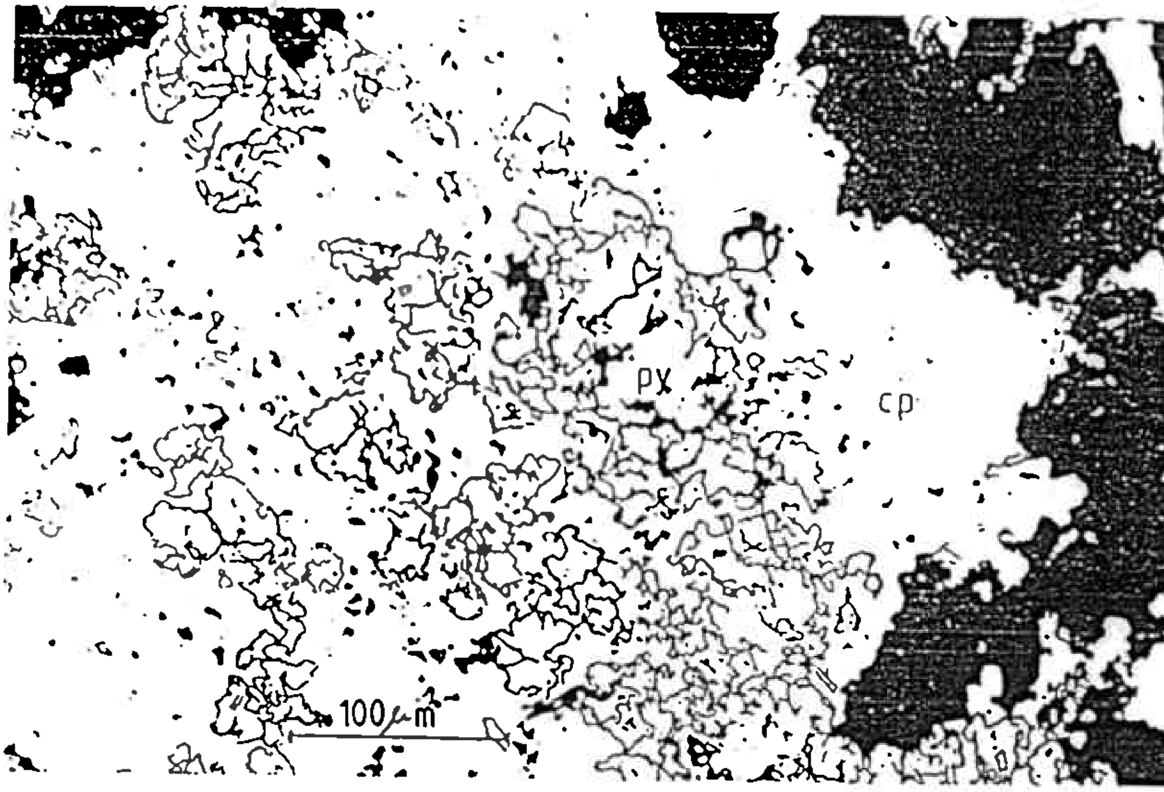

D-deposit
Au/Cu
Au ppm/Cu%
0.1-1 =Cu-Au-ore
1-10 =Au-Cu-ore
10-100=Au (-Cu)-ore
>100 =Au-ore

