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Tittel

Report on Colombium in the Søve Deposits at Ulefoss

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Bjørlykke Harald	11.11 1952	Norsk Bergverk as

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Geologi Geokjemi Malmberegning		Søve Tufte Hydrogangen Filadelfia Fen jengruver Cappelen forkomsten
Råstoffgruppe	**Råstofftype**	
Malm/metall	Cb, apatitt	

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

En engelsk oversettelse av BV 807.
Som konklusjon peker rapporten på at det er påvist 1,4 mill tonn i feltet, men at mulighetene for mulig og antatt malm er svært store , spesielt i områdeet for Hydrogangen og Tufte. Dette bør kunne gi grunnlag for et gruve anlegg med stor kapasitet.

Reports
on

Columbium in the Stve deposits at Ulefoss.

by

Dr.H.Björlykke.

Previous Reports and Publications :

4. W.C. Brögger : "Das Fengebiet in Telemark, Norwegen "
Vidensk.Selsk.Skr. I No 9 1921.

3. H.Björlykke : "Norwegische Mikrolithmineralien "
Norsk Geol.Tidsskr. B 14 pp 145-161 1934.

14. Egil Sæther : "Foreløbig meddelelse om resultat av undersökelser i Fensfeltet." Norsk Geol. Tidsskr.B 26 p.66 1948.

15. Egil Sæther : "Rapport over undersökelser i Fensfeltet" sommeren 1946. (1946)

12. G.Richter : " Geologischer Bericht über das Vorkommen von Kalksteinen mit Nioberzen im Fengebiet bei Ulefoss, südliches Telemark ." (1944)

2. Hans Aubert : " Identifisering av de Nb-Ta-førende mineraler i sövitt og forsök på deres magnetiske separasjon." Tidsskr.f.Kjemi, Bergv.etc.No.10 1947.

5. C.W.Carstens : "Rapport over Hydrogangen og Cappelengangen ved Ulefoss." 1944.

8. J.Horvath : "Nioh, Ulefoss." 1946.

1. Olge Adamson : "Report on the Columbium Occurrence of the Fen Region, near Ulefoss in Southern Norway. 1950.

9. Mittert : Bericht über die Befahrung des Kalk-Niob-Apatit-Vorkommens bei Ulefoss in Telemark 28/5-1943.

13. K.Stenvik, A.Kvalheim, E.Hvoslef Eide and K. Kristoffersen, Sövitforekomstene i Fensfeltet og deres utnyttelse 16.sept. 1946.

6. O.G.Gjösteen : "Laboratorieforsök med oppredning av sövitt."

10. Arth.O.Poulsen : Forekomstene av sövitt i Holla. 30 april 1943.

11. Arth. O. Poulsen :Foreløbig rapport over diamantboringene på Tufte, Ulefoss. 13/8-1943.

7. J. Horvath : Bericht über das Niob-vorkommen bei Ulefoss. udatert.

16. J.H.L. Vogt: Norges jernmalmforekomster. N.G.U. nr.51 (1910)

17. J.H.L. Vogt: Jernmalm og jernverk. N.G.U. no.85 (1918)

The Columbium deposits in the Fen area at Söve, near Ulefoss, Norway.

Location.

The Columbium bearing area at Söve covers about 6 square kilometers (3 km N-S and 2 km. E-W) and is situated near Ulefoss, a village of about 1000 inhabitants, at the shore of the lake Nor-sjö, (15 m.a.s.l.)

It belongs to the County of Telemark and the nearest harbour is the port of Skien, about 30 km by road in SE direction.
The lake Nor sjö is also connected with the sea by a river system of locks which can take ships up to 200 - 300 tons. The waterway down to the port of Skien is about 2¼ km.
The distance from Ulefoss to the railway Oslo-Kristiansand S. Junction at Lunde, is 10 km. and the distance Ulefoss-Oslo by road is about 170 km.

Ownership.

The ground of the northern part of the columbium-bearing ore area belongs to the Söve Agricultural School, owned by the County of Telemark.
South of this area two farm named TUFTE have been purchased by the Norwegian Government and now belongs to A/S Norsk Bergverk.

Topography.

The topography of the Fen region shows moderate relief with a maximum height of 160 m. The average height is 50 -70 m.a.s.l.

The greatest part of the area is covered with a heavy soil mantle of clay and morainic gravels and has been cultivated and used for farming.

Geology.

The Fen region has long ago attracted the interest of Norwegian Geologists because of the rare rocks which occur in this area.

In the year 1880 B.Cappelen gave a collection of samples of some of these rocks to the University of Oslo.
In 1908 the district was visited by the Norwegian Geologist Professor W.Werenskiold and in 1918 by Professor J.H.L.Vogt.

Vogt especially concentrated his study on the old iron mines in the area which have been in production from the year 1652 until 1927 when they were laid down.
In the year 1918 the geology of the area was studied by professor V.M.Goldschmidt. During his field work Goldschmidt also became aware of some small cubic crystals of a mineral apparently belonging to the pyrochlor group in the limestone in a quarry, (the Hydro Quarry situated on the shore of lake Norsjö

Later on the same mineral was found by microscopic studies of thin sections in many different rocks of the area.
Based on the field work of professor Goldschmidt and professor Brögger, a petrographical description of the rock was published by Brögger (1921)
This paper has become a classic work on alkaline rock areas.
The rocks of the Fen district differ very much in appearance and mineral composition from the common eruptive rocks.
Especially interesting are the calcite bearing rocks which according to Brögger are supposed to be eruptive rocks, formed by the crystallization of calcite bearing magmas.
To distinguish the eruptive limestone from the common limestones of sedimentary origin, this has been given the name of Sövite.
Also the other characteristic rocks of the area have been named after the farms in the district.

The chief characteristic rocks of the Fen area.

Carbonate rocks :

1. Sövite, a calcite rock which contains minor amounts of apatite, magnetite, silicates and columbium minerals.
2. Rauhaugite, an ankerite rock(composed of calcium, magnesium and iron carbonate) with apatite, magnetite silicates and niobates as minor constituents.
3. Rödberg, (red rock) a calcite rock which is red, coloured by fine dessiminations of hematite. In some parts of the rock the hematite is the chief mineral component forming iron ores.
These ores have been mined from 1652 up to recent years in many mines within the area.

Alkaline silicate rocks:

The most abundant alkaline rocks are the nepheline-bearing urtite, ijolite and melteigite.

Vibetoite is a rock which is almost entirely composed of pyroxenes and amphiboles.

Hollaite, is a carbonate-silicate rock chiefly composed of calcite and pyroxene.

The youngest rock of the area is the damtjernite which is a dark porphyr with large porphyric crystals of biotite in a finegrained matrix.

Fenite is a syenitic rock which especially occurs along the borders of the area and is supposed to have been formed by a reaction between the alkaline magmas and the surrounding gneiss.

In most of the rocks columbium minerals have been found by microscopic study of thin sections and many assays of rock samples of different rocks show small amounts of columbium.

However only the sövites have yet been subject to more systematic study of the columbium content.

The sövites occur as more or less dike-shaped bodies which seem to penetrate the silicate rocks with the exception of the damtjernite.

Also small veins of sövite occur abundantly within most of the silicate rocks of the area.

Along the borders the sövites use to be especially rich in silicate-minerals, mostly biotite and hornblende and show a gradual transition into the surrounding silicate rocks.

As a general rule the greatest content of columbium minerals are found near the border against the silicate-rocks and in the adjacent part of these.

Geochemistry.

