Some notes on the Lille Kufjord layered gabbro, Seiland, Finnmark, northern Norway

BY

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With 6 text-figures

In 1953 an expedition, sponsored by Norges Geologiske Undersøkelse and under the leadership of Prof. T. F. W. Barth, was sent to the coastal district of Vest-Finnmark. As a member of the team I spent a fortnight on the investigation of the layered basic rocks of Lille Kufjord in the southwestern part of the island of Seiland. In 1952 this locality with its conspicuously banded and possibly intrusive rocks had been visited by Barth and Neumann of the Geological Museum in Oslo. Preliminary investigation of their thin sections showed the layered complex to be of gabbroic composition with intercalated peridotite bands.

My original task was to look for possible ore deposits, especially of chromium and nickel. As no important ore bodies were detected, most attention was paid to the interesting rocks of the layered complex.

I wish to express my gratitude to Prof. Barth, who stimulated the work both in the field and the laboratory. To the director of the Survey, Mr. S. Føyn, I am grateful for the facilities so generously accorded in this research. Further I wish to thank all colleagues at NGU for their help and friendly cooperation during my stay in Norway.

General geology

The basic petrological province of Vest Finnmark shows a great variety of basic and ultrabasic rock types. Surveys over large areas by Barth (2) and Krauskopf (6) have revealed that an explanation of the origin of these interesting rocks will meet with severe problems. One of the main difficulties is the close association of basic rocks of igneous appearance and basic rocks of obvious metamorphic origin. This is also the case at Lille Kufjord.

The gabbro of the Lille Kufjord area is well exposed, showing a pronounced layering of bands with different compositions. There are a great number of individual layers, ranging in thickness from less than half a meter to several meters.

On the basis of field observations a geological map was drawn (see fig. 1). At its western boundary the layered complex is adjoined by garnet-gneisses, the contact being almost parallel with the eastern side of Lille Kufjord. The distinct foliation of the gneiss has the same orientation as the layering of the basic rokcs. The dip of the last decreases from 60° to 30° going from the contact to the top of Kufjordtind, but more to the N. E. the dip becomes steeper again and reaches a value of 70°—80°, corresponding to the dip of the adjoining rocks (basic granulites with acid lenses).

The lower slopes along the Lille Kufjord valley are heavily covered by talus, so only a few outcrops of the contact between the garnet-gneiss and the gabbro could be detected. At the contact the gneiss contains graphite in a zone of at least 10 meters wide. In the valley of Lille Kufjordelv several blocks of gneiss (2 to 4 meters across) are exposed with their foliation clearly bent indicating a deformation of the nearby contact. In brook A the gneiss shows mylonitization at the contact.

The gabbroic rock between the contact and the P 1 peridotite layer seems to be an almost homogeneous rock with about 40 percent of plagioclase. It is granular and of medium grain, without any mineral orientation. It shows slightly more melanocratic schlieren and under the peridotite layer there is a faint banding. Here the gabbro contains disseminated grains of sulphides, at certain places amounting to a few percent. A remarkably fresh peridotite band of about 20 meters thickness overlies the gabbro with a sharp border. In this peridotite layer P 1 there is some plagioclase arran-