Fig 10



F.G. ~~10~~ 11

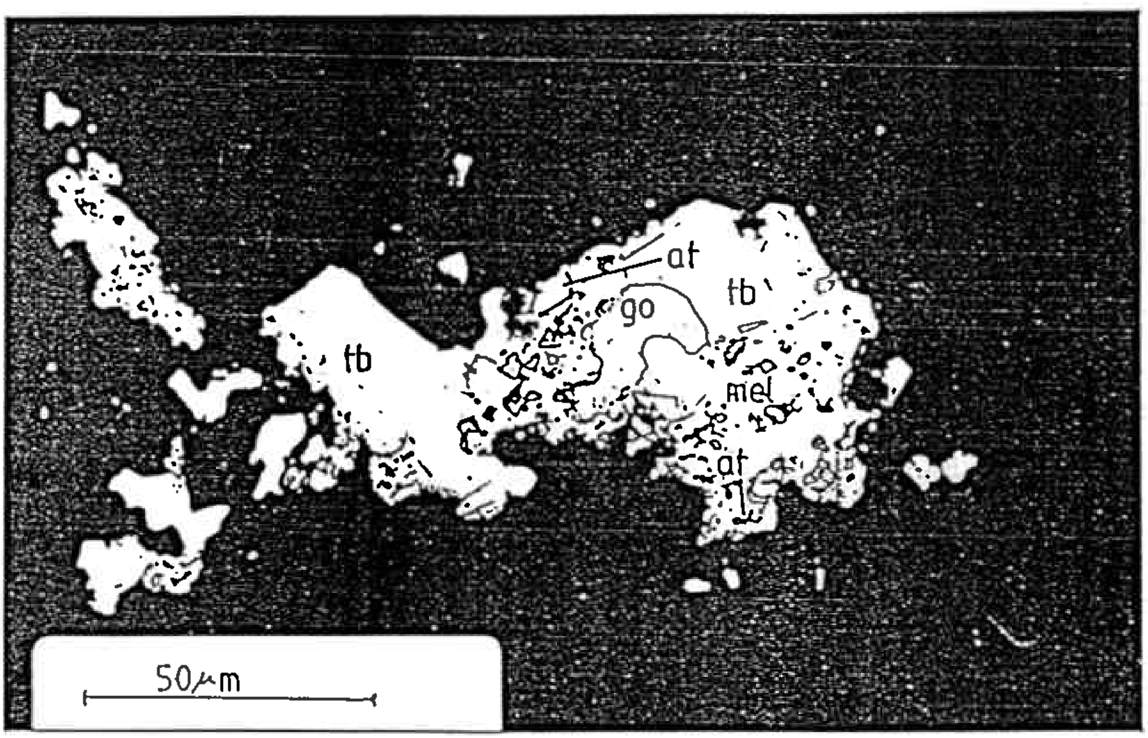


Fig ~~12~~ ~~21~~ 12

