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Tittel

The Radiometric survey of the Modum Area

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Sammendrag

27th March 1957.

TVA/[illegible]

To the director of the Geological Survey of Norway.

The radiometric survey of the Modum area.

Report

by Tony Van Autenboer.

I OBJECT OF THE SURVEY.

During a systematic check of samples in the geological museum at Töyen, Co-ore from the Skutterud-mines at Modum proved to be radio-active. In the fall of 1955 a short visit to the area was paid by Siggerud who located some radioactive anomalies.

The very location of those anomalies along the fahl-band and continuing in that same N-S direction down to Haugfoss, as well as the radiometric analyses which were carried out in the laboratory, made a detailed radiometric checking of the whole area highly important.

From the fifteenth of May until the end of June 1956, Siggerud, Skjerlie and Van Autenboer covered the area with scintillometer-readings looking for a possible Uranium deposit of economic interest; but also paying attention to U-mineralizations of scientific interest only. In the meantime student-real Wiik and technician Eriksen were occupied in checking the old open mine-pits. After the field-work in Finnmarken Van Autenboer returned and continued the work in the Northern part of the area until the end of October.

II [illegible]

One can mention the following reports, publications and maps.

1. Siggerud : Rapport fra den foreløpige undersøkelse etter uran på Modum (Oct. 1955).

   Diskusjonsforslag for planleggingen av det videre arbeidet i Modum.

2. Vokes : Report of inspection. (Feb. 1957)

3. Rosenqvist : Noen observasjoner omkring Modum kobolt-gruver. N.G.T. 1949 187-216

4. Beltzen : Undersøkelser av koboltforekomster på Modum (with maps over the disused Co-mines). 1952

5. [illegible] Poulson : Das Vorkommen [illegible] Mineralien in Norwegen. 1914

6. Olge J. Adamson : Cobalt occurrences in Norway June 1950

7. Bugge : Kongsbergfeltets geologi. N.G.U. 82

8. Neumann, H. : Silver deposits at Kongsberg. N.G.U. 162

9. Jüsang : Copy of the unpublished geological maps.

10. Jüsang : Verbal communication; Report Til det akademiske Kollegium Universitetet i Oslo.

11. Topographical maps 1:50.000 F 340 Tyristrand
F 350 Eiker

12. Geological map [illegible] Bugge. *Eiker.*

13. [illegible] of the German army.

14. Over the mines we utilized a certain number of old mine-maps (NGUs archives) and those of [illegible]eltzen.

III GEOGRAPHY and GEOLOGY.

1. Situation.

The investigated area was situated in the Modum district, roughly between Amot, [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], Svensbye, [illegible], [illegible], [illegible], [illegible], Sysle and Amot.

The principal Co-mines are situated on the Skutterud-area between the [illegible] and [illegible] Modum [illegible]distrikt. Claims were staked both by [illegible] and the Industri-department. The easiest approach to the mines is from V[illegible]. The distance along the road is approximately [illegible] km, and one is able to reach the Skutterud-mines with a four-wheel drive vehicle. To the north and south there are a series of prospects and claims. The mining for Cobalt went on from 1776 to 1898. On the [illegible] side of Snarum-river a few prospects were opened, but never attained any economic importance. Magnesite was mined in several places, such as [illegible]stadtjern, Butjern, Langerud and Lypingen and is still mined on a reduced scale. Some pegmatite-quarries were opened for mica during the war. At Hassel grube some iron has been mined.

d. Geology.

No geological mapping has been carried out by the NGU party, and for detailed information reference to the above-mentioned publications is made. The area belongs to the Kongsberg-Bamble formation, and the main rock-types are gneisses, different mica-schists, amphibolites and different quartzites. The main strike is north-south. Pegmatites cutting through the different rock types are observed all over the area. These pegmatites often contain relics of amphibolites and are considered as the youngest rock-type. Migmatites are observed near [illegible]foss. Two fahlband-zones, or mineralized shear-zones cut through the formation, one west and one east (the main zone) of Snarum river. The cobalt mineralization occurs in these zones.

Fahlbands.

Definition and description.

As the term fahlband is a German mining expression which has been controversed, the definition given by Bateman will be adopted. (1) A fahlband is a shear zone deposit, formed through the replacement of the sheared rock. Rupture and crushing in discontinuous patches expresses the fracturing of the rock. The rock in the zone is platy or schistose and commonly altered. The walls are vague and irregular, sheared rock merges into the unsheared and the intensity of the shearing varies from place to place. Shear-zones contain smaller openings parallel to the shearing, and this makes them excellent channelways from mineralization solutions. Shear zones favor replacement rather than cavity filling.