According to Rankama the average content of columbium and tantalum in igneous rocks are calculated to 24 g/t Cb and 2,1 g/t Ta. The average abundance ratio Cb/Ta is thus 11,4. The Columbium ores at Söve contain about 0,1-0,2% Cb corresponding to 1-2000 g/t and thus representing an enrichment of about 100 times the average of igneous rocks.

The amount of Ta present in the Sövites is about 1-2% of the amount of Columbium and is about the same as the igneous rock average.

In his paper (4) Brögger has published the following chemical analyses of Sövite from the Hydro and Cappelen deposits :

1. Chemical analyses of an average sample of 50 kg from the Hydro Quarry. Analyst L.Thomassen.

2. Chemical analyses of a fine-to middle-grained " Schliere " poor in Silicate minerals . Hydro Quarry. Analyst L.Thomassen.

3. Chemical analyses of sample from Cappelen Quarry. Analyst L. Thomassen.

	1.	2.	3.
SiO_2	3.36	0.73	2.00
TiO_2	0.30	-	0.19
Al_2O_3	1.69	0.60	0.66
Fe_2O_3	6.13	0.53	2.44
FeO	2.99	0.67	2.06
MnO	0.31	0.28	0.29
MgO	3.10	2.83	2.25
CaO	44.35	50.47	48.72
BaO	0.10	-	0.04
Na_2O	0.04	0.01	0.02
K_2O	0.50	0.25	0.32
H_2O-	0.16	0.04	0.10
H_2O+	(0.34)	(0.09)	(0.10)
P_2O_5	3.26	0.95	3.38
$Cb_2O_5 + Te_2O_5$	0.80	0.78	0.82
CO_2	32.80	41.44	36.22
Cl	0.02	0.03	0.02
F	ca.0.28	0.08	ca. 0.29
S	0.42	0.29	0.51
SO_3	0.06	-	0.02
	100.81	100.07	100.45
H_2O+	0.14	0.09	0.10
	100.67	99.98	100.35

According to these analyses and microscopical study W.C.Brögger has calculated the mineral composition :

	1.	2.	3.
Calcite	67.65	79.91	74.46
Dolomite	6.37	13.34	7.45
Mica	8.61	2.05	3.84
Magnetite	8.oo	0.14	2.90
Tremolite	-	-	1.oo
Apatite	7.75	2.77	8.o1
Koppite	1.40	1.15	1.36
Pyrite	0.89	0.54	1.08
Barite	0.16	-	0.06
	100.83	99.90	100.16

An analysis of Sövite carried out by Forsvarets Forskningsinstitutt, analyst: Sv.Jarp, shows following results :

SiO_2	2.12 %
TiO_2	0.28 "
Al_2O_3	1.92 "
Fe_2O_3	6.28 "
Mn O	0.30 "
Mg O	2.44 "
Ca O	42.35 "
Na_2O) K_2O)	0.60 "
P_2O_5	3.84 "
CO_2	39.16 "
F	0.32 "
S	0.30 "
Cb_2O_5	0.32 "
	100.23

Chemical analyses of columbium ore concentrate also show small amounts of Thorium and rare earth elements.

The chief Sövite Occurrences in the Northern part of the area are the dike-shaped bodies, the Cappelen-dike and the Hydro-dike, and a large area of Sövite around the farm Tuftø.

Also numerous smaller dikes are known in the Northern part of the district.
Of these the Philadelfia dike west of the Hydro-Occurrence has been explored by 3 diamond drill holes.

The Nordsjö dike at the shore of the lake near the Cappelen deposit seems to be a part of this sövite body.
On the southern side of the Söve Agricultural School, near the farm houses also some smaller sövite dikes have been explored by trenches and diamond drill holes.
Farther South around the Tuftø farms the Columbium bearing sövite forms a large central body which seems to be the largest sövite body in the area.
However, this Sövite area is rather inhomogenous and built up by zones of Sövites with rather different mineral composition, and also small layers of rödberg(red rock) and Silicate rocks occur within the Sövite body. Especially has the central part of the area been explored by many trenches and diamond-drill holes.

The Western and Southern part of the area also exhibit large outcrops of Sövite of varying contents of Columbium. These have not, however, yet been subject to sufficient exploration.

The large area of rödberg in the eastern part of the district have been sampled with hand specimens and some of these show considerable content of Columbium.

Also many of the silicate rocks within the area are known to contain some Columbium minerals. Thus a ijolitic rock from Melteig in the southern part of the area according to chemical analyses (W.C.Brögger p.399) has a content of 0.70% $Cb_2O_5 + Ta_2O_5$.

The Mineralogy of the columbium bearing Sövites.

The pyrochlore mineral which was observed by professor V.M.Goldschmidt in the limestone of the Hydro Quarry was isolated by professor W.C.Brögger by dissolving the calcite in nitric acid, and the crystals were analysed by A.Rödland. The result of this analysis showed a content of 37% Ta_2O_5, 26% Nb_2O_5 and 13.84 % CaO and the mineral was according to this analysis classified by Brögger

as a microlite.

During his study of microlite minerals H.Björlykke (1934) also studied some samples of the supposed microlite mineral from the Hydro Quarry at Söve.
As the X-rays diagrams of this mineral did not agree very well with the other microlite minerals an X-ray spectrographical analysis was carried out and showed that the old analysis of Rödland was not correct as the mineral according to X-ray spectrogramme was chiefly a niobate of calcium with only very small content of tantalum. The composition of the mineral appears in this way like a mineral named Koppite which had previously been described from Kaiserstuhl in Germany where it occurred under geological conditions similar to those of Söve.
In 1947 F.Aubert by means of X-ray diagrammes also identified the Columbium mineral Columbite in columbium bearing sövites.
The Koppite mineral studied by Brögger and Björlykke had a yellow-brown colour and occurred in octahedral crystals.

Microscopical studies carried out last year on different samples of sövites show however, that this rock also contain some apparently cubic koppitelike columbium minerals which differ in colour and partly in crystal habit from the originally described koppite. The colour of this mineral differs from colourless to slight yellow and black. Samples of these minerals picked out under the microscope are now subject to a study by means of X-ray diagrams and chemical analyses.

The following minerals have been found in the columbium bearing sövites :
Calcite, $CaCO_3$, spesific Gravity 2,7, Hardness 3, Composition : 56 CaO and 44 CO_2. This mineral is the chief mineral component of the sövites. According to the chemical analyses also small amounts of iron and magnesium are present as carbonates.
Apatite, calcium-phosphate, Sp.Gr.3,1 - 3,2 H 5. The Apatite in the sövites is nearly a pure Fluorapatite.

Fluorite, CaF_2 Sp.Gr.3.2 H.Y. This mineral has been found by W.C.Brögger in thin sections of sövites.

Magnetite: Fe_3O_4, sp.Gr.5.2 H 6. According to chemical analyses the magnetite of the columbium ores contain 0.5 Vanadium.

Hematite Fe_2O_3, sp.Gr. 5,3 H 6. This mineral occurs in sövites as small thin plates.

Pyrite FeS_2, sp.Gr. 5,0 H.6 occurs in small well defined crystals mostly in cubes with striated faces.

Barite, $BaSO_4$, sp.Gr. 4,5 H 3.

Corundum, Al_2O_3 Sp.Gr. 4,0 H.9 occurs dessiminated in small colourless or slightly yellow elipsoidic grains without crystal outlines.

Rutile, TiO_2, Sp. Gr.4,7 H.6 has been found in some concentrate samples as small red coloured tetragonal crystals.