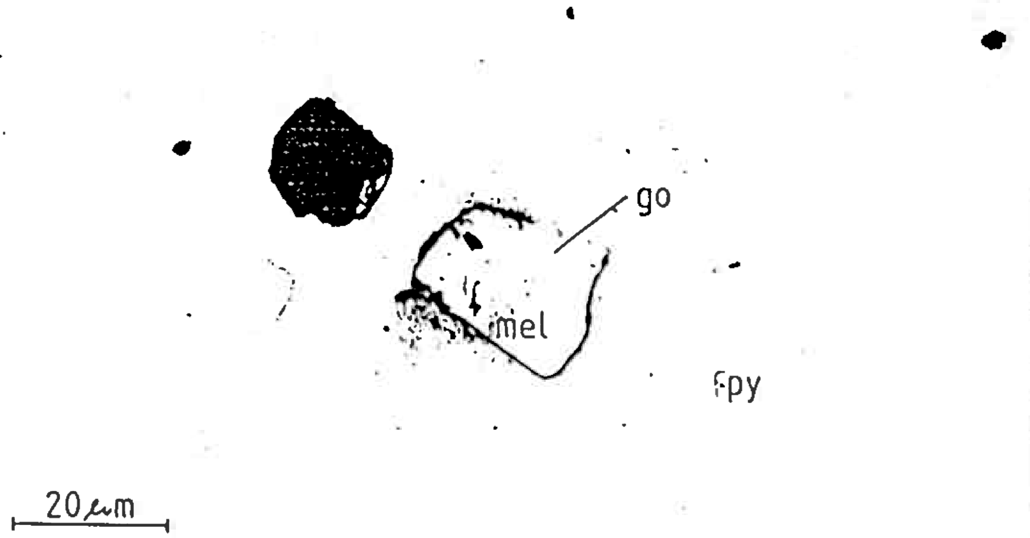


Fig. 13

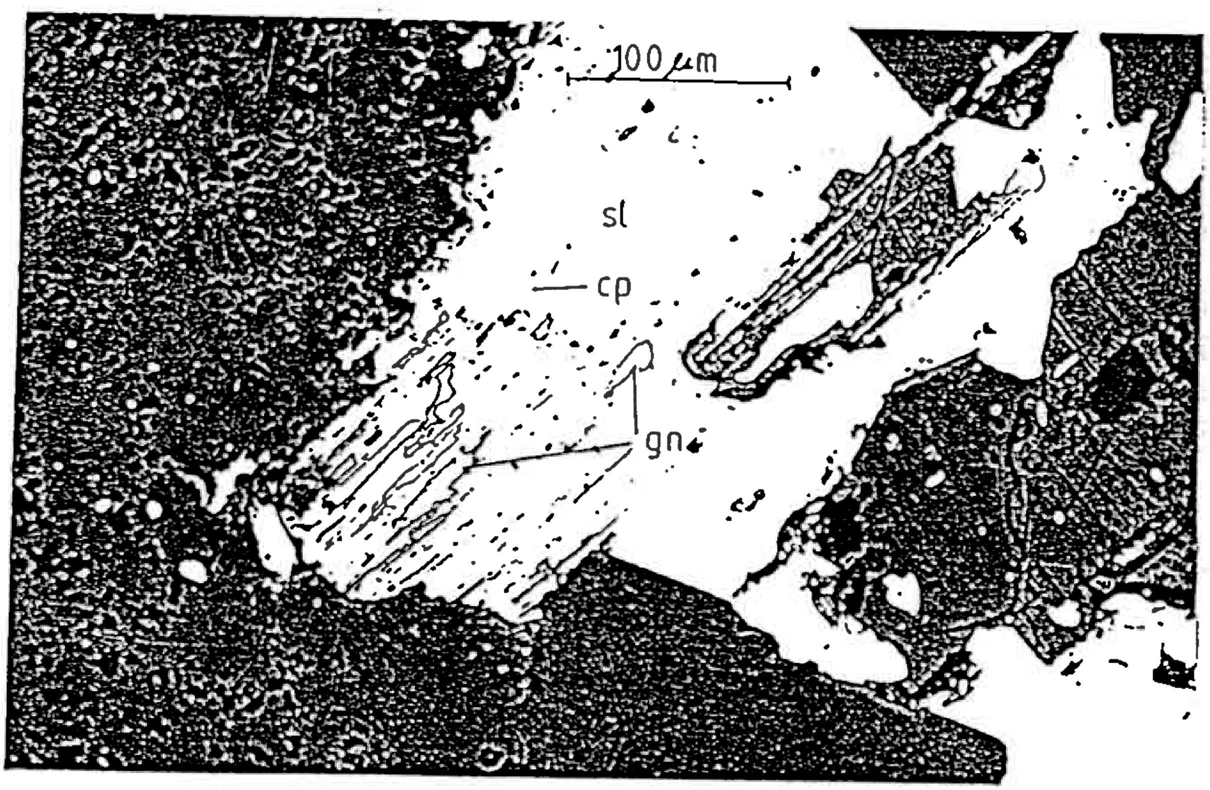
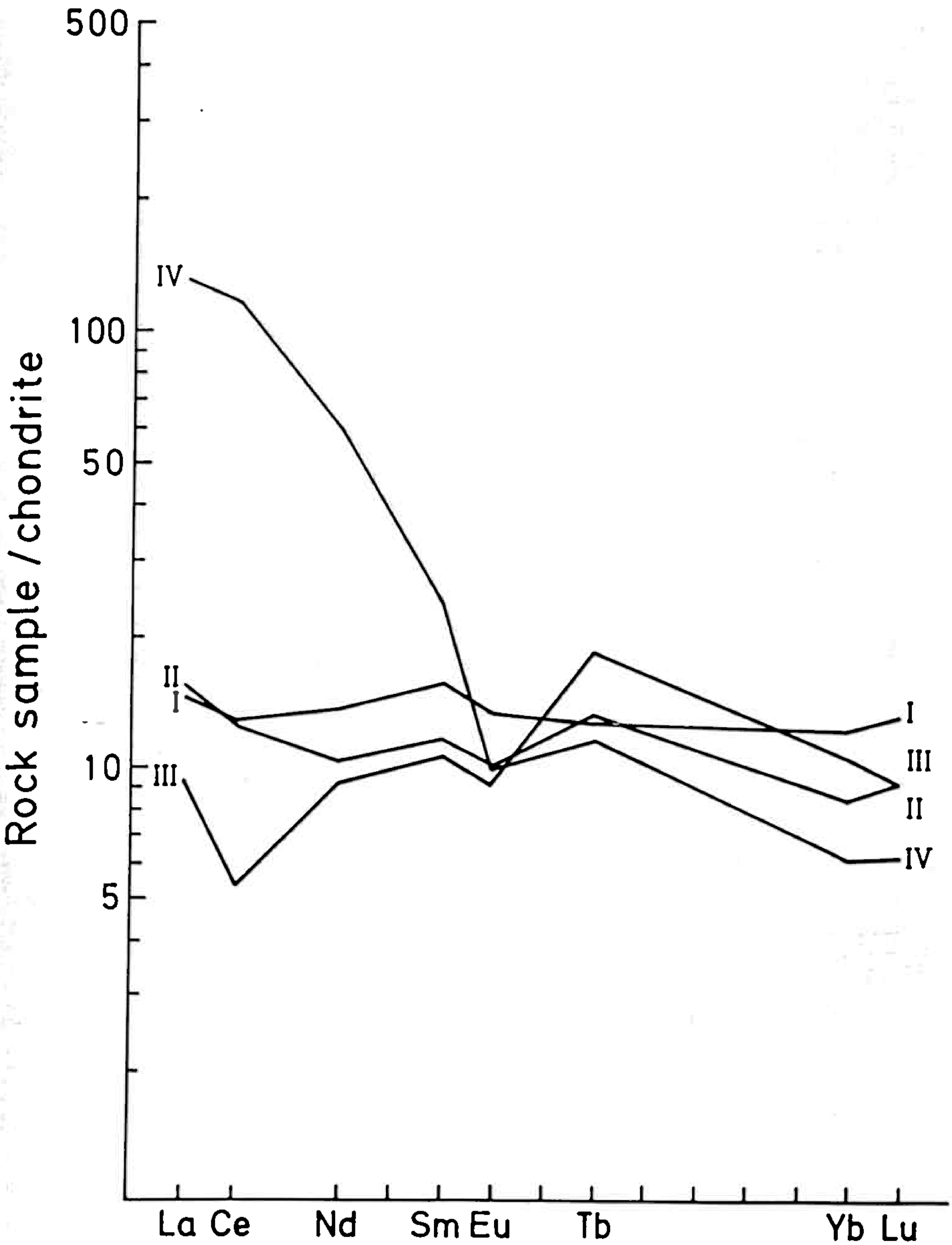