This definition can be entirely adopted as far as the [illegible] is concerned. It should be mentioned that break[illegible]

(1) Bateman "Economic mineral deposits".

perpendicular to the main [illegible] are observed. The fahlbands follow the main structures (N-S dir. nearly vertical). The rock is strongly impregnated along the fissures with sulphides which shows after altering a typical rust colour, which can be easily recognized. The geology and petrography of the fahlband have been studied by Rosenqvist (op.cit.).

Three different fahlband-zones can be distinguished : the Main fahlband, economically the most important, the East fahlband, and a few small rusty breccia-zones (10-15 m broad) further East (near Sandungen).

The Main fahlband-zone is about 10 km long and run approximately N-S, W of Snarum river. The maximum wideness is about 150 m.

It begins near [illegible] S-W of [illegible]tjern ending North of Svartfjell. It seems to follow the topographically higher situated places, and when it can be observed continuously between [illegible]tjern and the Skuterud mines, it cannot be found in the valleys, north of the Skuterud mines, in the valleys between [illegible] and Nordkollen, and Nordkollen and Svartfjell.

In the main fahlband-zone different fahlbands can be observed (three at Skuterudgruben : [illegible], Midtre and Vestre fahlband after Rosenqvist), and in these different ore-shoots can be distinguished.

Only a few prospects were opened in the Eastern fahlband, but attained no economic importance.

In the small breccia-zones further East no mineralization is known to occur except for a sulphide impregnation.

Between 1776 and [illegible] there was intense Co mining in this fahlband, and 40 mines and 80 quarries and prospects are located over the area. Beginning in the South there are the Skuterud mines, then the [illegible] mines and the Svartfjell mines in the North. The Skuterud mines are by far the most important. They are divided in the South mines, Middle mines and North mines.

IV THE SURVEY.

a. General outlines.

The radiometric survey was done in a scale of 1 : 10.000 which should be largely sufficient to detect any orebody of economic interest. In the beginning almost every outcrop was checked, while later more attention was paid to rocks in which a mineralization was more likely to occur.

The fahlband-zones, easily observed by their rusty colour, were checked wherever they were known to exist. Jösang's maps were useful for this purpose. Hydrothermal mineralizations containing Uranium minerals associated with Co and Ni sulfides and sulfoarsenides (and native Ag) are frequent and well-known. Thus the checking of the fahlbands with a known Co-mineralization was done carefully meter by meter, and the open pits were logged at regular intervals. The old addits, crosscuts and stopes were visited and checked as far as access, and elementary precaution did not forbid it. An attempt was made to locate the fahlband, in places where it had not been observed before. In this fashion the areas, W and E of Hutjern, N of Middagshvile, S of Nevdeskollen, N of Svartekollen and the fahlband on E Snarum were carefully looked over.

Special attention was paid to the old Iron mines near Snot, the pegmatites and the magnesite deposits all over the area. Attention was also paid to the claims which were numerous in the fahlband-zones.

b. Instruments.

The scintillometer (S.P.I.) proved to be the most sensitive and accurate, and in general the best all-round instrument, although some care in handling was required.

A logging-unit with 50 m probe was built in the laboratory and used for the checking of the old mine pits.

Different types of G.M. counters were used in the field and proved to be more useful than the scintillometer for taking samples.

A four-wheel driven car with built-in G.M. counter and recorder was useful for road-checking. It proved to be a good means of transportation, as it could be used on most of the forest-roads and thus made access to the mines possible.

A Pioneer drill was available and was tested on different rock types, in order to check its readiness for use in Finnmarken.

V [illegible].

Radioactive anomalies were discovered all over the area, but none of them proved to be of an economic interest.

The anomalies are pointed out on map, and will be discussed in detail :

a. Fahlband-zones.

The Fahlband-zones always present a radioactivity slightly higher than the surrounding rocks, as will be demonstrated later. All along the western fahlband (i.e. from Muggerud cinin over Skutterud-mines to Middagshvile and Svartfjell) radioactive zones were found, but they always proved to be very small zones of a few cm^2.

Muggerud.

Fahlband 0.05 MR/H_r with locally: 0.2 MR/H_r

Gneissic rocks in contact with the fahlband 0.015 - 0.01 MR/H_r

Kruthus.

Fahlband 0.04 and quartzitic gneiss at the contact with fahlband 0.04

Amphibolites - <0.025

Mellom Grube. south end. 1 MR/H_r

Svartfjell.

Tips 0.030 MR/H_r with locally .15 MR/H_r

. 1 MR/H_r

. 1 MR/H_r

.0.05 MR/H_r

In two places (at both ends of the Northern pit of the Middle Grube of the Skutterud mines) larger anomalies were detected. The first one at the south end is located where the adit (Verbepingstoll) cuts the fahlband-zone. The zone is about 5 m broad and presents a radioactivity up to 1 MR/H_r. The second one is situated at the northern end of the same mine, also in the fahlband and presents about the same radioactivity. Between the two places the fahlband has been mined for cobalt, no ore is left, and the radioactive anomalies are reduced to small spots probably due to a secondary enrichment. In both cases the uranium content is quite high (up to 3 kg per ton), but the ore which is present is of too small a quantity to be of possible economic interest. The tips coming from this mining area underlye tips of more recent mining periods and could not be checked. On the tips some Co-ore could be found, and these samples were generally radioactive.