Silicate minerals :

Hornblende, Sp.Gr.2,9-3,2 H 5,5. 3 different hornblende minerals have been met with in ore concentrates and thin sections.

The most abundant is the tremalite which occurs in radiating columnar aggregates. The other types are green common hornblende and blue coloured sodiumrich amphibole.

Mica, Sp.Gr. 3,0 H 3. The most abundant mica is a biotite but muscovite also occurs in some types of sövites.

Topaz, Sp.Gr.3,5 H 8 is present in small amounts as small colourless crystals.

Zircon, $ZrSiO_4$, Sp. Gr. 4.2 H 7. The Zircon of the sövites occurs as small tetragonal crystals with well defined crystal outlines.

The occurrence of Lomonite and columbite in columbium minerals has been given by means of X-ray diagrams.

Lomonite, $Ce_2Nb_2O_7$ Sp.Gr. 4,5 H 5. This mineral usually occurs as well defined small octahedrons. Colour brown to gray. Luster adamantine.

Columbite, $FeCb_2O_6$, Sp.Gr. 5,3 H 6. Usually without crystal outlines. Colour black.

Besides these minerals the sövites also contain some Cb- minerals which differ in colour and partly also in crystal habit from the

originally described koppite.

Thus a black mineral which occurs in spinell-like crystals differs very much in composition and structure from koppite.

A preliminary chemical analysis of crystals of this mineral picked out under the binocular microscope shows content of about 76 % Nb_2O_5 and 6 % MgO. The Debye - Scherrer diagram showed nothing in common with that of koppite and the pattern does not seem to agree with a cubic lattice.
Also some colourless or slightly yellow crystals exist, which are perhaps, new columbium mineral species.

The study of these minerals is going on in colaboration of professor Ivar Oftedal, at the Mineralogical Faculty (Institute) of the University of Oslo.

In an approx. 50 % Columbium Oxide Concentrate produced from sövites, Civil-engineer K.Stokland has found 2.7 % ThO_2 in a Hydro-product, 1.5 % ThO_2 in the Cappelen product and 1.7 % in a Turte product.

The content of rare earth elements were about 0.5%.
These elements are supposed to be present as substitutions in the columbium minerals.
The Sövites are usually rather course-grained rocks. Microscopic study of thin sections shows that the calcite grains can be estimated to an average of about 2 mm in diameter and may in some parts of the rock be up to 20 mm.
The columbium minerals of koppite and columbite usually exhibit a poikilitic structure when studied in thin sections. The poikilitic inclusions are chiefly calcite and apatite. The diameter of the koppite and columbite crystals vary from 0.1 to 10 mm and may be estimated to an average of about 1 mm.

The magnetic crystals are usually larger than the koppites and show seldom a poikilitic structure.
The silicate minerals of mica and hornblende, form usually grains with a diameter of more than 1 mm. The average may be estimated to about 5 mm.

The apatite is visible under the microscope as rounded grains without crystal outlines. The diameters vary from 0,1 to 3 mm and may average about 0,2 mm.

Development work.

In 1940 the Norwegian Government became interested in sövites because of their content of phosphate, as the import of foreign phosphates were cut off during the war.
Professor V.M. Goldschmidt as the director of the State Raw-Material committee then, started some development work in the Söve area in collaboration with Norges Geologiske Undersökelse(Geological Survey in Norway) This development work included some diamond drilling and chemical analyses of phosphoric acid and columbium.
According to the report of the State Geologist Arth.O.Poulsen, six trenches in Tufte area were worked out and 30 samples were analysed.
At the same time the Norsk Hydro A/S, carried out some diamond-drilling in the Hydro Deposit under the directive of their consulting Geologist Dr. C.W.Carstens. According to this development work, the Columbium-bearing sövite ore of the Hydro-Deposit was estimated to 750 000 tons measured ore down to the level of Lake Nordsjö.
In 1943 the Germans became interested in the columbium content of the sövites. They started a survey of the area, and the Norweginn development work was stopped. The German development work was directed by the German firm I.G.Farbenindustrie A.G. Until the Capitulation in May 1945 the Germans had spent about 1. mill. Norw. kroner (approx. 140 000.- dollars) on the Söve project. They had planned to start the columbium concentrate production in the autumn of 1945.
The German development work included a great number of trenches, diamond-drilling and chemical analyses. They also carried out much researchwork to find a good method for the treatment of the ore.
After the war in 1945-46 the Statens Råstoffkomite(The State Raw-Material Committee) continued the development work in the Söve Area. The Geological research was directed by cand.real.Egil Sæther. According to his report, the available amount of ore should contain 680 000 tons phosphoric acid and 12000 ton Columbium.
In 1951, the ore deposit at Söve was transferred to the mining Company A/S Norsk Bergverk, which was started by the Norweginn Goverment, the same year.
Until Dec. 1951, Dr. Olge Adamson, worked as consulting geologist for the Söve Deposit, and after that time Dr. Harald Björlykke was engaged as geologist by the Company.

In the Spring of 1952, an extensive diamond drilling program was carried out in order to prove a sufficient tonnage of measured ore for a large mining plan, with production of 140 000 tons raw ore per year.

The development work has met with many difficulties as it is probably the first time that this type of Columbium Ore deposits have been subject to extensive development work, in order to plan production of Columbium Concentrates. No experience from previous work was therefore available.

The Geological formation of these Columbium ore deposits is also subject to different opinions among the geologists and very little knowledge of these types of ore was available beforehand.

As the Columbium minerals occur in very small amounts and often are very difficult to identify without microscopic study, the valuation of the ore must entirely depend on the chemical analyses. Thus numerous, costly chemical analyses had to be carried out to form a sufficient basis for an economic valuation of the deposits. Much stress has therefore, been laid on the analytical research work to get the analyses as correct as possible.

Table showing the development work in the Fen Area.

	Number	Total lenght.	Number of analysed samp.
Diamond drill holes:			
Cappelen deposit...	8	690.29 m	170
Hydro	23	2823.42 "	669
Filadelfia	2	167.36 "	23
Söve	4	421.60 "	125
Tufte	8	877.55 "	455
Total:	45	4980.22 m	1442

	Number	total lenght	Number of analysed samples.
Trenches :			
Cappelen deposit	5	135 m	90
Hydro	16	309 "	206
Filadelfia	2	35.5	17
Norsjö	2	60,5	17
Söve	4	241.5	71
Tufte	11	1045.-	707
Hotvedtbakken			8
Prestegårdshagen			4
Fen iron mines			6
Total :	40	1826.5	1126

Besides this, the German Geologist Richter has analysed 179 hand specimen samples from different places within the area. Until to-day the development work in the Fen Area, amounts to 4980 m. diamond drill holes and 1826,5 m. trenches.
In all 2747 samples have been analysed for Cb_2O_5, P_2O_5 and carbonates. For the most part of these samples both spectrographical and chemical determinations of the columbium oxide have been carried out. For many samples, two different assays of Columbium have been made to check the results.

HB/RA

The Cappelen Ore Deposit.

The Cappelen ore deposit forms a dike-shaped body of columbium-bearing sövite which outcrops in the Northern part of the area near the shore of lake Norsjö.

The ore outcrop has been exposed over an area of 5000 square meters.

The ore body strikes E-W with a varying dip from 30 - 60°.
The surrounding rocks are fenite and hollaite.
Usually the border of the sövite is especially rich in mica.

5 trenches across the outcrop have been sampled and assayed, each sample covers 1,5 m. In all 77 ore samples covering a total length of 115,50 m of the exposed ore have been analyzed for columbium phosphoric acid and carbonates.

