RESTRICTED

COBALT OCCURRENCES IN NORWAY

1. The Modum Cobalt Deposit
2. Cobalt in Slag at Evje
3. Cobalt in Norwegian Pyrites
4. Miscellaneous Cobalt Occurrences in Norway

Olge J. Adamson
June 2, 1950

RESTRICTED

RESTRICTED

Report on the Modum Cobalt Deposit in Southern Norway

by

Olge J. Adamson
Oslo, May 25, 1950

RESTRICTED

Contents

Sources of Information p.1
Summary. 2
Location and Ownership 3
History 3
Past Production 4
Geology 6
The Fahlband Rocks 7
The Ore Minerals 8
The Main Fahlband Zone 9
The Skutterud Mines 10
The Saafstad Mines 11
The Svartfjell Mines 11
Persistence of Ore in Depth 12
The Metal Content of the Ore 13
German Investigations in 1941 - 1943 15
Ore Reserves 16
Ore Reserves in Tailing Dumps 17
Recommendations 18

List of Maps:

Fig. 1. Key map.
Fig. 2. Topographical map showing the situation of Modum.
Fig. 3. Sketch map of the fahlband zones.
Fig. 4. Schematic profile through the fahlband zones.
Fig. 5. Map showing the topography of the area around the Modum deposits.
Fig. 6. Map showing the different fahlbands in the Central mines of the Skutterud mining district.
Fig. 7. Map of the Ludwig-Eugen adit and the Clara adit in the Central mines. (Assay map)
Fig. 8. Map showing the main workings in the Central mines. (Assay map)

Sources of Information

1. Ivan Th. Rosenquist: "Noen observasjoner og refleksjoner omkring Modum Koboltgruver (nedl.). I. Fahlbaandene." Norsk Geologisk Tidsskrift. Bd. 27. (1949)
2. Ivan Th. Rosenquist: "Foreløpig rapport om Modum Koboltgruver." (1941)
3. Thv. Lindeman: "Modums Blaafarveverk." Det Kgl. Norske Videnskabers Selskabs Skrifter. No. 5. Trondheim. (1932)
4. Beyschlag, Krusch, vogt: "Die Lagerstatten der nutzbaren Mineralien und Gesteine." Stuttgart. p. 624 (1913)
5. K.F. Bøbert: Articles in Karstens Archiv f. Mineralogie, Geognosie und Bergbau. Vol. 4 (1932) and Vol. 21 (1847)
6. J. Maximillian Graff: "Modum Blaufarbenwerke." (1883)
7. Report of the Cobalt Mines at Modum collected from different sources. (Date of original report unknown. Translated into English in 1936)
8. Karl Herman Muller: "Bericht uber die Geognostischen und technischen Verhaltnisse der zu Modum Balufarbenwerke in Norwegen gehørende Kobaltbergbaues." (1857)
9. E. Flood: "Preliminaer rapport over koboltforekomsten ved Modum Gruben." (1941)
10. Dr. Kauter: "Bericht uber die Befahrung der alten Modum Gruben." (1941)
11. Georg Fischer: "Bericht uber die geologische Grubenaufnahme in Modum." (1941)
12. Kløckner-Humboldt-Deutz Ag. Cologne: "Bericht uber Aufbereitungsversuche mit Kobalterz von Modum fur A/S Malmundersøkelser, Oslo." (1941)
13. Gesellschaft fur praktische Lagerstattenforschung: "Bericht uber die geoelektrischen Versuchsmessungen bei Sysle in Norwegen. (1943)
14. Joseph Horvath: "Kobalt in Modum." (1945)
15. Verbal communication with Ivan Th. Rosenquist. (1950)

Reports 6 - 13 were borrowed with kind permission from the Norwegian Geologocal Survey. Material for preparing the maps attached to this report was also borrowed from the Survey.

Summary

The cobalt ore of the Modum deposits is not of economic grade with present prices. However, the ore reserves and the possible ore reserves are so large that it should be well worth keeping the deposits in mind if the demand for cobalt should become critical.

Cobalt minerals, chiefly cobaltite (cobalt-arsen-sulphide) and danaite (cobalt-arsen-pyrite) occur as impregnations in quartz-mica-schists and related rocks. The mineralized rocks are called fahlbands. The fahlbands are in a northtrending zone about 100 meters wide over a length of about 10 kilometers. Other ore minerals include skutterudite (cobalt arsenide), arsenopyrite, pyrrhotine, pyrite, chalcopyrite, metallic bismuth, metallic copper and graphite.

The deposits were worked from 1776 to 1898. The total amount of cobalt contained in cobalt products produced at Modum can be estimated at about 1,000 tons. Arsenic was produced as a by-product. Mining has been to depths of 130 meters.

The grade of the crude ore was probably between 0.06 percent and 0.1 percent cobalt the greater part of the time the Modum mines were in operation. After 1850 someone started selective mining with a small production of higher grade ore, 0.15 to 0.2 percent cobalt. The recovery of cobalt from the crude ore was probably only about 0.02 percent up to 1850 and better in later years. There is probably more cobalt left in the tailing dumps at Modum than there has been recovered.

There are probably still left about 6 million tons of ore with a probable average grade of 0.06 to 0.08 percent cobalt above the level of the deepest workings (130 meters below the surface). There would be a possibility of producing certain tonnages of higher grade ore, about 0.15 percent cobalt. If one considers ore with 0.05 percent cobalt or less, the reserves of the Main fahlband zone are probably several 10 million tons.

There are several million tons of tailing dumps at Modum. The dumps may contain about 0.05 percent cobalt. However, no assaying of the dumps has been made.

Apart from cobalt the ore contains about 0.15 percent copper, about 1 percent arsen, a few hundredths percent bismuth and about 5 percent graphite. A large part of the fahlband rocks have about 10 percent sillimannite.

If the mines are re-opened there would seem to be a possibility of producing graphite and sillimannite as by-products of the cobalt mining. Bismuth may also be a by-product of some of the ore.

Location and Ownership

Modum is a farm and industry district 45 kilometers in a straight line west from Oslo. The old mines can be reached by train from Oslo over Drammen and Vikersund to Sysle station on the Krøderen railway and thence about three kilometers by road. The nearest town is Hønefoss, 30 kilometers by road or train in a north-northeasterly direction. There are two good road connections between Modum and Oslo, a northern route along Lake Tyrifjord over Hønefoss and a southern route over Drammen. Each route is about 100 kilometers. There are hotels at Modum and Vikersund.

The district of Modum comprises the parishes of Heggen, Nykirke and Snarum. It has an area of about 500 square meters, of which 300 square meters are covered by wood (mostly pine). The population is about 12,000. There is considerable timber and woodpulp industry in the district. There are several hydro-electric power stations with a total capacity of more than 30,000 kw.