Rosenqvist (op.cit.) gives a series of analyses showing a decreasing Co content with increasing depth. As far as the uranium is concerned, the anomalies seemed to be reduced to smaller zones or to pegmatite veins, when reaching deeper levels. The fact can also be added that the Eastern fahlband, topographically lower, was economically unimportant for cobalt, and showed a radioactivity only slightly higher than the surrounding rocks. The rust colour coming from the alteration of the sulfide impregnation is much less pronounced. The museum samples, rich in cobalt, were also rich in radioactive minerals. It seems obvious that a uranium mineralization took place together with a cobalt mineralization, and that the richest Co-mineralization was also the richest U-mineralization. It seems logical to assume that the ore mined for cobalt was also a radioactive ore. This fact will be discussed further on. As far as cobalt is concerned, no ore was visible in the mines, and the only mineral commonly observed was the secondary mineral erythrite. An other secondary mineral observed was malachite. No radioactive minerals accompanied these secondary deposits.

Radioactive samples were also found near the old mills at Haugfoss bridge and near Amot verk. Some of them proved to be non-treated ores, while others were slag-products. Small pieces of cobalt blue were not active. The sand in the bay downstream from the old ore mill at Haugfoss presented a slight radioactivity. The origin of this anomaly could be found in the products coming from the old ore mills. It might provide a faint indication about the solubility of uraninite if one considers the fact that the mill and the mining stopped simultaneously in 1890.

The results of the logging of the open pits are shown on the maps. The anomalies at both ends of the northern pits of Middle Gruben are clearly marked. The northern anomaly is explained by the intrusion of frequent pegmatites through the fahlband at that place. Vertically the anomalies seem to be irregularly distributed along the open pits, although these pits follow the main strike of the rocks.

Over the rest of the fahlbands some radioactive anomalies were found (at [illegible], Svartfjell, Haggerud skjerp) but in all the cases they were small zones of some square centimeters.

The Eastern fahlband presented a radioactivity as a whole only slightly higher than the surrounding rocks.

The attempt made to find the fahlband where it was not observed before was negative.

The radioactivity of the fahlband-rocks are mainly due to uraninite in cubic crystals, and in a minor extent to some monazite and zircon grains (with halo). The radioactivity of the altered rust-zones must be due to the uranyl ion retained by the gossan, as will be explained later.

b. The radiometric survey over the rest of the area took most of the time. Several anomalies were located, but checked more closely they proved to be small impregnation zones of no economic interest. Anyhow samples were taken, and the mineralization studied out of a scientific point of view.

These results will form the object of an ulterior publication. On the map the different localities are given. A short review of the different types is given.

1. The pegmatites, frequent all over the area (see map) very often contain radioactive minerals in the mica-rich zones. Containing relics of amphibolites, they are younger than the other rocks and must be considered as igneous, except perhaps for the migmatites near Haugfoss. The identified radioactive minerals in the most active zone observed were a Th-rich uraninite (up to 1 cm large grains) closely associated with kasolite. The kasolite also occurred close to the uraninite in thin folios between the mica-sheets. This mineral with

formula $3PbO3UO_3 3SiO_2 4H_2O$ is a seldom mineral, and it was compared with a sample of chinkolobwe furnished by Prof. J. Thoreau. The X-ray analysis showed an identical film (Debye Scherrer) for both samples. The mineral was highly radioactive and metamict, and this must explain the lower refraction index, (about 1,8 while for chinkolobwe n_p = 1,90 n_m = 1,91 n_g = 1,95) and the lower hardness. A spectrographical analysis showed the elements Pb,U,Si and the presence of Th,Y,Yb. Silicium was more abundant than the above mentioned formula would indicate. The mineral is soluble in acid with weak effervescence.

The presence of Thorium can be explained by some impurities of the uraninite with which the kasolite was intimely associated. As for the excess of silicium, we can mention a Kasolite-like mineral from Russia by name orlite which contains more silicium ($3PbO.3UO_3.4SiO_2.6H_2O$). No further information on this mineral is available. (1)

Some migration of the radioactive elements from the pegmatites (veins or bodies into the neighbouring rocks seem to have taken place. Some rocks present a radioactivity slightly higher near the contact with the pegmatites, (e.g. pegmatite veins/gneiss in Ludvig stoll. Pegmatite/amphibolite near Østeraasen). Some of the other U-mineralisations described later seem to express a hydrothermal phase of the pegmatites.