The total length of the diamond drill holes amounts to 690,29 m.

Trenches and diamond drill holes at the Cappelen deposit.

Trenches:

	Length of ore	Ore Samples	Average % Cb_2O_5	% P_2O_5	% $CaCO_3$
1 C	43,50	29	0,357	3,41	75,0
3 C	13,50	9	0,310	3,78	75,5
3 C S	37,50	25	0,420	3,74	80,1
4 C	18,00	12	0,270	2,61	80,6
5 C	3,00	2	0,350		
	115,50	77	0,35	3,23	78

NB/RA 6.10.52.

Diamond drill holes.

	Section	Az.	Dip	Length of the hole Total	In ore	Number of ass.samples	Average % Nb_2O_5	% P_2O_5	% $CaCO_3$	Drilled by
C 1		330°	45°	40 m	16 m	30	0,240			A/S Norsk Hydro
C 2	C38	35,5°	30°	82,50 m	62,20 m	19	0.306	3.0	71.1	German
C 3	C38		70°	60.20		17	0.22	1.8	46.0	" the dates lost
C 4				120. -	64.00	32				" unknown locality
C 5	C1	NO	45°	86.45	27.50	31	0.44-0.34	4.0	66.0	A/S Norsk Bergverk
C 6	C4	NO	45°	58.- "	32.88	30	0.26-0.27	2.77	49.7	" " "
C 7				123.94	16.6	6	0.20	3.90	52.0	" " "
C 8				119.20	3.9	5	0.40	2.94	82.8	" " "
				690.29	223.68	170	0.33	2.93	60.3	

Average total 0.342 Nb_2O_5 3.05 P_2O_5 67 % $CaCO_3$

The mineral composition of the Cappelen ore.

According to chemical analyses and microscopical studies the mineral composition of the ore is calculated to average:

Calcite (included 1 - 2 % magnesiumcarbonate and iron-carbonate)	67 %
Columbium minerals (chiefly Koppite) .	0,4 "
Apatite	7.7 "
Magnetite and hematite	3.- "
Pyrite	1.- "
Barite	0.04 "
Rest, Silicate minerals, chiefly hornblende and mica:.....	20.86 "

Microscopic studies of the ore also show very small amounts of Rutile (TiO_2) Corundum (Al_2O_3, Zircon ($ZrSiO_4$) and Topaz.

The ore reserves of the Cappelen deposit.

The first calculation of ore reserves of the Cappelen deposit was carried out by the well-known Norwegian mining geologist Dr.C.W.Carstens in his report of Jan. 15, 1944.
His calculation was based on the data of 2 trenches and 4 diamond drill holes and gave a result of 135 000 t measured ore averaging 0,30 % Cb_2O_5.

In his report of 1946 the German geologist Horvath calculated the ore reserves of Cappelen to 120 000 t measured ore averaging 0,5 % Cb_2O_5.

The Norwegian geologist Dr. Olge Adamson has in his report of March 13, 1950 calculated the tonnages of the Cappelen deposit to 175 000 t measured ore with an average of 0,25 - 0,3 % Cb_2O_5.

In Dec. 1951 the Cappelen ore reserves were calculated by mining engineer N. Musmus to 300 000 t measured ore averaging 0,29 % Cb_2O_5 down to the level of Lake Norsjø.
In the spring 1952 two additional diamond drill holes were drilled in order to explore the ore body down to a level of + 50 m.
As, however, the dip of the dike was less than assumed, the diamond drill hole C 7 cut the footwall of the ore in a depth of + 20 m o.s.l.

According to the results of the new development work the tonnages of the Cappelen deposit may be calculated as follows:

Section C 3 S (and C 3).

Horizontal width of the ore in the trench	65 m
Length of the ore belonging to this section	30 "
Horizontal width of the ore in d.d.h. C 2	60 "
Depth of the ore proved by drilling	+ 4,5 m a.s.l.
Average level of the trench	31,5 " " " "

Vertical measured ore area in the section $\frac{65 + 60}{2} \cdot 36 = 2250\ m^2$

Volume of measured ore belonging to the section $2250 \cdot 30 = 67\ 500\ m^3$

HB/RA
6.10.1952.

Section C 1. (D.d.h. C 5 and C 7)

Horizontal width of the ore in the trench	56	m
Length of the ore belonging to this section	31	"
Horizontal width of the ore in d.d.h. C 7	35	"
Depth of the ore proved by drilling	+ 20	" a.s.l.
Average level of the trench	33	" " " "

Vertical measured ore area in the section $\frac{35 + 56}{2} \cdot 53 = 2411$ m^2

Volume of measured ore belonging to this section 2411 x 31 = 74 741 m^3

Section C 4 (D.d.h. C 6).

Horizontal width of the ore in the trench	41	m
Length of the ore belonging to this section	31	"
Horizontal width of the ore in d.d.h. C 6	41	"
Depth of the ore proved by drilling	+ 9,5	m a.s.l.
Average level of the trench	33,5	" " " "

Vertical measured ore area in the section 41 . 24 = 984 m^2

Volume of measured ore belonging to this section 984 . 31 = 30 504 m^3

Total ore reserves of measured ore in the Cappelen deposit.

Section	Measured ore Volume	Tonnage	Lowest level of measured ore
C 3 S	67 500 m^3	182 250 t	+ 4,5 m.a.s.l.
C 1	74 741 "	201 800 "	+ 20 " " " "
C 4	30 504 "	82 360 "	+ 9,5 " " " "
Total	172 745 m^3	466 410 t	

According to the previously mentioned calculated total average of 0,342 % Cb_2O_5, 3,05 % P_2O_5 and 67 % $CaCO_3$, the measured ore in the Cappelen deposit will contain a calculated tonnage of :

1 595 t	Cb_2O_5	(Columbian oxide)
14 225 "	P_2O_5	corresponding to 34 400 t apatite
312 495 "	$CaCO_3$	(Calcite)

As the Cappelen ore body has a rather irregular shape, it is difficult to calculate any amount of indicated ore. It is, however, reasonable to assume that the total tonnage may be proved to be considerably greater than measured.

The Hydro deposit.

The dike-shaped body of the columbium bearing sovite ore forming the Hydro ore deposit is exposed on the surface by 16 trenches from the Hydro Quarry on the shore of Lake Norsjö, about 550 m in SW direction where it peters out.
The average width of the dike is about 22 m and the total length of the trenches amounts to 309 m.
The ore body strikes about NE-SW with a dip varying from 40-70 ° in SE direction.
The surrounding rock is a red colored fenite which is syenitic rock supposed to have been formed by a metasomatic reaction between the alkaline magma of the area and the surrounding gneis.

In the depth, the deposit has been explored by 23 diamond drill holes with a total length of 2823.42m.
Besides these, a 118 m. long tunnel has been driven from the shore of Lake Nor-sjö in SE direction cutting the dike at a vertical angle. This tunnel exposes horizontal width of the ore of 53 m and has not reached the hanging wall of the dike. A horizontal diamond drill hole has been drilled from the face in the continuation of the tunnel and shows additional 3.89 m ore, before cutting the hanging wall. In this way the horizontal width of the ore dike amounts to 56.89. During the mining of the tunnel the ore was very carefully sampled and assayed. No work had yet been carried out to explore the supposed continuation of the dike in NE direction under the bottom of Lake Norsjö.