At Modum there are two parallel cobalt ore bearing zones, from 50 to 400 meters wide, both running about 10 kilometers in a northerly direction. The two zones are approximately two kilometers apart. They are separated by the Snarum River, which here has an altitude of about 100 meters above sea level. Most of the old mines are on the western side of the river, only a few smaller ones having been opened in the eastern mineralized zone. The western mines lie along a mountain ridge which is cut by several cross-valleys. The highest point within the mining district is about 460 meters above sea level.

Around the Skutterud mines a few claims are held by civil engineer Magne Mortensson of the Technical University, Trondheim. The rest of the mining district is free. The mines are situated on the ground of various farmers.

History

The Modum mines were worked from 1776 to 1898. There are about 40 larger mines (partly open-cast and partly underground) and about 80 quarries and prospects. There were three main mining areas from south to north: the Skutterud mines, the Saafstad mines and the Svartfjell mines. The Skutterud mines were by far the most productive. The mines mentioned are all on the western side of the Snarum River. The smaller mines on the eastern side of the river were worked from 1822 to 1849.

The Modum mines had peak production in the period 1830 to about 1840. There was a smelter at Snarum which manufactured cobalt smalt (potassium cobalt silicate) used as a glaze and coloring agent in the porcelain and glass industries. Arsenic was produced as a by-product. At this time more than 1,000 men were employed at the mines and smelter.

The deposits were at first worked by the Danish-Norwegian Government. Later on they were in private hands, and from about 1840 they were worked by a firm from Freiberg, Saxony in Germany.

After the invention of the synthetic paint ultramarine in 1848, cobalt prices fell and the mining at Modum declined. The mines were definitely abandoned in 1898.

Past Production

Production statistics are incomplete and it is difficult to estimate the grade of the produced ore and the amount of cobalt recovered from the ore. Production figures are given largely in terms of barrels (of 1/4 cubic meter), and assays were made only of the cobalt slick.

The ore was concentrated by hand picking to a concentrate which, in general, probably contained 0.6 percent cobalt. Washing of this concentrate produced a cobalt slick with about 30 percent cobalt. The slick was sent to the smelter for production of cobalt smalt.

The following data for the year 1830 (a year of high production) will give an idea of how much cobalt was actually recovered from the ore. During that year there was produced

200,000 barrels of ore (about 125,000 tons). 6000 barrels of concentrate (less than 4,000 tons) were produced by hand picking. Washing of this concentrate produced 120 barrels of cobalt slick with 30 percent cobalt (about 80 tons), that is 100 kg concentrate gave 2 kg of slick with 30 percent cobalt. The cobalt content of the slick was about 25 tons. Thus, 0.6 percent cobalt was recovered from the 6,000 barrels of slick. If one calculates the recovery of cobalt from the crude ore, it is seen that it is only 0.02 percent.

There is no information on the actual grade of the crude ore, but it probably was between 0.06 and 0.1 percent cobalt. In all probability the tailing dumps of 1830 contain about 0.05 percent cobalt.

Recovery was probably better in later years. An 1850 report mentions that recovery that year was 0.07 percent cobalt. It seems that concentration was given to the selective mining of higher grade ore. The grade of the ore may have been 0.1 to 0.2 percent cobalt.

According to statistic figures from the period 1878 to 1882, about 6,000 tons of crude ore were mined annually. The cobalt content of the slick produced in each of these years was about 10 tons. This would indicate a recovery of 0.17 percent cobalt from the crude ore. The actual cobalt content of the crude ore at this time was probably over 0.2 percent. From 1890 to 1898 there was recovered only about 0.05 percent cobalt from the crude ore.

It is possible to give only a rough estimate of the amount of cobalt contained in slick produced from ore of the Modum mines during their operation period from 1776 to 1898.

From 1856 to 1898 cobalt products were manufactured for a total content of 257 tons of cobalt, an average of 6.1 tons of cobalt annually. From 1878 to 1882 51 tons of cobalt contained in slick were produced.

Above, the cobalt content of the slick produced in 1830 was calculated at 25 tons. The years 1830 to 1840 are described as "the flourishing period" of the Modum mines. If we assume that 25 tons was the average annual production at this time, this means a total production of 250 tons of cobalt contained in slick in the period 1830 to 1840.

The average annual production from 1840 to 1856 was probably considerably smaller than from 1830 to 1840. Total production in this period can be estimated at about 200 tons of cobalt contained in slick.

The slick produced from 1776 to 1830 contained little more than 300 tons of cobalt. Thus, the total amount of cobalt contained in cobalt products produced at Modum from 1776 to 1898 can be estimated at about 1,000 tons.

Because of poor recovery, particularly in the years prior to 1850, there is probably more cobalt left in the tailing dumps than there has been recovered. A calculation of the tonnage of the tailing dumps is therefore of interest. (See "Ore Reserves in Tailing Dumps".)

Geology

Cobalt occurs as impregnations of cobaltite (cobalt-arsen-sulphide), danaite (cobalt-arsen-pyrite) and skutterudite (cobalt arsenide) in quartz-mica-schists and related rocks of the Pre-Cambrian Age. Cobaltite is the chief cobalt ore mineral. Other ore minerals are arsenopyrite, pyrrhotine (iron sulphide), pyrite, chalcopyrite (copper-iron-sulphide), metallic bismuth, metallic copper, graphite and a little molybdenite. Erythrine (cobalt-arsen-oxide) and malachite (copper carbonate) have been formed by alteration of the primary cobalt and copper minerals. The secondary minerals occur in insignificant amounts.

The mineralized rocks are called fahlbands. The fahlbands generally follow the prevailing rock structure, which runs in a northerly direction with a steep eastern dip. The fahlbands are ore-bearing zones within the quartz-mica-schists and the related rocks. There are transitions from strongly mineralized rocks to barren rocks. In the field the extent of the fahlbands are recognized by the rusty color they attain upon weathering. Fahlband is a convenient mining term rather than a geological term.

There are two fahlband zones at Modum: the Main fahlband zone and the Eastern fahlband zone. The fahlband zones are composed of several individual fahlbands separated by amphibolite layers.

The Main fahlband zone is west of the Snarum River and runs approximately parallel to the river in a stretch of about 10 kilometers. It is generally about 100 meters wide, but may widen to about 400 meters in certain places. Most of the old mines are in this zone.

The Eastern fahlband zone, east of the Snarum River, is generally about 50 meters wide, but may widen to about 300 meters in some places. There are a few prospects at the northern end of the fahlband zone, near Snarum Church. There are also a few old workings at the southern end (which actually are on the western side of the Snarum River which here makes an eastbound twist).

Some kilometers west of the Main fahlband zone have been observed small impregnations of cobalt minerals. Several small fahlbands have also been observed east of the Eastern fahlband zone between the Snarum River and Lake Tyrifjord.