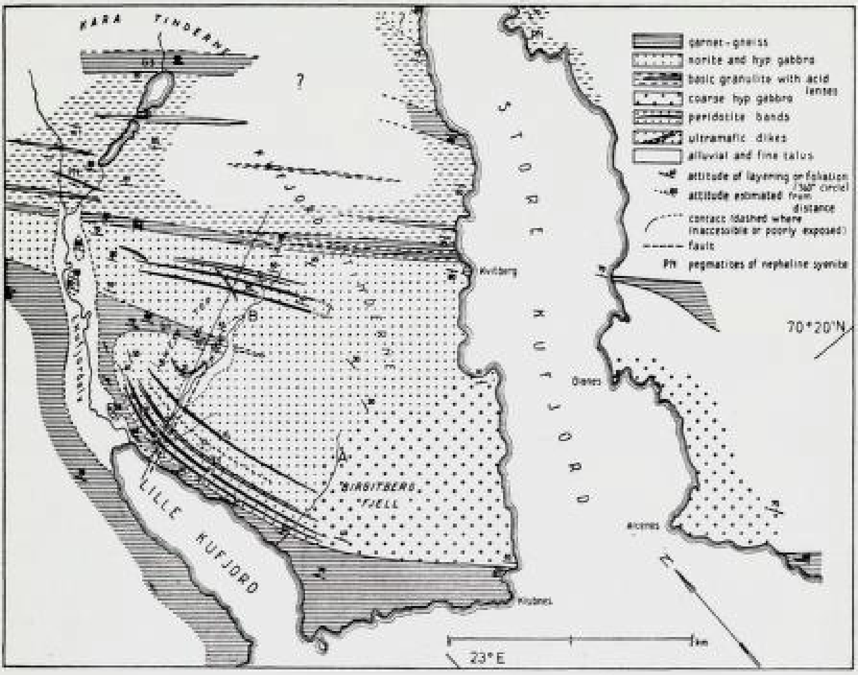

Fig. 1. Geologic map of the Lille Kufjord Area.
Geologisk kart over Lille Kufjord-området.

Garnet gneiss — *granatgneis,* norite and hyp. gabbro — *noritt og hypersthen-gabbro,* basic granulite with acid lenses — *basisk granulitt med sure (kiselsyrerike) linser,* coarse hyp. gabbro — *grovkornet hypersthengabbro,* peridotite bands — *olivensteinsbånd,* ultramafic dykes — *ganger av ultrabasiske bergarter,* alluvial and fine talus —— *elveavsetninger og skredjord,* attitude of layering etc. — *strøk og fall av lag- og skifrighetsflater,* attitude estimated etc. — *strøk og fall anslått fra avstand,* contact etc. — *grense mellom bergarter (med brutte streker hvor util-gjengelig eller dårlig blottet),* fault — *forkastning,* PN — *nefelinsyenitt-pegmatitt.*

ged in parallel ledges, but not so much that a banding results. Like most other peridotite bands the P 1 layer is marked by a dark brown weathering colour.

The gabbro between the P 1 and the P 2 layers in its lower part shows rather narrow bands (10—30 cm wide), varying in amount of mafic minerals. Upwardly there are broader bands of more homogeneneous gabbroic rock with about 45 percent of plagioclase.

The P 2 peridotite layer (thickness 40 m) is more serpentinized than the P 1 layer and in its upper part has alternating bands, about

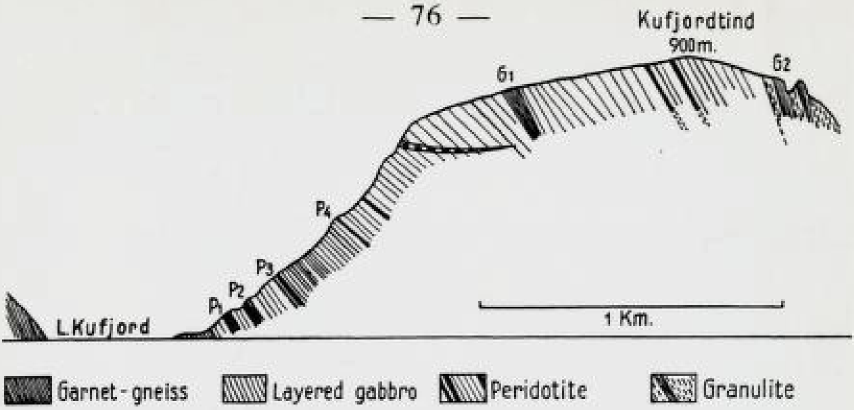

Fig. 2. Section over west top of Kufjordtind.
Profil over vesttoppen i Kufjordtind. Garnet-gneiss — *granat-gneis,* layered gabbro — *lagdelt gabbro.*

1 meter broad, of plagioclase-free and plagioclase-bearing ultrabasic rocks. At the footwall the peridotite-layers have very sharp borders with the gabbro. The border at the hanging wall is more gradational.

The gabbro immediately above the P 2 layer is fairly homogeneous and contains about 50 percent of plagioclase. Higher up it has a very pronounced layering with bands, generally a few meters wide, which vary considerably in their content of mafic minerals.

Seen from a distance there is another thick ultrabasic band about 100 meters above the P 2 peridotite layer. On closer inspection it proved to be less homogeneous than the P 1 and P 2 layers as there were much lighter bands of 1 to 2 meter thickness between the ultrabasic layers. But all was painted dark by grey, brown and sometimes greenish weatheringcolours. At the base of this complex there are about 10 meters of peridotite, the P 3 layer. At its footwall it contains at places up to 5 percent of sulphides. Higher up in this layer, however, hardly any sulphide is visible with the naked eye. In the P 1 and P 2 layers only an occasional grain of sulphide could be detected.