(see tables overleaf)

Trenches Hydro deposit :

Trench	Length of ore	Analysed ore samples	Cb_2O_5 Chem.	Average P_2O_5	Carbonates.
H6(9)	40.5 m	27	0.126%	2.56%	51.7%
H7(2)	22.5 "	15	0.108"	3.39"	48.3%
H8(4)	22.5 "	15	0.149"	2.50"	88.6"
H9(10)	24.0 "	16	0.136"	2.59"	53.5"
H10(5)	22.5 "	15	0.159"	2.74"	80.8"
H11	37.5 "	19	0.175"	2.60"	90.5"
H12	18.0 "	12	0.185"	2.98"	80.1"
H13	15.0 "	10	0.131"	3.43"	71.9"
H14	27.0 "	18	0.166"	2.84"	74.9"
H15	10.5 "	7	0.173"	1.84"	78.1"
H16	7.5 "	5	0.162"	1.54"	64.2"
H17	7.5 "	5	0.234"	3.57"	51.7"
H18	3.0 "	2	0.235"	3.43"	55.6"
Total :	249.0 m	166			
average:			0.152%	2.749%	75.5%

X)(see overleaf table

The Hydro Tunnel:

Lenght of ore	Number of analyses	Cb_2O_5	P_2O_5	$CaCO_3$
56.89 m	33	0.206 %	2.96 %	63.8 %

The total average of the Hydro deposit calculated analyses of trenches and diamond drilled holes gives: 0.177 % Columbium Oxide Cb_2O_5 (according to the chemical analyses) 3.29 % phosphoric acid (P_2O_5) corresponding to 7.8 % apatite and 66.1 % carbonate minerals, chiefly calcite.

Diamond drill holes Hydro deposit.

Drill hole	Section	Az	Dip	Length of drill hole: Total	Length of drill hole: in ore	Core recovery %	Average %: Cb_2O_5 Chem.	Average %: Cb_2O_5 Spectr.	Average %: P_2O_5	Average %: Carbonates	Drilled by:
H 6a (8)	H 6	309°	45°	79.30	30.0	51		0.21	4.88	70.0	The Germans
H 6b(22)	"	357°	45°	194.41	3.0	9	0.55		5.00	42.0	A/S Norsk Bergverk
H 7a (1)	H 7	309°	60°	62.20	35.0	16		0.274			A/S Norsk Hydro
H 7b (5)	"	309°	45°	104.50	33.50	23	0.153	0.207	3.07	87.0	The Germans
H 8a (2)	H 8	129°	30°	62.80	26.0	16		0.127			A/S Norsk Hydro
H 8b (6)	"	309°	43°	77.50	22.4	27	0.179	0.308	5.00	79.5	The Germans
H 9a (9)	H 9	140°	50°	110.20	19.27	27	0.15	0.28	6.13	81.0	A/S Norsk Bergverk
H 9b (7)	H 9	309°	45°	70.00	33.10	24	0.148	0.191	4.21	61.5	The Germans
H 10a (3)	H 10	145°	22°	97.75	56.0	36	0.255	-	-	-	A/S Norsk Hydro
H 10b(24)	"	365°	45°	192.14	4.98	7	0.15		4.10	48.2	A/S Norsk Bergverk
H 11a(10)	H 11	145°	50°	127.12	42.28	27	0.135	0.169	-	-	" " "
H 11b(13)	"		90°	257.0	26.04	08	0.15	0.18	3.64	50.0	A/S Norsk Hydro
H 12a (4)	H 12	145°	20°	81.37	39.4	16	0.277				" " "
H 12b(15)	"	325°	60°	97.02	30.55	28	0.20	0.26	4.02	72.1	A/S Norsk Bergverk
H 13a(14)	H 13	325°	60°	96.60	30.07	23	0.20	0.27	2.85	60.4	" " "
H 13b(16)	"	-	90°	312.27	38.20	93	0.25	0.26	3.43	77.0	" " "
H 14a(11)	H 14	325°	45°	100.00	31.00	34	0.231	0.20	4.66	55.5	" " "
H 14b(12)	"	325°	75°	110.70	43.00	67	0.140	0.155	1.76	32.0	" " "
H 14c(20)	"	321°	50°	134.56	36.51	14	0.20	0.18	2.36	37.0	" " "
H 16a(17)	H 16	361°	50°	79.44	13.68	12	0.348	0.425	3.17	45.3	" " "
H 18a(18)	H 18	360.80°	53.30°	99.88	14.71	16	0.30	0.25	3.43	46.0	" " "
H 18b(19)	"	362.60°	42.20°	72.72	22.69	15	0.268	0.32	3.06	64.3	" " "
H 18c(21)	"	365°	45°	198.94	5.69	12	0.17	0.31	2.84	74.3	" " "
"	"	"	"	"	5.58		0.36	0.52	3.88	88.8	
"	"	"	"	"	8.19		0.15				
					6.78		0.20		2.70	72.0	
Total				2823.42	658.42	683					
Average							0.191%	0.233%	3.61%	61.5%	

The Mineral composition of the Hydro dike.

The ore of the Hydro deposit differs from the Cappelen ore by being somewhat richer in dolomite and contains a less amount of magnetite. The mineral composition of a sample from the Hydro Quarry calculated by Brögger and cited before, does not agree with the average composition of the deposit. Especially is the amount of magnetite far too high.

According to the 669 chemical analyses and microscopic study of samples and drill cores from different parts of the ore body the average mineral composition of the ore may be estimated as follows :

Carbonate minerals (chiefly calcite)		66.1 %
Apatite		7.8 "
Columbium minerals		0.3 "
Magnetite	approx	1.0 "
Pyrite	"	1.0 "
Rest: silicate minerals (chiefly mica:		25.- "

Besides these, also very small amounts of hematite, barite, topaz and corundum have been observed in thin sections and ore concentrates. With regard to the silicate minerals the Hydro ore differs from that of the Cappelen deposit by being poor in hornblende and in some parts of the deposit the ore contains small amounts of chlorite minerals.

The columbium minerals also show some difference from those of the Cappelen ore.

The koppite in the Hydro ore is more uniform in appearance and crystal habit and have a light brown color. In some parts of the deposit columbit occurs more abundantly also.

The ore body of the Hydro deposit exhibit a marked zoning with a central part of white marble, composed of nearly pure carbonate minerals and a darker marginal zone with more silicates which often gradually change into the surrounding silicate rocks.

According to the analyses, the white, nearly pure carbonate rock is very poor in columbium minerals. Thus the richest ore is usually found in the silicate bearing sovites of the marginal zones.

The ore calculation is based on the mining of the whole width of the dike, and in this way the average content of columbium oxide is considerably lower than that of the Cappelan deposit.

If however, selective mining of the marginal zones is carried out the ore average will be considerably higher.

Also in a vertical direction the ore of the Hydro dike exhibits a distinct difference as the deeper parts of the ore body, according to the analyses of diamond drill cores are richer in silicate minerals, than the ore in the trenches.

Thus the average of carbonate minerals in the trenches is calculated to 75.5 % while the amount of carbonate minerals in the drill cores average 61.5 % carbonates.

Smaller dikes and veins of columbium bearing sovites occur abundantly within the fenites of the hanging wall.

The ore reserves of the Hydro deposit.

The first calculation of the ore reserves of the Hydro deposit was carried out by Dr. C.W. Carstens and gave as result a tonnage of 608,125 tons ore, averaging 0.21 % Cb_2O_5 down to the level of Lake Norsjö (15 m a.s.l.)
In his report of 1946 the German mining geologist Dr. Horvath calculated the Hydro ore to 600,000 tons down to the mentioned level and averaging 0.23 % Cb_2O_5. Dr.Olge Adamsen has in his report of 1950 calculated the tonnage of the Hydro ore deposit down to the level of Lake Nordsjö to 750,000 tons with an average content of 0.2 % Cb_2O_5 .