The fahlband zones occur in a rock complex with various types of quartz-mica-schists, quartzites, gneisses, granites and massive garnet-amphibolite. Sillimannite (aluminum silicate) and tourmaline (a complex sodium-iron-aluminum silicate with boron) are characteristic minerals of the mica-schists.

Within the individual fahlbands there are bands - conforming to the fahlbands in strike and dip - that show stronger mineralization than the bordering fahlband rocks. These bands were referred to by the miners as ore bands, and are generally from four to eight meters wide. Within the ore bands may occur streaks of a few centimeters width with high concentration of ore minerals.

The average cobalt content of the ore bands in the Main fahlband zone is probably about 0.08 percent. The cobalt content of the richer ore streaks may be about 10 percent. Most assays on samples from the Eastern fahlband zone show only about 0.01 percent cobalt. Only a few assays show up to 0.05 percent. Considering the very low cobalt content of this fahlband zone, a detailed description of it is not justified. The remainder of this report deals only with the Main fahlband zone.

The Fahlband Rocks (See Fig. 4)

The fahlbands are essentially composed of quartz-mica-schists with tourmaline (brown and green) and/or sillimannite.

The most common rock is a quartz-tourmaline-sillimannite-mica-schist with about 10 percent sillimannite (aluminum silicate). The sillimannite has a tendency to collect in bands and lenses of a few centimeters width. The mica is

partly phlogopite(magnesia mica) and partly muscovite (potash mica). The rock has small amounts of apatite (calcium phosphate) and sphene (calcium-titanium-silicate) - about 1 percent. Graphite occurs in amounts of 0.2 to 0.5 percent. Generally the quartz-tourmaline-sillimannite-mica-schist has less than 0.5 percent cobalt.

The best cobalt ore is generally found in a quartz-phlogopite-tourmaline-schist which is next in abundance after the above mentioned rock. Phlogopite is the predominant mica mineral in this rock. Graphite and rutile (titanium oxide) occur as accessory minerals.

Other rocks within the fahlbands include quartzites, sillimannite-quartzites, sillimannite-muscovite-quartzites, two-mica-schists (a rock essentially composed of muscovite and phlogopite), biotite-chlorite-hornblende-schists with and without tourmaline, mica-gneiss, feldspar-bearing mica schists, sillimannite granites and granite pegmatites.

A diopside-quartz-pyrite rock is found in small lenses within the above mentioned rocks. (Diopside is a magnesium-calcium-silicate.) On the border between this rock and the mica-schists is often found a layer of a few centimeters width of an actinolite-calcite-quartz rock with impregnations of ore minerals. (Actinolite is an amphibole mineral.)

Narrow quartz-tourmaline veins and albite veins traverse the fahlbands in several directions. These veins often have a comparatively high cobalt content. A sample from the eastern stope in the Central mines of the Skutterud mining district showed as much as 0.172 percent cobalt. The tourmaline of the quartz-tourmaline veins is of a peculiar type, containing 0.1 percent chromium, 0.1 percent titanium, and only 0.001 percent nickel. These veins often contain large individuals (about one centimeter) of well crystallized skutterudite (cobalt-arsenide).

The individual fahlbands of the Main fahlband zone are separated from each other by layers and lenses of foliated amphibolite (see Fig. 6). The amphibole of this rock has to a large extent been transformed into biotite (a mica mineral). The amphibolite generally has a certain impregnation of ore minerals. Four samples of amphibolite taken between the western stope and the middle stope in the Central mines of the Skutterud mining district showed cobalt contents of 0.03 to 0.04 percent.

The Ore Minerals

Cobalt ore minerals occur as impregnations in the fahlband rocks together with other ore minerals, mostly sulphides and arsenides. The size of the individual mineral grains varies from a pinhead or less to about five millimeters. Crystals of about two centimeters may be found, but they are rare.

The ore minerals are:

Cobaltite	CoAsS
Denaite	(Fe, Co) AsS
Skutterudite	$CoAs_3$
Arsenopyrite.	FeAsS
Pyrrhotine	FeS
Pyrite	FeS_2
Chalcopyrite	$CuFeS_2$
Metallic bismuth . . .	Bi
Metallic copper	Cu
Graphite	C
Molybdenite	MoS_2
Erythrite	$Co_3(AsO_4)_2 \cdot 8H_2O$
Malachite	$Cu_2CO_3(OH)_2$
Tennantite (?)	Cu_3AsS_3

Chemical analyses of the cobalt ore minerals as given by Bøbert are quoted below. The trace elements were determined by spectrographical analysis in recent years (analyst Ivar Oftedahl).

Cobaltite is the chief ore mineral at Modum. Analysis:

Cobalt	33.10 percent	Antimony	0.001 percent
Arsen	43.46 "	Nickel	0.10 "
Iron	3.23 "	Bismuth (about)	0.001 "
Sulphur	20.08 "	Copper	Traces
	99.87 percent		

Danaite (cobalt-arsen-pyrite) is also common. In this mineral iron and cobalt can replace each other (isomorphous mixture) and the mineral, therefore, has a varying content of cobalt. The maximum cobalt content of danaite is about 12 percent. In certain parts of the fahlbands it is more frequent than cobaltite. The following chemical analysis has been made of a specimen from the Skutterud mines:

Cobalt	8.31 percent	Antimony	0 percent
Arsen	47.53 "	Nickel	1 "
Iron	26.54 "	Bismuth	0 "
Sulphur	17.57 "	Copper	traces
	99.97 percent	Silver	0 percent

Skutterudite (cobalt arsenide) is of rare occurrence except in the Weisscobalt stope in the Central mines of the Skutterud mining district. Analysis:

Cobalt	20.01 percent	Antimony	about 0.01 percent
Arsen	77.84 "	Nickel	traces (o.01percent)
Iron	1.51 "	Bismuth	0 "
Sulphur	0.69 "	Silver	(0 percent)
	100.05 percent	Copper	0 "

The secondary cobalt mineral erythrite is found only in insignificant amounts.

The Main Fahlband Zone (see Fig. 3 and Fig. 5)

The Main fahlband zone has an extension of about 10 kilometers in a northernly direction. The average width is about 100 meters. In some places, particularly in the southern part of the zone, it may be 350 to 400 meters wide. The dip is generally 70 to 80 meters towards east. The fahlband zone conforms to the prevailing rock structure.

To the west the Main fahlband zone borders to a rock complex of sillimannite-quartz-mica-schists, quartzites, gneisses and granites. To the east it borders a 500 meters broad zone of massive garnet amphibolite.

The Main fahlband zone is composed of several individual fahlbands separated by narrow amphibolite layers. These are rarely more than 30 meters wide, but they generally extend considerably in the direction of the strike and dip of the fahlbands. Small amphibolite bodies also occur within the separate fahlbands. The amphibolite is strongly foliated and biotized. The amphibolite has often nearly the same content of ore minerals as the fahlbands. This amphibolite is thus quite different from the massive garnet-amphibolite which borders the Main fahlband zone to the east.