A diagrammatic sketch of the type of banding of the lower part of the profile is given in fig. 3.

Above P 3 no more sampling could be done. The slope is very steep here and covered by dangerous talus. About 150 meter higher than P 3 there is another thick peridotite layer, P 4. Between the P 3 and P 4 layers occurs banded gabbro with a few thin dark bands, probably peridotite. The impression was gained that the gabbro higher up becomes more leucocratic. Above the P 4 layer thin ultrabasic layers are still intercalated in the gabbro. Fig. 4 gives an impression of the rock sequence described so far.

The eastern part of the cross-section of fig. 2 was studied in the upper part of brook B and the E-slope of Lille Kufjord valley. Peculiar is the protruding «finger» G 1 of the gneiss into the gabbro. The garnet-gneiss is the same rock as at the fiord side; it also contains graphite at its borders with the gabbro. N. E. of G 1 the rock is again layered owing to a changing ratio of leucocratic and melanocratic minerals. The gabbro here contains 50 to 60 percent of plagioclase. It is much finer grained, however, and shows a faint foliation, which was lacking at the fiord side. Here, too, ultramafic layers are intercalated in the gabbro, but these are only 5 to 10 meters thick. N. E. of these peridotite layers, at G 2, the gabbro shows a concordant contact with a rock-complex consisting of amphibolites and garnet-gneisses.

The layered basic rocks described

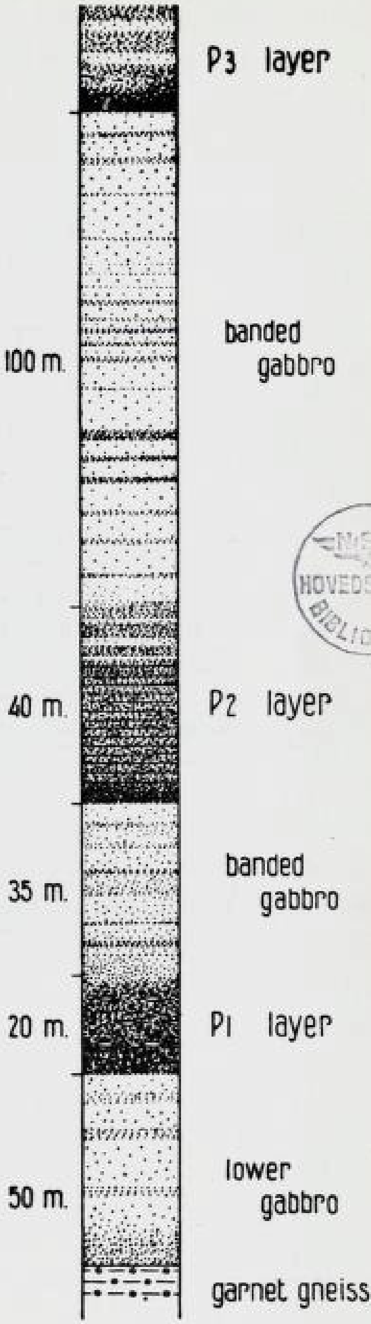

Fig. 3. Diagrammatic sketch of the lower part of the layered basic rocks.

Diagram av den undre del av de lagdelte basiske bergarter.

in literature usually have their most basic component at the base. The Stillwater intrusive has ultrabasic rocks at its lower contact and then banded anorthosite and norite (8). In the Bushveld too the pyroxenite layers occur only in the lower part of the formation. In the Lille Kufjord area there is no overall differentiation with ultrabasites at the base and less mafic rocks at the top. Here is rather an interlayering of ultrabasic and basic rock types throughout the whole complex.

The rhythmically repeated banding and gravity stratification described by Wager and Deer from the Skaergaard (12) is also lacking here. It has been pointed out already, that the footwall of the peridotite-layers has a sharp and the hanging wall a more gradational border. This is perhaps also the case with some of the gabbro layers, but a general rule could not be detected.

It may be mentioned, that the gabbro at the fiord side contact is finer grained than the lower gabbro in general. It has more plagioclase and the graphite, which is present in the garnet-gneiss all along the contact, occurs also in the extreme contact-gabbro. The phenomena described could perhaps be explained as a chilled margin of a gabbro intrusion. Remarkable then is the fact, that there is no noticeable contact-metamorphism.