In December 1951 mining Engineer N. Museus calculated the tonnage of ore in the Hydro deposit down to the same level, to 590,000 tons, averaging 0.174 % Cb_2O_5.

In order to have a good margin of security, Museus calculated the average of the diamond drill holes, in such a way, that the missing drill cores within the ore body, were assumed to be without any content of columbium.

Since the calculation of engineer Museus was carried out, many new analyses of previously drilled holes have been available and in the spring of 1952, two additional holes were drilled in order to cut the dike in the level of + 50 m.a.s.l.

All analyses of the diamond drilled cores are now completed and a new calculation of the ore reserves in the Hydro deposit has given the following results, based on the ore area in each vertical section:

Section H6.

Horizontal width of the ore in the trench	28	m
Lenght of the ore body belonging to this section	20.75	m.
Horizontal width of the ore in d.d.h. 6 b	9.0	"
Depth of ore proved by drilling	110.0	"
Average level of the trench	35.5	" a.s.l.

Measured ore area in the section $\frac{28 + 9}{2} \cdot 110 = 2035$ m²

Ore area down to level of + 50 m a.s.l. $\frac{28+9}{2} \cdot 85.5 = 1582$ m²

Volume of measured ore belonging to the section: ..... 2035 x 20.75 = 42225 m3

Volume of ore down to level +50 m a.s.l. 1582 x 20.75 = 33526 m³

Section H7

Horizontal width of the ore in the trench	23.0m
Lenght of the ore body belonging to this section	23.5 "
Horizontal width of the ore in d.d.h. H7 b	42.5 "
Depth of the ore proved by drilling	58.0 "
Average level of the trench	41.5 "a.s.l.

Measured ore area in the section $\frac{425 + 23}{2} \cdot 58 =$ 1877 m²

Ore area down to level +50m a.s.l. $\frac{425 + 23}{2} \cdot 91.5 =$ 3007 m²

Volume of measured ore belonging to the section..... 1877 x 23.5 = 45528 m³

Volume of ore down to level of +50m a.s.l.: 3007 x 23.5 = 72168 m³

Section H8.

Horizontal width of the ore in the trench	22.5m
Length of the ore body belonging to this section	23.0"
Horizontal width of the ore in d.d.h. H8 b	22.5"
Depth of the ore proved by drilling	39.0"
Average level of the trench	50.0"

Measured ore area in the section 22.5 x 39 = 877 m²

Ore area down to level of + 50 m a.s.l. 22.5 x 100 = 2250 m²

Volume of measured ore belonging to this section : 23 x 877 = 20171m³

" " ore down to level of + 50 m a.s.l.: 23 x 2250 = 51750 m³

Section H9.

Horizontal width of the ore in the trench	28 m
Length of the ore body belonging to this section	19 "
Horizontal width of the ore in d.d.h. H9 a	28 "
Depth of the ore proved by drilling	43 "
Average level of the trench	54.5 m a.s.l.

Measured ore area in the section 28 x 43 = 1204 m²

Ore area down to level of +50 m a.s.l. : 28 x 104.5 = 2926 m²

Volume of measured ore belonging to section: 19 x 1204 = 22876 m³

" " ore down to level of + 50m a.s.l. 19 x 2926 = 55594 m³

Section H 10

Horizontal width of the ore in the trench	27 m
Length of the ore belonging to this section	19 "
Horizontal width of the ore in d.d.h. H 10 a	45 "
Depth of the ore proved by drilling	37 "
Average level of the trench	50 m a.s.l.

Measured ore area in the section $\frac{45 + 27}{2} \cdot 37 =$ 1332 m²

Ore area down to level of + 50m a.s.l. $\frac{45 + 27}{2} \cdot 100 =$ 3600 m²

Volume of measured ore belonging to the section 19 x 1332 = 24308 m3
" " ore down to level of +50 m a.s.l. 19 x 3600 = 68400 m3

Section H 11.

Horizontal width of the ore in the trench	29 m
Length of the ore belonging to this section	20.5 m
Horizontal width of the ore in d.d.h. H 11a	41 "
Depth of the ore proved by drilling	39 "
average level of the trench	53m a.s.l.

Measured ore area belonging to this section $\frac{41 + 29}{2} \cdot 39 = 1365\ m^2$
Ore area down to level of + 50m a.s.l. $\frac{41 + 29}{2} \cdot 103 = 3605\ m^2$
Volume of measured ore belonging to the section : 20.5 x 1365 = 27982 m3
Volume of ore down to level of + 50 m.a.s.l. 20.5 x 3605 = 73902 m3

Section H 12.

Horizontal width of the ore in the trench	19 m.
Length of the ore body belonging to this section	20.5"
Horizontal width of the ore in d.d.h. H 12b	32 "
Depth of the ore proved by drilling	57 "
Average level of the trench	53 m.a.s.l.

Measured ore area in the section $\frac{19 + 32}{2} \cdot 57 = 1453\ m^2$

Ore area down to level of + 50 m.a.s.l. $\frac{19 + 32}{2} \cdot 103 = 2626\ m^2$

Volume of measured ore belonging to this section 20.5 x 1453 = 29786 m3
" " ore down to level of + 50m a.s.l. 20.5 x 2626 = 53833 m3.

Section H 13.

Horizontal width of the ore in the trench	22.5 "
Length of the ore body belonging to this section	20 "
Horizontal width of the ore in d.d.h. H 13 a	30 "
Depth of the ore proved by drilling	50 "
Average level of the trench	52.5 m.a.s.l.

Measured ore area in the section $\frac{30 + 22.5}{2} \cdot 50 = 1312\ m^2$
Ore area down to level of + 50 m.a.s.l. $\frac{30 + 22.}{2} \cdot 102.5 = 2690\ m^2$

Volume of measured ore belonging to this section : 20 x 1312 = 26240 m3
" " ore down to level of + 50m a.s.l. : 20 x 2690 = 53800 m3

Section H 14

Horizontal width of the ore in the trench	50 m.
Length of the ore body belonging to this section	29.75 "
Horizontal width of the ore in d.d.h. H 14 b	60 "
Depth of the ore proved by drilling	60 "
Average level of the trench	53 m a.s.l.

Measured ore area in the section $\frac{60 + 50}{2} \cdot 60 = 3300\ m^2$

Ore area down to level of + 50 m a.s.l. $\frac{60 + 50}{2} \cdot 103 = 5665\ m^2$

Volume of measured ore belonging to this section 29.75 x 3300 = 98175 m^3

" " ore down to the level of + 50 m a.s.l.:29.75 x 5665 =168534m^3

Section H 16.

Horizontal width of the ore in the trench	10 m
Length of the ore body belonging to this section	39.5
Horizontal width of the ore in d.d.h. H 16 a	20 "
Depth of the ore proved by drilling	17 "
Average level of the trench	43 "

Measured ore area in the section $\frac{10 + 20}{2} \cdot 17 = 255\ m^2$

Ore area down to level of +50m a.s.l. $\frac{10 + 20}{2} \cdot 93 = 1395\ m^2$

Volume of measured ore belonging to this section 39.5 x 255 = 10072 m^3

" " ore down to level of + 50m a.s.l. 39.5 x 1395 = 54602 m^3

5.