2. Brannerite bearing fissures in greenschists (near Haugfoss bridge.)

This was the first discovery of the Uranium-Titanium mineral in Norway, and reference to a published notice is made. (1)[2] Brannerite is a pegmatite or high-temperature vein mineral as the Thorium content shows. In this case a genetic relation with nearby pegmatites is accepted.

3. Uraninite-bearing fissures in amphibolite (valley S of Trekasthøyda).

The uraninite occurs in thin fissures in an amphibolitic rock, containing olive green amphiboles, biotite and zoisite, plagioclase, some quartz with undulating extinction, ilmenite

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(1) "Contribution a l'etude des mineraux d'uranium Francais" Chervet et Branche Nancy.

(1)[2] "Brannerite a new mineral in Norway" Van Autenboer and Skjerlie. NGU's year-book 1957.

with a leucoxene rim, some rutile. Secondary uranophane forms a cover over the rock. The uraninite occurs in small cubic crystals.

Pegmatites can be observed very near-by and also here a genetic relation seems probable.

4. Breccia (300 m N.E. of Laugfoss bridge on the N side of the river.

One to two meter broad breccia zones alternate with pegmatitic zones over 100 m. Massive pegmatites are observed close by. The brecciated rock, in which the Uranium mineralization occurs, is formed by equidimensional quartz grains, together with some rutile and anatase. In the more crushed quartz recrystallise as large crystals together with hematite and calcite. Calcite mixed with hematite form secondary deposits in the shear zones. Quartz and galena are found in geodes with a typical red color, while a pyrite and chalcopyrite impregnation provides the rock with a typical rust color.

The border between the pegmatite and the gneiss is obviously tectonic with observed pressing. The strike of the gneiss varies between N-S and N30W with a nearly vertical fall. Slide zones are visible having the same strike as the gneiss. The radioactivity is found mainly in small spots in the brecciated rocks. The scintillometer reads a maximum of 2 MR/Hr (on a flat surface) while in the pegmatites it was about 0.02 MR/Hr within small mica zones.

The anatase crystals seem to be radioactive and are spectrographically analysed. The fourvalent U^{+4} ion is known to substitute titanium in titanite e.g. (1) and could explain this anomaly. Another explanation could be provided by the well known fact that Uranium remains in solution until the ultimate stage of solidification, and can be finally deposited as a film on the surface of the grain. Leaching by dilute acids of as much as 40 % of the uranium content of some igneous rocks can thus be explained. Some of the U-content in the anatase can be leached out easily by weak acidic solutions.

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(1) "Principles of Geochemistry" Mason.

5. Breccia at Åmot Pukkverk.

(W side of Drammenselven near Embretsfoss factory).

A radioactive mineral was found in the calcite matrix of a breccia visible on the W side of a quarry. The breccia forming rocks (amphibolites, quartz- and mica schists) of the quarry are precambrian, but the brecciation can probably be counted for as Permian and as suggested by Dons (1) in relation with the formation of the W side of the Oslo graben. The breccia is visible over a maximum N-S length of some 100 meters. Precambrian pegmatites occur north, south and west of the quarry, but do not carry any radioactive minerals. Two Permian N-S going diabase dykes strike through the quarry. Coal blend is found in great amounts interwoven with calcite, quartz and chlorite in one place in the breccia. An hydrothermal origin of Permian age is admitted as at the origin of the coal blend in the breccia by Dons. The spectrographical analysis given by this author revealed Ca,Mg,Fe,Al, V,Ni,Mn,Mo and traces of Ag,Cu,Ti,Yt,Pb,Co. A carefully performed radiometric analysis revealed no radioactive material in the coal blend. The radioactive mineral is contained in round dark nodules in the calcite matrix of the breccia on the W side of the quarry. The nodules seem to be most frequent near the level of the quarry and are absent near the top.

The minerals in the radioactive nodules were ilmenite, rutile, some magnetite and a yellowish brown mineral giving a non identified X-Ray diagram. A spectrographical analysis of this mineral gave abundant Ti, Mg, and Si, some V and Yb, and traces of Fe,Ca,Na,Y. This mineral seems to be related with a mineral structurally close to ilmenite, Geikielite.

The radioactive mineral will be sent for X-Ray analysis. For this occurrence a Permian age as suggested by Dons for the coal blend seems to be the most probable. The neighbourhood of the Oslo area and the Permian eruptives do correlate this fact.

(1) Coal blend and Uraniferous hydrocarbon in Norway by J.A. Dons Norsk Geologisk Tidsskrift, 36 p. 248.