Another pecularity of this layered gabbro is that the banding does not continue all through the occurrence. In the southern slope of Kufjordtind, towards Birgitbergfjell, the layering disappears gradually in a coarse grained and structureless rock, which also exists along the coast of Store Kufjord and at the other side of the fiord near Altenes. Only along the contact with the gneiss could faint indications of parallelly arranged schlieren be seen. Further north in the fiord at Kvitberg is a rounded outcrop of white rock. It looks like an intrusive plug. In thin section it proved to consist of a slightly schistose pegmatitic rock (85 % quartz, 13 % orthoclase, 2 % garnet).

To the N. E. the layered gabbro is in contact, without appreciable discordance, against a highly metamorphic rock of basic composition. This metamorphic rock shows bands or lenses of acid gneisses with sharp borders. Immediately at the contact is a very sheared and crushed zone G 2, about 100 meters wide, of a quartz-albite-garnet-sillimanite rock. In the field it was marked by its pronounced rusty colour in all shades of brown and yellow. On inspection it contained about 10 percent of sulphides.

Fig. 4. View of the west slope of Kufjordtind with the two lower peridotite bands and the composite third peridotite band (x).

Vesthellingen av Kufjordtind med de to underste og det tredje sammensatte olivinsteinsbånd (x).

The main rock in this formation is a fine grained, distinctly foliated rock of dark appearance with about 40 percent of leucocratic minerals. The dark constituents are pyroxene, hornblende and biotite. In the field it was named «gabbro-gneiss» as it macroscopically does not differ so very much from a gabbro. There are a few lenses in it that are richer in feldspar. Very similar rocks were found by Krauskopf at the west-coast of the Øksfjord peninsula (6).

It should be added that ultramafic dikes, rich in hornblende, cut through the gabbro and the gneisses at several places. Such a dike was met, e. g. at the top of W. Kufjordtind (see fig. 2). The dikes of nepheline-syenite pegmatite, which are so characteristic for other parts of the Seiland-area (1), are not abundant here.

Thin sections were made of representative samples, both of the layered and of the other rocks.

As a whole the gabbroic rocks, described above, are very fresh and have as essential minerals plagioclase, clinopyroxene, orthopyroxene, olivine and hornblende. Accessory minerals are spinel, sulphides, ilmenite and rarely apatite. The amount of dark minerals varies from about 50 to about 60 percent. Depending on the ratio of clinopyroxene and orthopyroxene the different layers are olivine-gabbros to meta-olivine-gabbros or olivine-norites to meta-olivine-norites.

The rocks are of equigranular texture and of medium grain. The plagioclase is lath-shaped or irregular; the mafic minerals are subhedral. The latter, gathered to small clusters, are slightly cataclastic and show sometimes an irregular extinction.

The gabbro between the contact against the gneiss and the P 1 layer somewhat unexpectedly shows an upward increase in orthopyroxene, olivine and spinel, whereas the clinopyroxene decreases. Clinopyroxene is the most abundant mafic mineral in the layers between P 1 and P 2; the rock immediately above P 2 has a predominance of orthopyroxene.

N. E. of G 1 the rock does not contain any olivine and shows an abundance of orthopyroxene over clinopyroxene. Compared to the lower gabbro at the fiord side, it is finer grained and shows more foliation. It also contains more ilmenite and small amounts of biotite.

The ultramafic layers contain 70 to 80 percent of partly serpentinized olivine; other essential minerals are clinopyroxene,