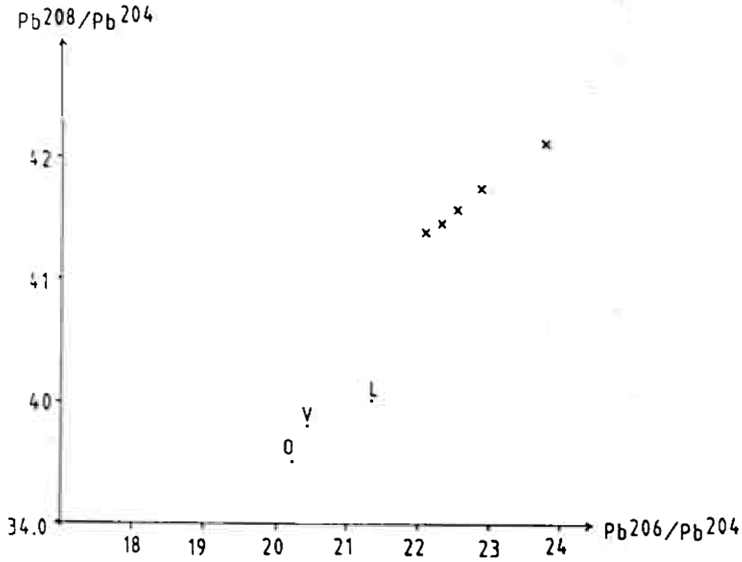
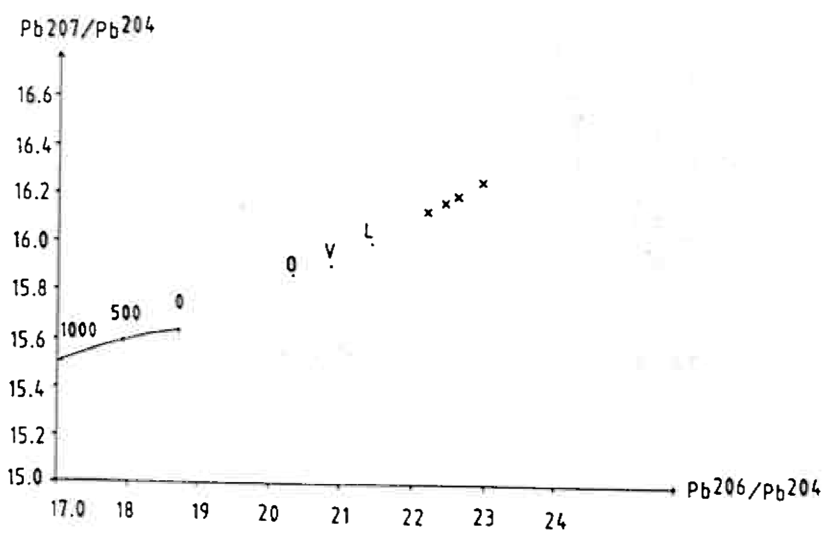