According to the dates given for each ore section the total volume of ore will amount to :

Section	Ore Volume proved by drilling	Ore Volume down to level +50m a.s.l.	Depth of ore body proved by drilling:
H 6	42225 m^3	33526 m^3	+76 m a.s.l.
H 7	45528	72168	+16 " "
H 8	20171	51750	+12 " "
H 9	22876	55594	+13 " "
H 10	24308	68400	+13.25 "
H 11	27982	73902	+11 " "
H 12	29786	53833	+ 4 " "
H 13	26240	53800	+ 2.5 "
H 14	98175	168534	+3.25 "
H 16	10072	54602	+24.5 "
Total	347363 m^3	652563 m^3	

This gives a tonnage of :
347363 x 2.7 = 937,880 tons measured ore, and
652583 x 2.7 =1761,974 " ore down to level + 50 m a.s.l.

As given in the description of the ore sections the horizontal width of the ore increases with the depth.

Thus the average horizontal width in the trenches is 25.45 m while the average of the diamond drill holes amounts to 34.10 m.
With the length of 235.50 m used by the ore reserve calculations the horizontal ore area of the surface will amount to 235.5 x 25.45 m = 5993 m^2 , while the horizontal ore area given by the diamond drill holes will be 235.5 x 34.10 = 8030 m^2

This marked increase of the horizontal ore area towards the depth forms a basis for assuming that the ore body should continue with at least the same ore area down to a very considerable depth.

In fact the vertical drilled diamond drill holes H 11 b and H 13 b confirm this supposition as they are cutting the columbium bearing sövite ore down to 235 m and 260 m below the surface, respectively. The vertical position of these holes makes it impossible, however, to use these dates for calculating the horizontal width of the ore. It would in this way be reasonable on account of these dates and geological data to calculate as indicated ore, the ore volume down to a level of + 230 m a.s.l. giving an estimation of indicated ore of about 5 million tons.

As inferred ore may be classified an assumed continuation of the the Hydro dike farther down, beyond the +230 m level and the assumed continuation in NE direction of the dike under the bottom of Lake Norsjö.

This will give a considerable amount of inferred ore.

With regard to the content of columbium oxide, the assays from the trenches show an average content of 0.152 % Cb_2O_5 and 2.749 % P_2O_5, while the average of the diamond drill holes are 0.192 % Cb_2O_5 and 3.61 % P_2O_5. According to this the content of columbium oxide and phosphoric acid increases in the deeper parts of the deposit.

It is therefore, very reasonable to assume that the content of columbium oxide and phosphoric acid of the indicated and inferred ore volume will be at least the same as calculated for the measured upper part of the ore body.

According to the calculated average of 0.177 % Cb_2O_5 and 3.29 % P_2O_5 (phosphoric acid) the content of these components will amount to :

Measured ore : 1660 tons columbium oxide (Cb_2O_5)
30396 " phosphoric acid (P_2O_5)

The ore reserves down to level + 50 m a.s.l. : 3119 tons columbium oxide(Cb_2O_5
59969 " phosphoric acid (P_2O_5)

The Tufte deposits.

The Tufte deposits occur in a central, large sövite body around the Tufte farms, about 700 m.south of the Agricultural School. The sövite rock is chiefly exposed near the farm houses and in some small river valleys.

The average height of the area is 70-80 m a.s.l.
The sövite area of Tufte is chiefly composed of a central, white colored sövite rock with a marginal zone where the sövite contains many small dikes and "Schlieren" of rödberg, rauhaugite, and silicate rocks, mostly greenstone.

The rocks of the Tufte area in some places, exhibit a slight, very steep parallel structure striking N - S to NE-SW.
The mineralization of the sövite is rather variable with rich ores intercepted by sövites with a very low content of columbium.

The rich ore seems to be arranged in zones conform with the general structure of the area.

The area has been explored by 8 trenches and 11 diamond drill holes and the long drill holes T7 and T8 give a good geological picture of the sövite body and its mineralization. Some parts of the ore zone in the Tufte area represent the richest ore, hitherto found in the district.

Trenches and diamond drill holes of the Tufto deposits

Trenches		Lenght of ore	Ore samples	Average % Cb_2O_5 Chem. spec.	P_2O_5	Carbonates
T 1	2- 13	18 m	12	0.231	4.99	78.7
-	31- 38	12 "	8	0.186	4.39	87.0
-	74- 89	24 "	16	0.260	4.06	82.7
T 2	2- 27	39 "	26	0.207	4.37	83.5
T 3	23- 34	18 "	12	0.236	3.92	63.4
T 4	11- 20	15 "	10	0.538		
T 5	2- 6	7.5 "	5	0.302	2.30	73.0
-	51- 58	12 "	8	0.212	5.63	82.6
-	80- 83	6 "	4	0.205	3.12	83.0
-	92- 97	9 "	6	0.311	4.48	86.9
T 6	40- 45	9 "	6.	0.691	6.57	72.8
-	64- 72	13.5 "	9	0.320		
T 7	45- 67	34.5 "	23	0.247	3.33	72.5
-	117-126	15 "	10	0.229	9.42	70.5
T 8	32- 44	19.5 "	13	0.226	3.38	85.3
	Total:	252.0 m	168			
		Average:		0.247 %	4.62%	78.2%

Diamond drill holes.

D.D.h.	Dip	Ore zone	Lenght o/d.h. m.Total	m.ore	Number ore samp.	Average % Cb_2O_5 Chem.Spec.	P_2O_5	Carbonates.
T 1	30°	0 - 35	65.20	35.0	16	0.315	0.637	5.31	65.20
T 2	45°	0 - 6	50.20	5.50	14	0.19	0.40	4.42	74.0
T 3	30°	50 - 68.85	79.63	18.85	18	0.185	0.393	4.87	77.2
T 4	45°	40 - 56.20	61.90	16.20	13	0.243	0.460	5.83	83.3
T 5	45°	15 - 31.60	49.80	16.60	10	0.234	0.315	3.19	56.5
T 6	10°	16.08- 31.46	146.90	15.38	98	0.275	0.348	3.94	72.2
T 7	45°	20.20- 31.-	177.61	10.80		0.275	0.420	3.38	85.3
-		149.79-157.70			119	0.235	0.396	5.39	78.4
T 8	15°	0 - 56.90	246.58	56.90		0.174	0.203	3.32	63.4
-		108.65-135.50		26.85		0.170	0.233	2.54	61.3
-		182.80-209.20		26.40	164	0.210	0.279	3.22	82.0
-		218.70-225.10		6.90		0.182	0.263	3.72	74.5
	Total:		877.88	235.58	452				
		Average :				0.224%		3.93%	72.3%

Total average of trenches and drill holes: 0.232% Cb_2O_5, 4.21 % P_2O_5, 75% carbonate.

As will be seen from the tables of assayed samples from trenches and diamond drill cores, some of these show up to 4 different ore zones with intervening sövite poor in columbium. The whole core of the 246 m long diamond drill hole 78 has been analysed and is supposed to give a good picture of the sövite body.

The average content of the whole core amounts to : 0.118% Cb_2O_5, 4.66% P_2O_5 and 65.7% carbonates which probably will agree rather well with the average of the sövite area of Tufte.

The mineral composition of the Tufte ore.

According to the chemical analyses of trench samples and diamond drill cores, the sövite of the Tufte area is considerably richer in carbonate minerals than the Hydro- and Cappelen sövite. No analyses of the magnesium-and iron carbonate have been carried out, but according to the general appearance of the rock the average content of magnesium and iron as carbonates, may be assumed to be considerably greater than that of the Hydro deposit. The amounts of phosphoric acid is also considerable higher.