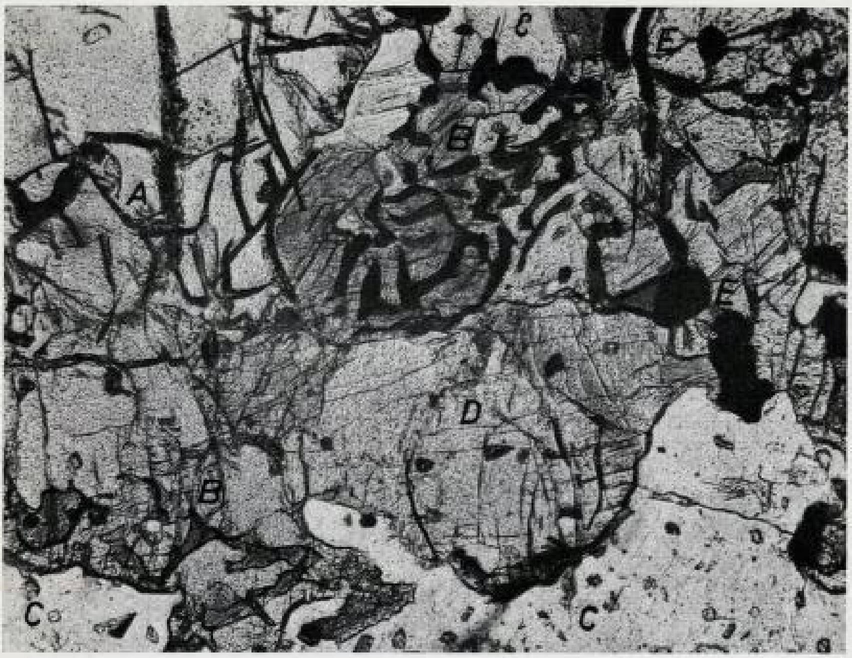

Fig. 5. Olivine-bearing norite with spinel — pyroxene myrmekite (75x) A — olivine, B myrmekite, C — plagioclase, D — orthopyroxene, E — interstitial sulphide.

Mikrofoto av polerslip som viser sulfidkorn (erts) i grunnmassen i P3-laget.

orthopyroxene and hornblende. The accessory minerals are biotite, plagioclase, green spinel and sulphides. The rocks are relatively coarse grained with rounded olivine crystals often embedded in much larger pyroxenes. From the base of a peridotite layer to its top there seems to be a decrease in olivine content, the plagioclase being more abundant in the upper part of such a peridotite layer. The thinner ultramafic bands between G 1 and G 2 contain 40 to 50 percent of remarkably fresh olivine and show more orthopyroxene than the layers at the fiord side.

The plagioclase of the layered gabbro is very fresh, generally twinned, and locally it shows slightly zonal extinction. In the thin sections preliminary determinations of the composition were made only for the feldspar, on albite twins. In the layered gabbro the feldspar varies from lime-rich andesine in the gabbro near the fiord side to labradorite in the gabbro above G 1. The plagioclase in the peritotite layers shows a higher content of anorthite than the plagioclase in the gabbro layers.

Characteristic are the reaction rims around the mafic minerals in the layered gabbro. For example, the olivine is usually surrounded by a rim of orthopyroxene. The clinopyroxene shows marginal replacement by hornblende. Where the olivine is in contact with plagioclase coronas of a peculiar myrmekitic aggregate of green spinel and pyroxene are formed (see fig. 5). Barth describes this as a reaction in the solid state (1). The myrmekite is typical for this rock, most of the spinel occurs as such. There are, however, also big individual grains of spinel and more seldom swarms of very small spinel grains not related to any myrmekite.

The basic metamorphic rock, indicated as granulite on the map, has as essential minerals plagioclase, augite, orthopyroxene, hornblende and biotite. Accessory minerals are ilmenite, magnetite and apatite. The plagioclase varies from sodium-rich to lime-rich andesine.

This rock can be considered as of basaltic bulk composition, whereas the acid lenses with the essential minerals quartz, plagioclase, antiperthite and garnet are of granitic bulk composition. In the latter accessory minerals are sillimanite, biotite, pyrrhotite, rutile and graphite.

Neither from field nor from laboratory evidence can conclusions be made as to whether the metamorphic rocks are of igneous or of sedimentary origin. Both petrologically and mineralogically they show similarity e. g., with the granulites from Lapland, described by Eskola (4). The difference is that in Lapland basic lenses occur in a hostrock of granitic composition.

Ore-mineralization.

At many places the gabbro and peridotite layers contain sulphide grains visible with the naked eye. Special concentrations occur in the gabbro immediately below the P 1 layer and at the base of the P 3 layer. Here there is in zones less than 50 cm wide about 5 percent of interstitial sulphides. This is, of course, not an ore of economic importance and the chance seems small — although it cannot be totally excluded — that layers richer in sulphides will be found here.