Fig. 14


Rock sample /chondrite
500
100
50
10
5
IV
II
I
III
I
III
II
IV
La Ce
Nd
Sm Eu
Tb
Yb Lu


Pb208/Pb204
42
41
40
34.0
18
19
20
21
22
23
24
Pb206/Pb204
O
V
L


Pb207/Pb204
16.6
16.4
16.2
16.0
15.8
15.6
15.4
15.2
15.0
17.0
18
19
20
21
22
23
24
Pb206/Pb204
1000
500
0
O
V
L

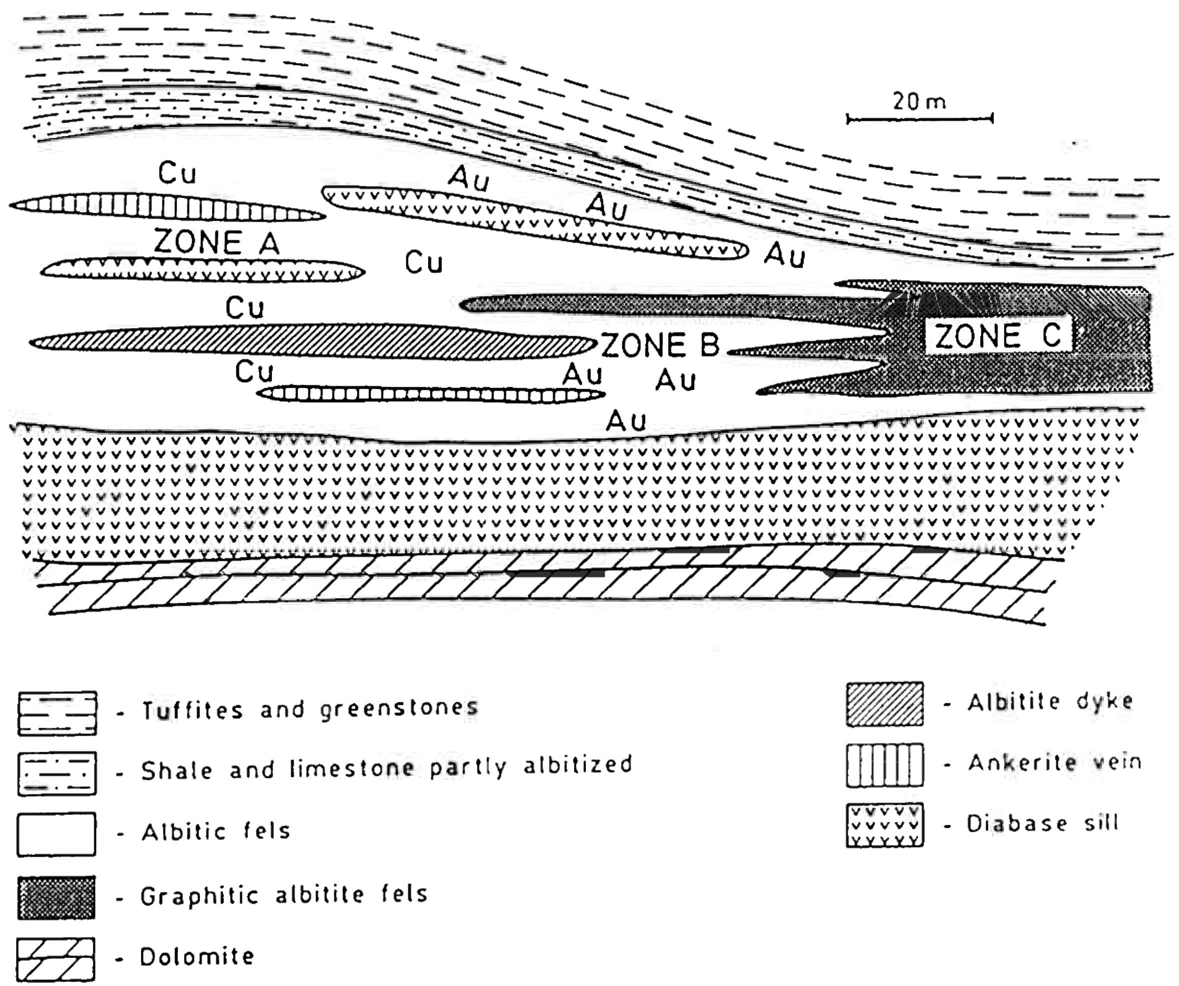

20 m
Cu
Au
Au
Au
ZONE A
Cu
Cu
ZONE B
ZONE C
Cu
Au
Au
Au
- Tuffites and greenstones
- Shale and limestone partly albitized
- Albitic fels
- Graphitic albitite fels
- Dolomite
- Albitite dyke
- Ankerite vein
- Diabase sill

Fig. 17

TABLES

TABLE 1 THE ORIGINAL ORE RESERVES BEFORE PRODUCTION STARTED AND THE MINEABLE ORE RESERVES (IN SITU) 1.1.1986.

TABLE 2 MICROPROBE ANALYSIS OF NATIVE GOLD. I) IS THE AVERAGE OF 11 ANALYSES OF GOLD IN COPPER ORE. II) IS THE AVERAGE OF 5 ANALYSES OF GOLD FROM GOLD ORE WITH MINOR COPPER.

TABLE 3 AVERAGE CHEMICAL COMPOSITION OF METADIABASE AND ALBITIC FELSITE.

TABLE 4 LEAD ISOTOPE COMPOSITION OF GALENAS FROM BIDJOVAGGE.

TABLE 1

MINEABLE RESERVES 1.1.1986.

	ORIGINAL RESERVES 1000T	1000 TONS	CU %	Au g/t	Au g/t RED [1]