Most of the old mines are from the southern end of the fahlband to about three kilometers northwards. Here are the Skutterud and Saafstad mines. At the northern end of the fahlband are the Svartfjell mines. Between the Saafstad and Svartfjell mines are a few prospects and small workings.

The greater part of the productive mining by far was carried out in the Skutterud mines, a mining district with three groups of mines connected by drifts and adits. The deepest workings are about 110 meters below the surface.

The Skutterud Mines (see Fig. 3, 6, 7 and 8)

In the Skutterud mining district there are three main fahlbands separated by amphibolite layers. They are referred to, from east to west, as the Troegerort, the Middle, and the Western fahlbands. Most of the old mines are in the Western and the Middle fahlbands which have been worked to a depth of about 110 meters below the surface, whereas the Troegerort fahlband has only been worked to a depth of about 70 meters.

The Skutterud mining district is divided into the Southern, Central and Northern mines. The Central mines were the larger ones. There were about 40 larger workings, partly open-cast and partly underground.

In the Skutterud mining district there are adit systems in three levels. The lowest adit is the Ludvig-Eugen adit (about 270 meters above sea level) then follows the Clara adit (about 330 meters above sea level) and the Forhaapning adit (about 350 meters above sea level). Each adit system has an entrance adit which is driven into the hillside in a westerly direction through the garnet amphibolite into the fahlband zone. The adits are then driven in a northernly and southernly direction parallel to the fahlbands. The adits run mostly in or near the Western fahlband.

The Ludvig-Eugen is the main adit and connects the Southern, Central and Northern mines. (It does not reach the Saafstad mines, however.) Ore from Forhaapnings adit and Clara adit was partly loaded through chutes to the Ludvig-Eugen adit level for underground haulage.

In the Troegerort fahlband one drift is driven, the Troeger drift, at a level of 316 meters above sea level (the same level as the Clara adit).

The Constantin shaft in the Central mines was the main shaft. Other shafts were Korrman and Ludvig-Wilhelm.

Underground mining was carried out by overhand and underhand stoping. There are several open-cast works down to the Clara adit level.

According to Dr. Rosenquist, who has made a scientific geological study of the Modum district, there are still about 6 million tons of cobalt ore above the level of the Ludvig-Eugen adit. This ore probably has an average grade of 0.06 to 0.08 percent cobalt. By selective mining it may be possible to mine a certain tonnage with a higher cobalt content, possibly 0.15 percent.

The Weisscobalt stope of the Central mines is of particular interest. Here only about 15,000 or/tons of ore have been mined. Geophysical prospecting carried out during the last war (see "German Investigations From 1941 to 1943") gave better indications here than in other parts of the Skutterud mining district. It seems to be the most promising area. The Weisscobalt stope is the only place where skutterudite (cobalt arsenide) is a common ore mineral. There are about equal amounts of cobaltite and skutterudite.

The Saafstad Mines

The Saafstad mines are about one kilometer north of the Northern mines of the Skutterud mining district. The two largest workings are the Middagshvile and the Middagskollen mines. They are both underground workings. The average grade of the ore was probably not over 0.05 percent cobalt. Probably they have produced a few hundred thousand tons of ore. Very little information can be obtained on the Saafstad mines.

The Svartfjell Mines

These mines are situated in the northern end of the Main fahlband zone. The largest working is a 38 meter deep open-cast. There is an adit at the bottom of the open-cast. The mines probably have produced about 100,000 tons of ore.

No ore reserve estimates have been made of the Svartfjell mines. Stray assays indicate that the ore is somewhat richer than the average ore of the Skutterud mines, several assays showing 0.11 percent cobalt. It also appears, upon mineralogical examination, that bismuth (in the form of metallic bismuth) is of more common occurrence than in the southern part of the Main fahlband zone; however, no assays have been made to confirm this impression. The ore also seems to have a higher content of graphite than the ore of the Skutterud mines, about 5 percent graphite.

Persistence of Ore in Depth

The rock complex at Modum is of Pre-Cambrian Age. A Norwegian geologist has advanced the theory that the cobalt ores as found in the Modum occurrences are due to a secondary enrichment which took place in Cambrian time. According to this theory it should be expected that the richer cobalt ore would be found at the highest points in the landscape (i.e. the points nearest the imaginary sub-Cambrian peneplain which has been situated somewhat above the highest hills of the mining district) and that the grade of the ore would decrease with depth. It may well be that a process as suggested has played a certain role in the formation of the cobalt ores. However, in disseminated ores of this kind it is quite possible that original ore of approximately the same grade as the ore at higher levels can be found at deeper levels, that is ore that has not undergone any hypothetical secondary enrichment.

The 86 assays made by the Germans from 1941 to 1943 do not disqualify the above mentioned theory. Actually they seem to indicate that the grade of the ore decreases with depth. However, investigations are too limited to allow a statement to the effect that this is the general rule. It should also be remembered that the regional variation in the grade of the ore is of the same magnitude as the apparent variation in depth, and it is only a question of a few hundredths percent. The absolute difference between the assays thus is very small even if the relative difference is comparatively high because of the very low grade of the ore. Final conclusions cannot be drawn regarding variations of ore grade in depth on the basis of investigations carried out up to now, and it cannot be considered proved that the ore has been definitely bottomed at the present deepest working level, i.e. 110 meters below the surface.

Below is given a table of assays on samples from different levels in the Main fahlband zone. Regarding the sampling methods, see "German Investigations 1941 - 1943."

The Main Fahlband Zone

Level	% Co	Average of:
Troegerort fahlband		
333 meters above sea level	0.062	6 assays
316 " " " "	0.042	6 "
Middle fahlband		
333 meters above sea level	0.093	7 "
316 " " " "	0.071	11 "
296 " " " "	0.04	2 "
Western fahlband		
333 meters above sea level	0.098	4 "
316 " " " "	0.053	5 "
296 " " " "	0.039	7 "
Svartfjell mines		
About 400 meters above sea level	0.072	26 "
Rødkollen prospect		
About 400 meters above sea level	0.021	7 "
Jupdal prospect		
About 360 meters above sea level	0.039	5 "
	Total:	86 assays

The Metal Content of the Ore

Several assays were made by the Germans in order to study the quantitative relationship between cobalt and other metals in the ore of the Main fahlband zone. Regarding the sampling method, see "German Investigations 1941 - 1943."

The content of cobalt and arsen was determined in three samples from the following localities (analyst Olaf Røer, Oslo Materialprøveanstalt).

	% Co	% AS	As/Co
Svartfjell mines	0.113	0.68	6.0
Central mines, Skutterud (northernmost stope)	0.299	2.20	7.3
Central mines, Skutterud (Weisscobalt stope)	0.052	0.11	2.1

The content of cobalt and iron was determined in five samples from unknown localities in the Main fahlband zone. Probably most of the samples were taken in the Skutterud mining district. The assays were made in the laboratories of the firm Klöckner-Humboldt-Deutz AG, Köln (Cologne). Only the iron soluble in aqua regia was determined, that is only iron in ore minerals and not iron in silicate minerals.