6. Magnesite.

Magnesite-serpentine deposits have been mined all over the area, and mining on a reduced scale is still going on. The deposits usually lay in contact with brecciated zones. An age-determination (after Jösang op.cit.) gave an early precambrian age for these deposits. Two of these deposits contain radioactive minerals. The first one in the quarry W of Overentjern was a 1 m^3 zone with a radioactivity up to 0.45 mR/H_r. The anomaly is located on the northern wall of the quarry in a brecciated magnesite zone. The second one in a quarry S. of Tingelstadtjern was only a few square cm. The radioactivity seems to originate in a red brown apatite. The fourvalent uranium ion is known to substitute the Ca^{++} in apatite and sphene where valence adjustment is permitted, as stated by Mason (1) and McKelvey, EL Everhart and Garrels (2). The Ca^{++} ion is replaced by the fourvalent uranium ion (respectively ionic radii 1.06 Å and 1.05 Å). The uranium is disseminated. Uranium can be leached from or introduced into apatite by ground water.

It forms from 0.00X % of primary igneous apatite and 0.00X % to 0.01X % of sedimentary marine apatite, while marine reworked apatite can contain up to 0.0X percent. (3) This substitution furnish a satisfactory explanation for the radioactivity.

No uranium was present in any of the other magnesite deposits, though apatite was found in other places (such as Butjern). This occurence was thus very local, and a uranium apport after the formation of the magnesite seems probable.

7. Fissures in amphibolites. (E.side of the road to Modum Verk (Haugfoss))

Some radioactive minerals are found together with rutile in an amphibolite underneath a house on the road to Amot Verk. The amphibolite is more or less brecciated. The radioactive mineral is separated and sent for X-ray analysis. A genetic relation with nearby pegmatites is probable.

(1) "Principles of geochemistry" Mason
(2) "Origin of U-deposits" Economic geology. Fiftieth Anniversary volume.
(3) "Uranium in apatite" Altschuler, Clarke and Young. Bulletin of the Geological Society of America. Vol 65 p 1225.

C. The laboratory work.

I. Qualitative Analysis.

The radioactive minerals were separated and identified after the general scheme : crushing; sieving; washing; heavy liquid separation; magnetic separation both with a hand-magnet and the Frantz-Isodynamic Separator; microscopical separation and identification. This identification was checked by means of X-Ray : at the Geological and Mineralogical Museum at Töyen. Further information was provided by spectrographical analyses (Institute for Atomic Energy). The radioactive minerals were traced step by step in their separation by radiometric analyses. The results have been given above. An important sample collection of Rosenqvist was checked with a scintillometer.

II. Quantitative Analysis.

Some fifty samples were taken and analysed radiometrically. The results are included. It should be noted that some of the samples are of pegmatites and do not represent an average sample. This is of course also true for the veins in amphibolites and for the breccia zones. These samples were later used as standards for other analyses.

No.	Rock	Locality	% e U_3O_8	Date
1	Gneiss	Tips near Krudthus	0,092	1/9
2	Gneiss	Near the open pit at the junction at Øster-tjern	0,021	"
3	Gneiss	-"-	0,022	"
4	Gneiss	-"-	0,05	"
5	Breccia	As No 3 to the N.	0,066	"
6	Breccia	-"-	0,032	"
7	Dark gneiss	On tip by the Jørgen Hugen stoll.	0,045	20/9
8	-"-	-"-	0,04	"
9	-"-	-"-	0,03	"

No.	Rock	Locality	% e U_3O_8	Date
10	Pegmatite	Tips northern open pit E of Sæthertjern	0,043	20/9
11	Pegmatite	The open pit furthest north E of Sæthertjern.	0,005	"
12	Pegmatite	- " -	0,036	"
13	-"-	- " -	trace	"
14	-"-	- " -	0,025	"
15	-"-	- " -	0,04	"
16	-"-	- " -	0,016	"
17	-"-	- " -	0,005	"
18	-"-	- " -	0,03	"
19	-"-	- " -	0,031	"
20				
21				
22				
23				
24				
25				
26	Gneiss	From tip at mine W of Sutjern.	0,043	21/9
27	Rust-zone	Mined in claim S of southern open cutting (Sutjern).	0,024	"
28	-"-	Like 27, but in the wall of the claim.	0,015	"

No.	Rock	Locality	% o U_3O8	Date
29	Gneiss	Claim S of southern open pit (Butjern)	0,031	21/9
30	Gneiss		0,37	"
31	Pegmatite	1 km from bridge at Haugfoss leading to V.spone Kpl. Modum.	0,023	"
32	Pegmatite	- " -	0,045	"
33	Amphibolite	E of local road leading into Modum verk	0,11	"
34	Amphibolite	W of local road leading into Modum verk	0,04	"
35	- " -	- " -	0,065	"
36	- " -	- " -	0,012	"
37	Greenschist	100 m. SW of crossing to Modum verk.	0,175	22/9
38	Breccia	Under the place right north on the other side of the river.	0,014	"
39	Ore	From the stamping mill right over the shop.	0,09	"
40	-"-	- " -	0,19	"
41	-"-	- " -	0,21	"
42	-"-	From the stamping mill right over the shop.	0,16	"
43	Amphibolite	Valley south of Trokasthöyda (354 m) Modum.	0,175	"