As no ore dressing test on a large scale has been carried out with the Tufte ore, we have no data for estimating the content of magnetite and pyrite. According to the macroscopic picture of the rocks the content of pyrite may be estimated to about the same value as the Cappelen, while the content of magnetite may be a little lower.

Thus the mineral composition of the Tufte ores may be estimated as follows:

Carbonates (incl.carbonates of magnecium and iron)		75%
Magnetite and hematite	about	2"
Pyrite	"	1"
Apatite	"	10.27%
Columbium minerals		0.4 %
Rest:silicate minerals,chiefly mica and hornblende		11.33
		100.-

In some of the richest ore zones in the Tufte area, the chief columbium mineral is a black mineral, which occurs in magnetite-like crystals, but differs from magnetite by being non magnetic. Some crystals of this mineral have been picked out under the binocular and been subject to mineralogical study.
A preliminary chemical analysis shows that it represents chiefly a magnesium columbate with 76 % Cb_2O_5. An X-ray diagram of the mineral powder does not agree with a cubic lattice.
The structure of the Tufte ore is very similar to that of the Hydro and Cappelen deposits.

The ore reserves in the Tufte area.

The exploration work hitherto carried out in the Tufte area is only preliminary and as the rocks are strongly covered with glacial drifts, we have not yet sufficient data for a more detailed geological picture of the area.
In this way it is difficult to combine the ore zones found in the different sections.
The special problem with this area is that it is built up of many ore zones within the same sövite rock complex and no relation between the ore zones and the difference in the composition of the rocks has yet been stated.
Thus the explorative work has not given sufficient base for calculating any considerable amount of measured ore.
However, the large width of the many ore zones and the geological observations make it reasonable to assume that this area will represent the largestreserves of probable ore in the district.

The Area between the Tufte- and the Hydro-Cappelen deposits.

According to the geological structure, the area between the Tufte and the Hydro-Cappelen deposits, is supposed to be built up of many dikes of sövite, striking E-W.

The outcrops within this area show that rocks are built up by layers of carbonate rocks and greenstones. Parts of the carbonate rocks are rich in magnesium and may be classified as rauhaugite. Also some smaller zones of redberg occur frequently. The carbonate layers are usually rather small and the content of columbium varies between wide limits. The area has been explored by some trenches and 4 diamond drill holes.

Trenches:

	Length Of ore	Ore samples	Average %		
			Cb_2O_5	P_2O_5	Carbonates
C and D	33 m.	30	0,365		

Diamond drill holes : Lenght of holes

	As	Dip	Total	In ore	Ass. samples	Average % Cb_2O_5	P_2O_5	Carbonate
S 1	157.65	37 °	125.1 m	12.5m	71	0.131		
S 2	138 °	29 °	121.5 "	5.5"	28	0.234	5.12	42.9
S 3			60.0 "	9.0 m	16	0.270	5.80	-
S 4			115.0 "	34.1 "	38	0.207	2.95	84.7
			421.6					

The Sövite area around Vibeto.

South of the Vibeto farm houses a sövite area of about 30 000 m^2 has been mapped.
From this area 23 samples have been assayed for Columbium.
The most abundant rock within the area is a white colored sövite with calcite as chief mineral component.
The assays of phosphoric acid show contents up to 9 % P_2O_5.
The content of columbium in the assayed samples is rather low, mostly less than 0.1% Cb_2O_5. Some analyses however, show 0.2 % and one single analysis shows 0.3% Cb_2O_5.
According to the results of the exploring work on the other deposits it is reasonable to assume that good columbium ores may occur near the border against the surrounding rocks and also that zones of good ore may be found within the sövite area.
An other sövite area of about 10 000 m^2 occurs about 100 m. south of the houses of the farm Rauhaug and also a small area SE of Vibeto. The sövite of these areas has not been assayed for columbium.

The area W of the Main road Ulefoss- Eidem:

This area is strongly covered with glacial drift, with only small outcrops of sövite but probably the underlying rock chiefly consists of sövite and is connected with the sövite body in the Tufte area.
At Prestegårdshagen the sövite has been sampled and assayed. These samples contained however, only small amounts of columbium.

The content of columbium in other rocks in the district:

Considerable contents of columbium have been found also in rauhaugite and redberg.
By further exploration of these rocks new deposits may be found.
Also some of the silicate rocks, especially the ijolites may contain zones with columbium ore.

Analyses:

Most of the samples and diamond drill cores have been assayed for columbium with both spectrographical and chemical methods. The chemical analyses for columbium and phosphoric acid have been carried out by the Institute of Defense (Försvarets Forskningsinstitutt) and by the Institute for Industrial Research (Sentral - institutt for Industriell Forskning)
The spectrographical assays for columbium have been carried out by The State Laboratory of Raw Materials (Statens Råstofflaboratorium). The spectrographical assays generally, show greater values than the chemical determinations. Much research work has therefore been made to explain this difference.
These investigations have given as result that by the method used for the chemical assays it is difficult to get a complete solution of columbium minerals. The checking of some of the chemical analyses shows that these are apt to indicate values which are approx. 10 percent too low.

As the chemical assays, according to Schultz's method now used, require much time and and are very costly, research work is going on to find new and cheaper methods for assaying the columbium ores. This work seems to have met with some success.

Ore dressing:

As the ore of the Söve Area contains considerable amounts of silicate minerals the burning of the ore did not seem to be a suitable process for recovering the columbium minerals.

Extensive research work has therefore been carried out by Docent M.Mortenson, at the ore dressing Laboratory of the Norwegian Institute of Technology in Trondheim. Mr. Mortenson is working out a method for mechanical concentration of the columbium minerals and the apatite.

This study has resulted in a combination of tabling, magnetic separation and flotation, giving a concentrate with more than 20 percent Cb_2O_5 and 50 percent apatite. The apatite will then be dissolved in nitric acid and used as phosphate fertilizer, giving a residue with more than 40 percent Cb_2O_5.
Further concentration of columbium by means of chemical treatment will also be possible if wanted.

Conclusions.

The exploration work hitherto carried out in the Fen district has given the following results:

Measured ore.	Tonnage	Average Cb_2O_5	Average P_2O_5	Amounts of Cb_2O_5	Amounts of P_2O_5	Amounts of Apatite
Cappelen deposit	466410 t	0.342%	3.05%	1595 t	14225 t	34700 t
Hydro " "	937880 "	0.177 "	3.29 "	1660 t	30856 "	75260 "
Total	1.404290 t			3255 t	44081 t	109960 t

The tonnage of possible ore in the Hydro deposit may be estimated to some 5 mill.tons.
In the Tufte area no ore reserves have been calculated as the geological structure is not sufficiently known.
According to the terms of the Mc Laughlin the Tufte deposits will be classified as partimensurate ore bodies as the ores are likely to extend much farther and deeper than the limits to which development can economically be carried out, and there is good reason to expect that new ones will be found within the area.
After our present knowledge from the exploration work hitherto carried out, it is reasonable to assume that the ore reserves in this area will turn out to be considerably larger than the Hydro-deposit. The ores of the Tufte area also show higher values in Columbium and phosphoric acid than the ore of the Hydro deposit.
Further ore reserves may be located in the other sövite areas in the district which are very little explored and those which have not been sampled at all. Also the large areas of rauhaugite and redberg may contain columbium ore bodies.
The amount of 1.4 mill.tons measured ore in the area, the large amounts of indicated and inferred ore, and the great possibility of finding new ore bodies, should allow the building of a mine plant of great capacity.

Oslo the 11th Nov.1952.

Harald Bugge