X-ray investigation showed pyrrhotite, chalcopyrite and pent-

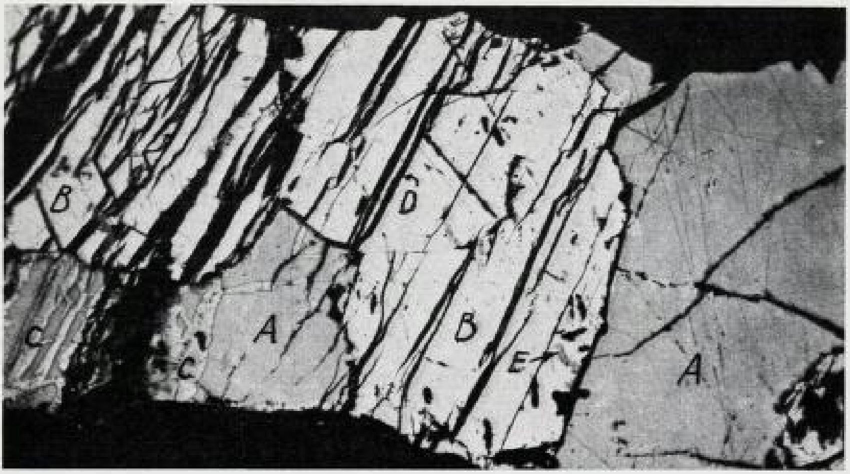

Fig. 6. Sulphide grains in the base of the P3-layer (100x). A — pyrrhotite, B — pentlandite, C — chalcopyrite, D — sphalerite, E — valleriite.
Mikrofoto av polerslip som viser sulfidkorn (erts) i grunnmassen i P3-laget. Pyrrhotite — *magnetkis*, chalcopyrite — *kopperkis*, sphalerite — *sinkblende*.

landite to be present, a result that promised a high copper and nickel percentage. Therefore spectroscopic and chemical gravimetric analyses were carried out on ore concentrates from some hand specimens. The results of these analyses were rather different. No final conclusion can yet be obtained, but the indications are that the sulphide concentrate contains 3—4 percent of Ni and 4—6 percent of Cu.

In polished surfaces pyrrhotite, pentlandite, chalcopyrite and sphalerite could be indentified. These sulphides are interstitial, so they must be of later origin than the silicates. The pentlandite appears as well defined crystals and does not seem to be an exsolution product of the pyrrhotite. The chalcopyrite occurs mostly in the pyrrhotite as orientated lamellae. Vein-like sphalerite cuts through all the other sulphides (see fig. 6). It should be added that the pentlandite has small inclusions of an anisotropic, strongly reflection-pleochroic mineral, much stronger pleochroic than pyrrhotite. According to Uytenbogaardt this could be valleriite, a copper mineral (10).

The mineral association is typical for ores occurring in basic intrusions. Pentlandite is not always found in nickeliferous sulphides, but it occurs generally in the Norwegian deposits (7).

The total of the Ni- and Cu-percentages is higher than that of other occurrences in Norway. For example the Lillefjellklump occurrence (3) has 1.77 percent Cu and 3.85 percent Ni, a sample from Mølland (5) 3.78 percent Ni and 0.98 percent Cu in the concentrate.

Big grains of pyrite occur in hydrothermal veins (about 20 cm wide) cutting through the layering; this pyrite contains up to 4 percent of Co, less than 1 percent of Ni and very little Cu. That Ni is concentrated in pyrrhotite and Co in pyrite is in agreement with known data (9).

Traces of platinum could not be detected in the spectroscopic work, but the element might be present in the usual amount of 2 to 20 g/ton in Ni-rich sulphide-concentrate (5).

As stated before, there is up to 10 percent of sulphide in the G 2 zone and in other layers of the «gabbro-gneiss». A rapid spectroscopic analysis showed the sulphide to have low contents of Ni, Co and Cu (each in the order of $^1/_8$ percent). It did not seem encouraging enough to do more work on it.

At certain places the gabbro layers contain visible concentrations of oxidic ore-minerals up to a few percent. The coarse grained gabbro at Birgitberg is rich in such minerals. X-ray determination of some specimens showed ilmenite to be present.

Trace elements.

Spectroscopic analyses of some mafic rock-types were made in order to determine the amounts of traces of certain metals, characteristic for basic intrusions.

From these preliminary results one might conclude that the magnitude for Cr is approximately x/10, for Ni x/ 10, for Co x/100 and for Cu x/1000 percent. Remarkable is that Cr, usually the more abundant element (9), does not come higher than Ni.