No.	Rock	Locality	% c U_3O_8	Date
44	Uranmerite fissures	300 m N of Haugfoss bridge	0,14	22/9
45	- " -	-"-	0,075	"
46	Gneiss	The beginning of E-running tunnel at shaft in Clarastoll.	trace	5/10
47	Gneiss	100 m from adit Clarastoll.	0,12	"
48	Glimmer-schist	Open pit north from prospecting tunnel.	0,075	"
49	Gneiss	Prospecting tunnel	0,043	6/10
50	Pegmatite	Lurvig ugen mine.	0,01	7/10

Four of the radiometric analyses were checked with chemical analyses. (IFA)

No.	Chemical Analysis	Radiometric Analysis
30	0.33 % U	0,37 % U
37	0.15 % U	0.175 % U
41	0.19 % U	0.21 % U
43	0.13 % U	0.175 % U

The radio-Uranium proved to be ~~slightly higher than~~ [illegible] the same as the chemical, which would prove that the Uranium family has attained equilibrium and is thus older than 10^6 years. (1)

(1) Rankama, Isotope Geology, p. 112.

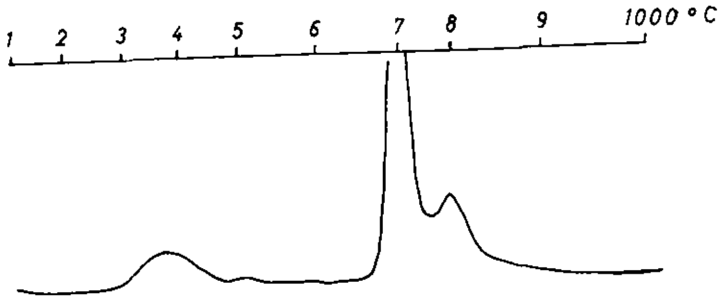
IV Differential Thermal Analyses, Autoradiographs.

D.T.A. analysis were carried out. (1). The Brannerite and Uraninite samples were from Rodum. Thorite from Langesund and Fergusonite from Evje were also analysed. The typical curve of Brannerite should be noticed. The exothermic peak at 700° was also observed on Euxenit, Samarskite, Yttrotantalite and Blomstrandin. (2). One of these exothermic peaks must be explained by the heat of recrystallization of the metamict minerals.

(1) Wilhelmsen (Jord-arts laboratory).

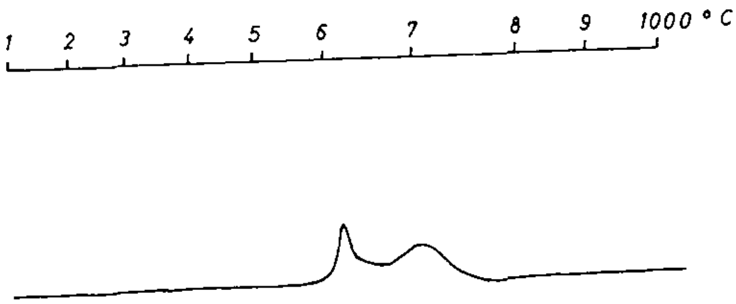
(2) Jord-arts laboratory archives.

FERGUSONITE



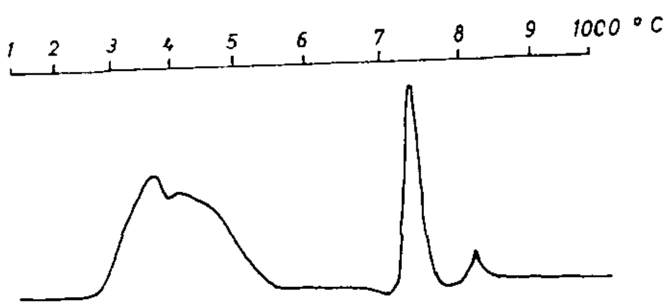
11/3 - 57
50 % Fergusonite
50 % Al_2O_3

THORITE



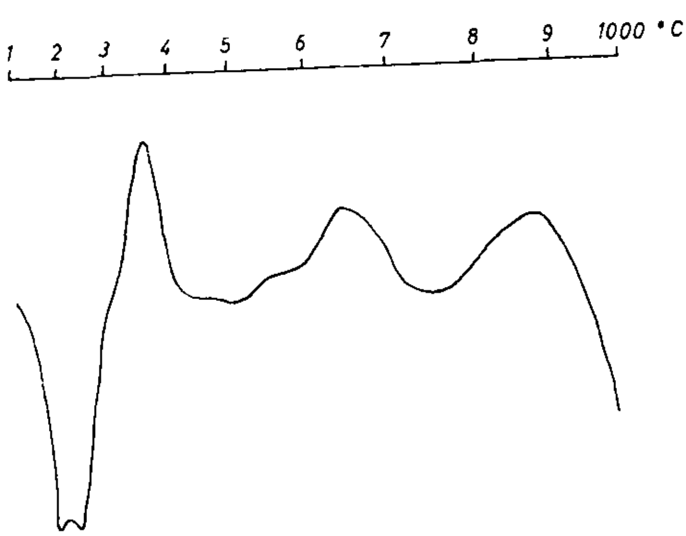
12/3 - 57
50 % Thorite
50 % Al_2O_3

BRANNERITE



22/2 - 57
1/3 Brannerite
2/3 Al_2O_3

URANINITE



8/3 - 57
100% Uraninite

13/3 - 57

Autoradiographs were useful to give an indication about the distribution of the Uranium crystals in the samples. Some autoradiographs are given here.