% Co	% Fe	Fe/Co
0.10	2.96	29.6
0.12	4.64	38.6
0.14	2.77	19.7
0.20	8.01	40.1
0.28	3.15	11.8

The content of cabalt and bismuth was determined in two samples from the following localities:

	% Co	% Bi	Bi/Co
Central mines, Skutterud	0.046	0.02	0.43
Svartfjell mines	0.06	traces	

The content of cobalt and copper was determined in three samples from the following localities:

	% Co	% Cu	Cu/Co
Central mines, Skutterud	0.046	0.16	3.5
Svartfjell mines 1	0.06	0.15	2.5
Svartfjell mines 2	0.113	0.145	1.3

The content of cobalt and nickel was determined in two samples from the Main fahlband zone and in four concentrates of ore from the Main fahlband zone. Samples of about 70 kilograms were concentrated by flotation in the laboratories of the firm Klöckner-Humboldt-Deutz AG, Köln. Most of the ore was grinded to 0.06 m/m before flotation. In one test cobalt minerals and graphite were flotated together. Assays of products from this test are referred to as Flotation Concentrate and Intermediate Product in the table below. The sample used for this test had a cobalt content of 0.039 percent, and the recovery of cobalt was about 70 percent. In another test graphite was flotated first and then cobalt minerals and other sulphides. Assays of products from this test are referred to as Graphite Concentrate and Cobalt Concentrate in the table below. The sample used for this test had a cobalt content of 0.041 percent. It gave 5 - 6 percent graphite concentrate with a content of 63.7 percent graphite, and 13 - 14 percent cobalt concentrate. The recovery of cobalt was about 70 percent.

	% Co	% Ni	Co/Ni
Southern part of the Central mines, Skutterud	0.318	0.07	4.55
Eastern stope in the Central mines, Skutterud	0.066	0.012	5.52
Flotation concentrate 44	0.512	0.091	5.65
Intermediate product 44	0.185	0.04	4.63
Graphite concentrate 44 (63.7 percent C)	0.18	0.043	4.25
Cobalt concentrate	0.783	0.132	5.9

In these samples no skutterudite was present, the only cobalt minerals being cobaltite and danaite (cobalt-arsenpyrite). Skutterudite has practically/nickel. A flotation concentrate on ore from the Weisscobalt stope (the part of the deposit richest in skutterudite) showed 3.63 percent cobalt and 0.23 percent nickel; that is, the relation Co/Ni here is 15.75.

As seen from the above assays the Co/Ni ratio is fairly constant in all samples, approximately 5.1, except when skutterudite occurs in the ore. There does not seem to be any correspondence between the content of cobalt and the content of any of the other metals.

German Investigations 1941 - 1943

Because of their cobalt shortage the Germans were particularly interested in the Modum mines during the last war. They started quite extensive investigations early in 1941, but discontinued work in 1943 concluding that the grade of the ore was too low to justify a re-opening of the mines.

The investigations were directed by the Abteilung Bergbau of the German Reichskommisariat in Oslo. The firm Sachsenerz had economic interests in the Modum project. The Germans spent altogether 115,000 Norwegian kroner ($23,000 at the rate current at that time) on investigations at Modum. 105,000 kroner was spent in 1941.

The investigations were concentrated on the Skutterud mines. Drifts and adits were cleared and made accessible, and the Clara adit and the Ludvig-Eugen adit were provided with rails (later removed). The purpose of this work was to establish the grade of the ore and its persistence in depth. Samples were taken by blasting. The samples were then crushed, coned and quartered before assaying.

The detailed reports on this work and the complete records of assays have been lost. There are, however, maps left showing the location of the samples and the result of a number of assays (see Figs. 7 and 8). The assays which could be identified are given in the chapters on the Metal Content of the Ore, and Persistence of Ore in Depth. (These assays have been recorded by Dr. Rosenquist.) A general report prepared by a German engineer (Joseph Horvath) in 1945 states that the average cobalt content of the ore bands in the Skutterud mining district was found to be about 0.08 percent. (A great number of the assays indicated in the maps in Figs. 7 and 8 show only about 0.02 percent cobalt. These assays have been made on samples outside the ore bands.)

Considerable geological mapping of the Skutterud mines was also carried out. The purpose of this work was to find out if any system in the distribution of the streaks of richer ore occurring in the ore bands could be found. The results were negative.

The greater part of the Main fahlband zone was investigated by geophysical prospecting, from the Central mines in the Skutterud district in the south to the Svartfjell mines in the north. The self-potential electrical method was used. The geophysical maps are missing except one of the Middagshvile

mine in the Safstad area. However, engineer Horvath, who was interrogated in 1945, stated that the best indications were found above the old mine workings. He claimed that the areas around the Weisscobalt stope in the Central mines of the Skutterud mining district and the Svartfjell mines were the most promising districts.

Some samples of ore from the Svartfjell mines, taken after the geophysical prospecting, showed as much as 0.2 to 0.3 % cobalt. However, it was considered that these richer ore bands were too narrow and limited to justify a further study.

The Germans also carried out some flotation tests on 70 kg samples. (See "The Metal Content of the Ore"). They found that about 5% graphite concentrate with about 63% graphite could be recovered from the ore. One cobalt concentrate contained about 0.8% cobalt and another contained about 3.6%. The recovery of cobalt from the ore was about 70%.

Ore Reserves

Dr. Rosenquist has made an estimate of the ore reserves of the Skutterud mining district. According to him there are still left about 6.000.000 tons of ore with probable average grade of 0.06% to 0.08% cobalt above the level of the Ludwig-Eugen adit (110 meters below the surface). The greater part of these reserves are in the Central mines. It is not possible to say anything about the ore reserves below the level of the Ludwig-Eugen adit (See "Persistence of Ore in Depth").

No reserve estimates have been made at the Safstad and Svartfjell mines, but reserves are considerably smaller than those of the Skutterud mining district.

The Main fahlband zone has been followed in a stretch of about 10 kilometers. Geophysical investigations carried out by the Germans during the last war seem to indicate that the best ore is in the Skutterud mining district in the southern end of the fahlband zone and in the Svartfjell mines in the northern end. If these investigations are relied upon, it cannot be expected that ore of the same grade will be found as in the area between the two mines. However, the Main fahlband zone shows continuous cobalt mineralization. If one considers ore with 0.05% cobalt or less the reserves of the Main fahlband zone are probably several 10 million tons.

Ore Reserves in Tailing Dumps

There are extensive tailing dumps at the Modum mines, particularly at the Central mines of the Sjutterud district. No assaying has been made of these dumps, but it is quite possible that they contain about 0.05% cobalt, not much less than the average grade of the crude ore.