Sample	Rock-type	% Cr_2O_3	%NiO	% Co O	%CuO
1	gabbro above P_2	±1/10	±1/10	±1/100	±1/1000
2	peridotiteP_1	±1/10	x/10	x/100	±1/100
3	gabbro belove P_1	x/10	x/100	x/100	x/1000

Sample 1 was split by heavy liquid separation in specific gravity fractions > 4, 4—2.9, ± 2.9 and < 2.9 each being analyzed spectroscopically.

		$\% Cr_2O_3$	%NiO	% Co O	%CuO
sp. gr. fraction	> 4	—	x/10	x/10	±1/10
sp. gr. fraction	4 – 2.9	x/10	x/10	x/100	x/100
sp. gr. fraction	± 2.9	x/10	x/100	x/100	x/1099
sp. gr. fraction	< 2.9	±1/10	x/100	± 1/100	±1/1000

The Ni, Co and Cu are concentrated in the heaviest fractions, probably because minor sulphide grains occur amongst the other heavy minerals. The two lightest fractions consist of plagioclase with impurities of mafic minerals.

Most of the Cr, as well as part of the Ni, are found in the 4—2.9 fraction, which consists of olivine and pyroxene. The Cr content $^1/_{10}$ % is normal or even low, as in a spinel rich rock there is not more than $^1/_{10}$ % of Cr.

According to Goldschmidt, a normal amount of Cr in ultrabasic rocks should be 3400 g/ton; according to Sahama, about 2000 g/ton (9). Common augite and hornblende may contain 1400 g/ton, in olivine there may be 1000 g/ton (9). A Cr — rich gabbro of the Skaergaard (Greenland) contains 1500 g/ton. (12).

Ni need not necessarily be present in such rocks to the amount of x/10 %. Goldschmidt gives for the Ni-content in a peridotite 3160 g/ton, but Sahama found in an ultrabasic rock only an amount of 800 g/ton (9). Olivine and orthopyroxene may contain up to 0.5 percent of Ni (9); usually there is much less. A Ni-rich rock of the Skaergaard gabbro contains 750 g/ton of Ni, a Co-rich rock 100 g/ton of Co (12).

The indications are that the silicate-minerals from Lille Kufjord have a moderate Cr content, but it seems evident that both the sulphides and silicates in the rock are relatively rich in Ni and Co.

A correlation between the amount of trace elements in the ordinary rock-forming minerals, and the accompaning ore desposits rock has been sought by various workers but no rule of general application has yet been found.

Sammendrag

Om den lagdelte gabbro-bergart i Lille Kufjord, Seiland, Vest-Finnmark.

Nyere undersøkelser ved Lille Kufjord på Seiland har vist at vi her har et bergartskompleks av lagdelt (båndet) gabbro med innleirete lag av ultrabasiske bergarter (olivinstein) i den midtre og øvre del av komplekset. Se fig. 2, 3 og 4.

Båndingen i komplekset går parallelt (konkordant) med strøket i de tilgrensende bergarter. Disse er granatgneiser og omvandlete gabbroide bergarter (granulitter).

Mikroskopiske undersøkelser har vist at den båndete gabbrobergart er hypersthenførende olivingabbro.

Lagdelte basiske eruptivbergarter av lignende type som de vi har på Seiland har mange steder i verden ellers vist seg å inneholde malmforekomster av stor økonomisk verdi. Av den grunn ble undersøkelsen av Seiland-bergartene tatt opp på NGU's program.

Den båndete olivingabbro og olivinsteinene inneholder mange steder korn av sulfidiske ertsmineraler. Noen lag er forholdsvis rike på sulfider og inneholder opp til 5 % av magnetkis, pentlanditt, kopperkis og sinkblende (fig. 6).

Innholdet av metaller i fremstilte konsentrater av ertsmineralene er 4—6 % kopper, 3—4 % nikkel og 0.2—0.4 % kobolt. Platina kunne ikke påvises i konsentratene.

De beskrevne forekomster er små og ertsmineralene utgjør bare en liten prosentdel av bergarten. De må derfor anses for å være av liten økonomisk verdi.

Innholdet av sporstoffer i bergartene ble undersøkt ved spektografiske metoder. Disse ga som resultat at de bergartsdannende mineraler er forholdsvis rike på nikkel og kobolt.

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