The Uraninite crystals are clearly marked on the sample of Nord-gruben. The sample from Middagskollen shows a linear arrangement of the Uraninite crystals along paralell to the shearing of the rock. The sample of Forhåpningsstoll shows clearly marked patches caused by Uraninite crystals, together with some weaker marked zones. The Uraninite crystals do not follow the shear-zones microscopically visible on the sample. The last sample (Mellomgruve - North mine) shows a concentration of uraninite crystals.

Nord grube

Middagskollen

Forhåpningsstoll

Mellomgruve   North mine

VI DISCUSSION OF THE ORIGIN.

A distinction between two different mineralization-ages is made. First the crystallisation of a late magmatic rest fraction in the Precambrian pegmatites together with the vein deposits expressing the hydrothermal phase. Secondly a Permian Ni-Co-U-mineralization of weaker shear zones underneath the horizontal Cambro-silurian strata now eroded. This age was also suggested by Vokes for the Cobalt mineralization; it provides us with a relation with the intrusives of the Oslo area, and the Kongsberg deposits.

1. The origin of the U-mineralization in the pegmatites presents no problem. The four-valent Uranium ions concentrate in the last magmatic fraction as suggested by the crystallisation of uraninite and other U-bearing pegmatite minerals. The oxidation of the insoluble U^{4+} ions gives the soluble Uranyl ion ($U^{+6}O_2$)$^{2+}$ which can be carried away in aqueous solution and deposited in veins by reduction into the U^{4+} ion.

The Th^{4+} ion is not oxidyzed into a similar soluble sexvalent ion, which explains its concentration in the magmatic phase and in high temperature veins, as well as its separation from Uranium as pointed out by the absence of thorium in low temperature-vein deposits and in secondary deposits. This explains the high Thorium-content in the Uraninite of the pegmatites and in the Brannerite, which is formed at high temperatures. (1)

O.M. Schoobnikowa gives a temperature of 700° for Brannerite (2).

Although younger than the other rocks, the pegmatites are considered to be Precambrian. An age determination by the Pb_{206}/U_{238} ratio method could give a serious indication.

The anomalies at the North end of North-grube on Skutterudflate can be explained by the frequent pegmatite dykes cutting through the fahlband at those places.

The other deposits supposed to be in relation with pegmatites as hydrothermal veins are the breccia at Haugfoss, the Uraninite bearing veins in the amphibolites south of

(1) Frondel "Mineralogy of Thorium" International conference on peaceful uses of atomic energy, vol. 6.

(2) O.M. Schoobnikowa, "Mineralii Urana i posledowatelenosti ich obrazowaniia." Akademicia Nacok S.S.S.R. 1946, p 75.

Trokasthöyca and the veins near Amot verk.

2. <u>The fahlbands</u>.

The fahlband-zones proved to be favourite zones for a Co-U mineralization. Cobalt has been mined, and the radiometric survey showed a higher background all over the fahlband-zones with much higher local anomalies. The richest mineralization seems to have taken place around Molken Grube. The old workings there reached a maximum depth of 120 m., and at both ends of this mine radioactive zones in the fahlband have been discovered. It seems probable that all the zone which was mined there was radioactive as pointed out before. Rosenqvist (op.cit.) publishes a series of analyses showing a decreasing Co content with increasing depth. The radioactive anomalies are also reduced in deeper levels in the mine. The Eastern fahlband topographically much lower was unimportant for Co, and the radioactivity is reduced to a background slightly higher than the surrounding rocks. (The rustcolor is also less pronounced). The location of the mines on higher levels and the negative result of the attempt to find the fahlband in the deeper valleys also point to a decreasing mineralization with increasing depth.

The radioactive minerals are represented mainly by Uraninite in cubic crystals with some monazite. Some zircon grains with a halo in the surrounding biotite crystals were observed. Uraninite is a typical primary mineral, monazite occurs preferentially in highly recrystallized sediments. Uraninite is the only four-valent Uranium mineral which is easily oxidized and destroyed on weathering. The U^{4+} ion is oxidyzed into the hexavalent state which is removed as very soluble. When the Uranium is associated with iron sulfides, the Uranyl ion may be retained for some time by absorption in the gossan. (1) Leaching of a rust-zone sample liberated about 20 % of the Uranium. This furnishes a good explanation for the radioactivity of the altered earthy zones of the fahlband. As far as the origin of the Cobalt is concerned, a secondary enrichment of a Precambrian deposit under a subcambrian peneplane was suggested by A. Bugge and reported by

(1) Origin of U.deposits McKelvey, Everhart, Garrels Ec.Geol. 50th Anniversary volume.