Recovery was very poor during the greater part of the time the Modum mines were in operation. Probably the grade of ore produced up to 1850 was mostly 0.08% cobalt. Production figures from 1830 (a year of high production) indicate that there was recovered only 0.02% cobalt from the crude ore that year (see page 4), leaving about 0.06% cobalt in the dumps. The rate of recovery was probably about the same before 1830, and not much better from 1830 to 1850.

After 1850 the annual production of crude ore was much less than in the years before. It seems that concentration was there on selective mining of higher grade ore with 0.15% to 0.20% cobalt. Recovery was then probably better but, even the dumps from these years probably contain a few hundredths percent cobalt.

The ore was concentrated by hand picking. Production figures from 1830 indicate that the amount of concentrate obtained was only about three percent of the amount of crude ore produced. The tonnage of the dumps from this year are thus not much smaller than the tonnage of the crude ore produced. The year 1830 can probably, in this respect, be taken as a representative year for the mining period 1796 - 1850.

It is difficult to estimate the tonnage of the tailing dumps from their appearance today. Dr. Rosenquist has calculated the amount of ore and rock material taken out of the Modum mines on the basis of the size of the old workings. He arrives at 10 - 12 million tons. This seems an extremely high figure. It will of course include material from shafts, adits and drafts which has not been included in the mines production statistics.

The production of ore that underwent concentration by hand picking can hardly have been more than 3 - 4 million tons, (see "Past Production"). The greater part of this tonnage was produced before 1850, i.e. before selective mining was started with a small production of higher grade ore.

The dumps are composed partly of material left after the hand picking concentration and partly of material that was considered as barren rock at the time of the mining. The two types of material cannot be distinguished. Probably a large part of the material considered as barren rock has about the same cobalt content as the material that has undergone concentration by hand picking.

Recommendations

The grade of the cobalt ore at the Modum deposits is too low to justify a study with a view to mining operations at the present time. However, the ore reserves and the possible ore reserves are so large that it should be well worth keeping the deposits in mind if the demand for cobalt should become critical. From this point of view it may be recommended to carry out some small scale investigations of certain parts of the Main fahlband zone, such as further assaying of the Svartfjell mines and the Weisscobalt stope.

As mentioned it looks as though there is a stronger bismuth mineralization in the Svartfjell mines area than in other parts of the Main fahlband zone. Assaying on bismuth in this area would be recommendable. The ore of the Svartfjell mines also seems to have a higher content of graphite than ore from other parts of the Main fahlband zone. It may be suggested to carry out concentration tests on graphite and also on the sillimannite of the quartz-sillimannite-mica-shists. If the mines are reopened some time in the future, there would seem to be a possibility of producing graphite and sillimannite as by products of the cobalt mining. The phlogopite of the phlogopite-tourmaline-shists is probably not of sufficient quality to meet the technical requirements.

There are extensive tailing dumps at the Central mines of the Skutterud mining district. To judge from old reports recovery was so poor that large parts of the tailing dumps probably have not much less content of cobalt than the actual ore. The cobalt content of the tailing dumps is estimated at about 0.05%. However, no assaying of the dumps has been made. The dumps ought to be sampled properly and assayed. If the guess on the grade of the dumps proves to be correct, it should be established whether it is possible to concentrate this material which has undergone considerable weathering in the course of time.

Cobalt in Slag at Evje, Southern Norway

There are about 700,000 tons of cobalt-containing slag dumps at Evje. The slag was obtained by smelting nickel-copper concentrates for production of nickel-copper matte.

Evje is situated on the river Otra about 50 kilometers north of the town of Kristiansand on the southern coast of Norway. The altitude is about 400 meters above sea level. From Grovane, a station 15 kilometers north of Kristiansand on the Oslo - Kristiansand railway, there is a narrow gauge railway to Evje. Evje can also be reached by road from Kristiansand.

The smelter at Evje discontinued operations in 1946. The smelter treated concentrates from the Flaat nickel mines near Evje and from Hosanger about 20 kilometers northeast of the town of Bergen on the western coast of Norway. The ore from both mines generally contained about 0.7 percent nickel and a few tenths percent copper. The ore was composed of pentlandite (nickel iron sulphide), pyrrhotite, pyrite and chalco-pyrite. The two mines were abandoned after the last war because of exhaustion of commercial grade ore. Most of the cobalt was in the pyrite.

The slag dumps belong to Raffineringsverket A/S in Kristiansand which operated the Flaat mine and the Hosanger mine.

The composition of the slag is as follows:

	250.000 tons produced before 1927	450.000 tons produced between 1927 and 1947.
Nickel.....	0.18 percent	0.18 percent
Cobalt.....	?	0.18 "
Copper.....	0.10 "	.23 "
Iron.....	28.- "	40.- "
SiO_2.....	37.- "	32.- "
S.....		1.60 "
CaO.....		3.- "
MgO.....		4.- "
Al_2O_3.....		7.- "

About 100,000 tons of the slag is probably inaccessible as it lies in a swamp.

Cobalt was not assayed in the 250,000 tons of slag produced before 1927, but probably the cobalt content is much the same as in the slag produced after 1927, i.e. 0.18 percent. The amount of cobalt contained in the slag is thus about 1000 tons.

The slag is a silicate glass with inclusions of sulphide particles. Nickel appears to have gathered in the sulphide particles whereas cobalt is largely in the form of silicates.

Several attempts have been made to recover the cobalt from the slag but with little success. By a reduction smelting process there has been obtained an iron product containing 0.86% cobalt, 0.61% nickel, 0.9% copper, 0.18% carbon, 0.10% silicium, 0.01% sulphur and 0.02% phosphorus. However, potential consumers in the United States and Germany have shown no interest in this product.

The information on the slag dumps at Evje given above has been obtained by courtesy of Mr. S. Giertsen, director of the Raffineringsverket A/S, Kristiansand and Dr. Harald Bjørlykke, state geologist with the Norwegian Geological Survey.

Olge J. Adamson

Oslo. May 27, 1950

RESTRICTED

Cobalt in Norwegian Pyrites

Contents

Introduction ..... p. 1

Operating Pyrite Mines..... 2

Non-Operating Pyrite Deposits..... 2

An Account of the Treatment of Pyrite Ores With a Bearing on Cobalt..... 3

- Crude Pyrites..... 3
- Flotation Pyrites..... 4
- The Orkla Process..... 4

Conclusion..... 5

RESTRICTED

Cobalt in Norwegian Pyrites

Introduction

Most Norwegian pyrites contain from 0.01 to 0.07 per cent cobalt. Generally the cobalt content is about 0.05 per cent. The amount of cobalt contained in the present annual production of pyrite (about 750,000 tons) is 350 to 400 tons.