A	349	200	2.10	> 1.80	> 1.30
B	546	389	1.02	3.25	2.33
C	2105	-	-	-	-
D	2000	208	0.94	3.30	2.39
"GOLD"[2]	58	37	0.57	6.00	4.20

[1] RED= reduced. Analyses with > 3g/t Au over the weighted mean are cut down to mean.

[2] "GOLD"= small gold ore in the footwall of the C-ore.

TABLE 2

	I	II
Au wt %	90.06	99.40
Ag wt %	9.48	0.46
Fe wt %	0.43	0.03
Cu wt %	*	0.02
Bi wt %	*	0.34
Total	99.97	100.25

* - not detected

Table 3

	METADIABASE WEST N=18 MIN. - MAKS.	X	METADIABASE ALBITE ALTERATION N=4 X	METADIABASE ALBITE ALTERATION N=6 X	ALBITIC FELSITE N=3 X
SiO_2	46.15 - 53.44	49.36	49.2	46.6	66.3
TiO_2	.53 - 2.31	1.22	1.4	1.5	0.6
Al_2O_3	12.03 - 15.88	13.55	12.7	13.5	14.0
Fe_2O_3	1.85 - 9.88	4.55	9.2	12.1	1.62*
FeO	5.46 - 13.36	8.62	-	-	-
MnO	.06 - .23	.16	0.12	0.10	0.05
MgO	3.50 - 9.98	6.52	5.4	7.1	1.5
CaO	4.91 - 10.72	8.48	8.3	6.6	3.2
Na_2O	1.8 - 6.8	3.8	4.9	4.0	7.5
K_2O	.05 - .84	.33	0.38	2.6	0.2
P_2O_5	.03 - .19	.09	0.12	0.12	0.06
H_2O-	.00 - .04	.01	-	-	-
H_2O+	.85 - 3.35	1.57	-	-	-
CO_2	.02 - 1.01	.28	-	-	-
LoI			5.4	4.0	2.9