Rosenqvist (op.cit.). The decreasing Co-content and the elongated-shallow orebodies, apparently connected with the present erosion surface, led him to this conclusion. This same author asserts without further evidence that a series of Cobalt-bearing sulphides show irrequivocally a Precambrian mineralization. Vokes (op.cit.) draws attention to the fact that the mineralogy of the Co-ores is not one which could result of a secondary enrichment. Cobaltite, skutterudite, danaite, are primary minerals, and the only secondary Co-minerals observed are erythrite and asbolane. These minerals are present only in minor amounts.
A hydrothermal mineralization having a horizontal ore control is proposed. The deposition must also have taken place close to the present surface. This author proposes a mineralization occuring in Permian times, when the Cambro-silurian sediments (mostly impermeable shales) cover the subcambrian peneplane and form a horizontal controling-roof. A mineralization coming up the fahlband-zones (representing a zone of weakness) would be stopped by the roof and spread longitudinally along the zone. The result would be horizontal ore shoots, the roof being horizontal. Vokes points further to the paralellism with the Permian Kongsberg mineralization. Belonging to a Co-Ni-Ag metallogenetic province on the W side of the Oslo eruptive province, these two deposits would be connected with the emplacement of the Permian eruptives in this province. Measurements made by this same author only gave a slight evidence of a deviation of the overall N-S strike being connected with an ore-body (Southern open cast of Sörgruven). He also made an attempt to deduce any linear structures in relation with the ore deposition.

Two types of lineation, coinciding in direction were observed :

1. A preferred orientation of the elongated minerals (biotite and hornblende)

2. Grooving - or large scale slickensiding.

The lineation is everywhere slightly N-plunging (usually under 20°) with a marked culmination in Mellom-gruven, (with a 40°N plunging crest), and a depression S of the Baeraa stolle (with a 30°N plunging through.) Structurally this can be explained by the action of a couple (from an overriding pressure from the N) on rocks already possessing a N-plunging lineation.

Also quoting Vogt, the feeding channel could be situated underneath North Grube, and the N-plunging structure could be accounted for it. This theory is corroborated by evidence resulting from the observations made during the radiometric survey and the laboratory investigations. The following points should be stressed: -

First it should be mentioned that the minerals causing the radioactivity of the fahlband are typically primary minerals, as pointed out before. The association of Co and U has been shown above. An Ni-Co-U metallogenetic association is a well-established fact. A common origin for both elements must be admitted, and the evidence for a hydrothermal origin of the Modum ore seems to be conclusive.

The theory of deposition underneath flat-lying Cambro-silurian sediments is also confirmed by the observed facts. Decreasing U-mineralization with increasing depth can be explained as a result of the stopping of upwards moving solutions by an impermeable roof, by which process the richest ore will be lying immediately under the roof or close to the actual surface. The richest U-mineralization occurring underneath Middle-gruve could point to a feeding channel in this neighbourhood. In this case the Uranium mineralization seems to be decreasing more rapidly than the Co-mineralization in the longitudinal repartition of the ore.

As to a Permian mineralization age we can point to the U-mineralization in the breccia at Aust Fahlverk. This breccia and its mineralization is obviously Permian, and furnishes us with a relation between Co-U mineralization in the fahlbands on one hand and the eruptives in the Oslo province on the other hand.

A Permian age also provides a relation with the Kongsberg mineralization. No U-mineralization was found in these mines, but they seem to belong to a same mettallogenetic province on the W-side of the Oslo graben.

An age determination carried out upon the Uraninite of Mellom gruve would furnish a more absolute data.

VI. PROPOSALS FOR FURTHER INVESTIGATION.

From an economic point of view no further investigation of the cobalt mines or the other above described occurrences is proposed. The adjacent area to the W and the area E towards the Oslo-field could be checked radiometrically, but as this checking is a purely technical problem, no special geological knowledge is required of the surveyors. It could be carried out by students or local people under the direction of a geologist. It is the writer's opinion that an airborne survey by helicopter, followed by ground checking of the observed anomalies would reduce the expenditure with regard to the time factor. This applies to the search for an orebody of economic importance. According to Poulsson (op.cit) strongly radioactive water has been found in Jellum. A visit to this place is indicated.

From a scientific point of view an age determination would be most interesting. This could be carried out upon the uraninite of the Skutterudfåste. An ore-microscopical study should complete this investigation.

Tony Van Autenboer