Norwegian pyrites are divided in cuprous pyrites and non-cuprous pyrites. All the operating pyrite mines except two (Stordø and Bjørkaasen) have mainly cuprous pyrites. Cuprous pyrites is a trade name applied to pyrite ores with more than one per cent copper. Generally they also have one per cent zinc or more.

The ore minerals of the pyrite ores are pyrite (iron sulphide), chalcopyrite (copper iron sulphide) and sphalerite (zinc sulphide). Cobalt occurs in the pyrite (isomorphous mixture of cobalt and iron in the pyrite), - chalcopyrite and sphalerite being practically cobaltfree. Cobalt minerals, that is minerals where cobalt is a main constituent, only occur as mineralogical rarities in some of the pyrite deposits.

The noncuprous pyrite ores are essentially composed of pyrite and have little or no chalcopyrite and sphalerite. "Non-cuprous pyrites" is also applied as a trade name to flotation pyrite concentrates of the cuprous pyrite ores from which chalcopyrite and sphalerite are separated in copper and zinc concentrates.

At present cobalt is not recovered from the Norwegian pyrite ores. Because cobalt is a constituent of the mineral pyrite it would have to be extracted by a chemical or metallurgical process. The Norwegian pyrite ores undergo mechanical treatment only, except part of the ore from the Løkken mines which is treated by the Orkla process. However, in this smelting process cobalt goes into an iron slag from which it does not seem to be recoverable.

Recently there has been discussed the possibility of treating Norwegian pyrite ores in a process which would allow the recovery of sulphur and iron, copper, zinc and other metals in the form of commercial products. Cobalt would be an important by-product of such a process. A process worked out (on paper only) by Mr. Egil Ronæss (previously head of the chemical department of the Research Institute of the Department of Defence, and at present chief chemical engineer with the Standard Telephone and Cable Company in Oslo) was discussed at a meeting a few months ago between Mr. Ronæss, Mr. Drogseth of the Department of Industry, Mr. Bandy and Mr. Vivian of ECA and myself.

The description of cobalt in Norwegian pyrite ores that follows will be of interest if a process of economic consequence is invented and its realization is decided upon.

Cobalt Content of Ores of Operating Pyrite Mines
(See fig. 1)

Mine	% of Co in the ore	Production in 1949 in tons Pyrite	Co Content	Ore reserves in tons
Løkken	0.06	460,000	275	9,000,000
Sulitjelma	0.06	80,000	50	4,000,000 ≠ 6,500,000 supposed ore
Bjørkaasen	0.01 ?	55,000	5 ?	1,000,000
Foldal	0.06	35,000	20	500,000 (?)≠ ≠
Killingdal	0.06	35,000	20	300,000 (?)≠ ≠
Vigsnes	0.03 ?	15,000	5 ?	300,000 (?)
Stordø	0	55,000	0	
Fosdalen	0	6,000	0	By-product of iron mining
Mofjellet	0	4,000	0	By-product of zinc mining.
		745,000	365 (≠10?)	15,000,000 ≠ 6,500,000 tons with a cobalt content of 8,000 tons (≠ 4,000 tons?)

The nickel content of the Norwegian pyrites is generally only 0.001 to 0.002 per cent. The Co:Ni ratio is thus mostly 30:1 to 20:1. All Norwegian pyrite ores are extremely low in arsen. The Løkken ore for instance generally has 0.05 per cent arsen. In other pyrite ores the arsen content varies from 0.01 to 0.18 per cent.

Cobalt Content of Ores of Non-Operating Pyrite Deposits

Deposit	% of Co in the ore	Ore Reserves in tons	Co content of Ore in tons
Joma	0.03 ?	15,600,000 ≠ large possible reserves	4,700 ? (≠)
Skorovas	0.01 ?	7,000,000	700 ?
Gjersvik	0.04 ?	1,500,000	600 ?
		24,000,000 tons	6,000 tons ? (≠)

The content of nickel and arsen is about the same as for the producing pyrite mines. The Joma deposit has several types of pyrite ore, the copper content for instance ranging from 0.4 to 7 per cent. The cobalt content shows considerable variation depending on the type of ore. Twenty-nine (29) cobalt assays have been made on different types of ore; most of them showed over 0.03 per cent cobalt. The highest assay showed 0.11 per cent cobalt, and one single assay showed only 0.003 per cent - 0.03 per cent seems a safe estimate of the average cobalt content in the Joma deposit.

An Account of the Treatment of Norwegian Pyrite Ores With a Bearing on Cobalt

From a trade point of view the Norwegian pyrites may be divided in two groups as mentioned: Cuprous pyrites and noncuprous pyrites. However, according to the treatment the pyrite ores undergo the pyrite fall in three groups:

I. Crude pyrite ore and table concentrate of pyrite ore where only rock material is removed.

II. Flotation pyrite - The crude pyrite ore is separated in three concentrates by flotation: Pyrite, copper and zinc.

III. Pyrite ore treated in the Orkla process for production of elemental sulphur and copper matte.

I. Crude pyrite ore and table concentrate of pyrite ore

This group comprises the total production of Stordø and Killingdal, about half the production of Løkken (215,000 tons in 1949) and the larger part of the Bjørkaasen production.

The Stordø ore is a noncuprous pyrite with no cobalt content.

The Bjørkaasen ore is a noncuprous pyrite (0.3 per cent copper) with a certain cobalt content.

The Løkken ore and the Killingdal ore are cobalt-containing cuprous pyrites.

In 1949 there was exported 245,000 tons of cobalt-containing crude cuprous pyrites (Løkken and Killingdal) and 55,000 tons of cobalt-containing noncuprous pyrite table concentrates (Bjørkaasen).

The chief consumers were Sweden, the British-American zone of Germany, and Eastern Europe. Norwegian consumption of cuprous pyrites in 1949 was negligible - 11 tons.

The pyrite ores are roasted for manufacture of sulfuric acid. The metal content of the pyrite ore (iron, copper, zinc, cadmium, gold, silver and cobalt) is collected in the cinder residue of the roasting. Before the last war copper, gold, silver and possibly cobalt were extracted from the cinder by leaching, particularly in Hamburg, Germany. The cinder was then sold to steelworks for its iron content (purple ore).

It is not known if the metal content of the cinder has been recovered since the war.

II. Flotation pyrite

The total production of Sulitjelma, Foldal and Vigsnes and part of the production of Bjørkaasen undergo flotation. There are produced pyrite and zinc concentrates. The pyrite concentrates are commercially noncuprous pyrites. They contain 0.25 to 0.4 per cent copper and 0.25 to 1.75 per cent zinc. The cobalt of the ore goes into the pyrite concentrates. (The small pyrite production of the Fosdalen iron mine and the Mofjellet zinc mine is also flotation pyrite).

In 1949 140,000 tons of flotation pyrite concentrates were produced. 125,000 tons were shipped from the mines. About 70,000 tons were exported, chiefly to Denmark and Eastern Europe. The rest was consumed in Norway.

The flotation pyrite concentrates are roasted for the manufacture of sulfuric acid in the same way as the crude pyrites and the pyrite table concentrates. Prior to the last war the cinder residue of the roasting was sold in Germany for its iron content, but since the war there has been no market for the cinder. The metal content of this cinder has never been recovered.

III. The Orkla process

About half the production of the Løkken mine (245,000 tons in 1949) is treated in the Orkla process. In this process the pyrite ore is smelted in a blast furnace fitted with a closed top. Quartz, limestone and coke are added to the charge. There are produced elemental sulphur and copper matte. In 1949 the production was 80,000 tons of sulphur and 12,000 tons of copper matte.

The cobalt of the pyrite goes mainly into an iron slag for which there is no market. The zinc goes partly into slag and partly in Cottrell gases.

Conclusion

The amount of cobalt contained in the present annual production of pyrite in Norway (about 750,000 tons) is 350 to 400 tons. By far the larger part is contained in the ore of the Løkken mine. The Stordø pyrite (noncuprous) is the only ore that has no content of cobalt.

245,000 tons of cobalt-containing cuprous pyrite were exported in 1949, mainly to Sweden, to the British-American zone of Germany and to Eastern Europe. Cobalt may be recoverable from the cinder residue after the roasting of this pyrite together with copper, gold and silver. The cobalt content is about 150 tons.

About 180,000 tons of cobalt-containing noncuprous pyrite (table concentrate and flotation concentrate) were shipped from the mines in 1949. About 65,000 tons were consumed in Norway and the rest was exported, mainly to Denmark and Eastern Europe. It is not likely that it will be economic to recover cobalt from the cinder residue after the roasting of this pyrite.

Fifty thousand tons (50,000) of cobalt-free noncuprous pyrite (Stordø) were exported in 1949 to Eastern Europe.

Two hundred forty-five thousand tons (245,000) of cobalt-containing pyrite were treated by the Orkla process in 1949. Cobalt does not seem to be recoverable from the iron slag of the Orkla process.

The amount of cobalt contained in the ore of operating pyrite mines in Norway is about 8,000 tons (≠ 4000 tons ?).

The amount of cobalt contained in the ore of non-operating pyrite deposits is possibly about 6000 tons.

Olge J. Adamson
Oslo, May 30, 1950

Miscellaneous Cobalt Occurrences in Norway

The Løddesøl Occurrence

Løddesøl is about 7 kilometers west-southwest of the town of Arendal on the southern coast of Norway. There is a skarn zone with pyrite and other sulphides. The cobalt occurs in the pyrite.

Skarn is the name of a rock resulting from contact metamorphism of limestone and is characterized by calcium silicate minerals. The skarn zone is 5 to 10 meters broad and borders calcite marble on one side and gneissous rocks on the other. It has been followed from the Hollet farm near Løddesøl about one kilometer in a northernly direction. There is a small prospect about two meters high and two meters wide near the road to Løddesøl.

The skarn zone contains pyrite, pyrrhotite, chalcopyrite, and marcasite (iron sulphide) together with graphite, phlogopite and small amounts of rutile, apatite and zircon.

A scientific study of the occurrence has been published by Jens Bugge. (Løddesøl skarnforekomst. Norsk Geologisk Tidsskrift. Vol. 25, p. 35. 1945.) He gives only qualitative information on the ore minerals and their paragenesis. There is no information on the grade of the ore or estimates of ore reserves. He states that the best developed crystals are found in the above-mentioned prospect.

A chemical analysis of the pyrite showed 2.5 percent cobalt and only 0.04 percent nickel. Probably practically all the cobalt of the occurrence is in pyrite which seems to be the predominant ore mineral in the occurrence. The average grade of the ore may be a few tenths percent cobalt.

Proper sampling of the ore would have to be carried out before anything could be said about the possibilities of the occurrence. It may prove to be a small cobalt source. The cobalt would have to be recovered from the cinder residue after the roasting of the pyrite.

The Holand Occurrence

Holand is a farm in the district of Osen in Bjørnør in the county of Sør-Trøndelag (around the town of Trondheim in western Norway). It is shown on the Namsos map (1:100,000). There are small fahlbands in amphibolite. The fahlbands are zones within

the amphibolite with impregnations of pyrite and other sulphide minerals. The cobalt occurs in the pyrite.

The Holand fahlbands are 20 to 40 centimeters wide and 10 meters long, being cut by a granite pegmatite. According to C. W. Carstens, the cobalt content of the ore is about 0.5 percent and the copper content 0.8 to 1 percent. (En koboltforekomst i "Vestranden". D.K.N.V.S. Forhandlinger. Vol.20. No. 21. Trondheim 1947.) Assays of pyrite crystals showed from 1.8 to 2.9 percent cobalt. This occurrence is of no economic interest.

There are several other fahlbands in the district. The occurrence of cobalt in the Holand fahlbands indicate that concentration of cobalt may be found in other fahlbands. However, an assay of a fahlband north of the Holand farm showed only o.06 percent cobalt.

Cobalt in Nickel Ores

The Norwegian nickel ores contain a few hundredths percent cobalt. The nickel content is generally 0.7 to 1 percent. The nickel occurs in pentlandite (iron nickel sulphide) and pyrrhotite. The cobalt occurs mostly in pyrite.

No nickel is mined in Norway at the present time. Apart from the Flaat and Hosanger mines (See: Cobalt in Slag at Evje, Southern Norway), which were closed after the last war because of exhaustion of ore, there are several small deposits, some of which have been worked on a small scale-- for instance, at Erteli southwest of Hønefoss and 40 kilometers west of Oslo, at Espedalen in Gausdal about 60 kilometers northwest of Lillehammer on the Oslo-Trondheim railway, and at Feøy, an island about 8 kilometers west-southwest from the town of Haugesund on the western coast of Norway.

The largest known nickel deposit is the Raana deposit on the south side of Ofotenfjord near Narvik in northern Norway. It is a low grade deposit. However, it is not of such low grade as stated by John W. Vanderwilt in his report of October 25, 1949, page 7, "Miscellaneous Mineral Deposits in Norway". Probably due to misprint or misunderstanding of information received he gives the nickel content as 0.05 percent. Actually it is exactly ten times as much!

Considerable investigations were carried out at the Raana deposit during the German occupation of Norway, 1940-1945,

including an exploratory tunnel about 200 meters long, 30 diamond drill holes with a total length of 3800 meters and geophysical prospecting. The ore is a nickel-containing pyrrhotite which occurs in a gabbro. Ore reserves are about 4 million tons with an average grade of 0.4 to 0.5 percent nickel. About 0.1 percent nickel occurs in silicate minerals. The nickel:cobalt ratio of the ore is generally 20:1.

Olge J. Adamson

Oslo, June 2, 1950