

AN OCCURRENCE OF UNUSUAL MINERALS AT BIDJOVAGGE, NORTHERN NORWAY

By

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Abstract.

A complex titanium mineral containing abundant vanadium, chromium, and iron is described. The distribution of minor cerium, yttrium and scandium characterizes the two phases of which the mineral is comprised. As associate minerals occur thortveitite, vanadio-rutile, vanadiochrome spinel, gadolinite, and euxinite. Microscopic, analytic (including microprobe), X-ray powder, and other data are given.

Introduction.

The Bidjovagge copper deposits, Pre-Cambrian in age, lie 40 km NNW of the village of Kautokeino in Finnmark, Northern Norway (Fig. 1), within a belt of predominantly volcanic, albite-rich rocks (Holmsen et al., 1957, Gjelsvik, 1957). These so-called greenstones in the vicinity of Bidjovagge are for the most part banded tuffs with associated diabasic sills. The hydrothermal chalcopyrite-pyrite-pyrrhotite-carbonate ore occurs in brecciated zones along a steep anticlinal limb consisting of albite fels, in part graphitic, and also apparently of tuffitic origin. Near one of the deposits is found a titanium mineral with complex and unusual composition. The investigation of this mineral in addition produced thortveitite, vanadiorutile, vanadiochrome spinel, gadolinite, and euxenite.

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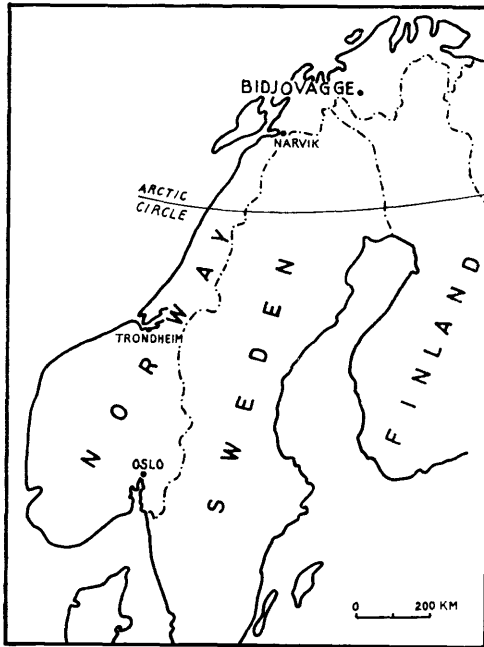


Fig. 1. Location map showing Bidjovagge.

Host rock.

The ore deposit locally known as A, from which the overburden has largely been removed, is confined to the light albite fels. Graphitic albite fels defines the hanging wall and a diabase sill the foot wall. Dividing the deposit in its upper portion lies a wedge of extremely hard, fine-grained, flint-like, light grey to reddish fels similar to the regional contact zone of the fels with the foot wall diabase. At the northern end of this wedge (local coordinates: 80N, 560E) and restricted to a few square metres are found the minerals described in this paper. The Bidjovagge area has been extensively investigated because of its ore and nowhere else there has a similar occurrence yet been observed.

Chemical analysis of the hard-fels (Fig. 2) embracing the minerals to be described shows 19.4 % Al_2O_3 , 10.8 % Na_2O , and c. 70 % SiO_2 , with several hundredths of a percent each of K_2O , CaO , and MgO , corresponding to 92 % albite. Differential thermal analysis shows $3\frac{1}{2}$ –4 % free quartz which occurs mainly as microscopic veins.

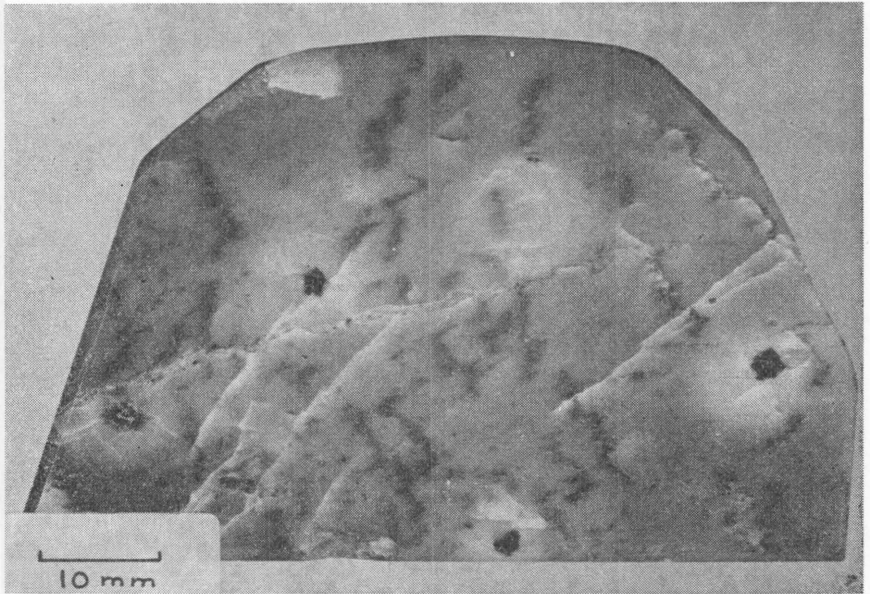


Fig. 2. Complex titanium mineral surrounded by reaction haloes in albite felds.
The dark stringers are vanadio-rutile.

Complex Titanium mineral.

Dispersed through the rock at intervals of several centimetres are seen 1–2 mm grains of a black mineral surrounded by reaction haloes (Fig. 2). The mineral has a metallic-adamantine luster, gives a black-brown streak, and is brittle.

In order to obtain a pure fraction a series of steps were performed involving crushing to a few mm, concentration by Carpco magnetic separator, selection of appropriate grains by pincette, grinding, and several stages of separation by Franz magnetic separator and heavy liquids. Table 1 presents an analysis of the mineral, where Ti, V, Cr, and Ce (and the total rare earths) were determined chemically and the remainder spectrophotically.

Grains of the mineral are seen to often consist of a center portion surrounded by more friable material. Usually these grains are not readily dissectable, but in one case it was possible to remove much of the friable envelopment, revealing a rather well-developed apparent octahedron (Fig. 3). In polished specimens the center portion often appears quadratic. Rarely the friable adherent has grown in such a way as to give the mineral

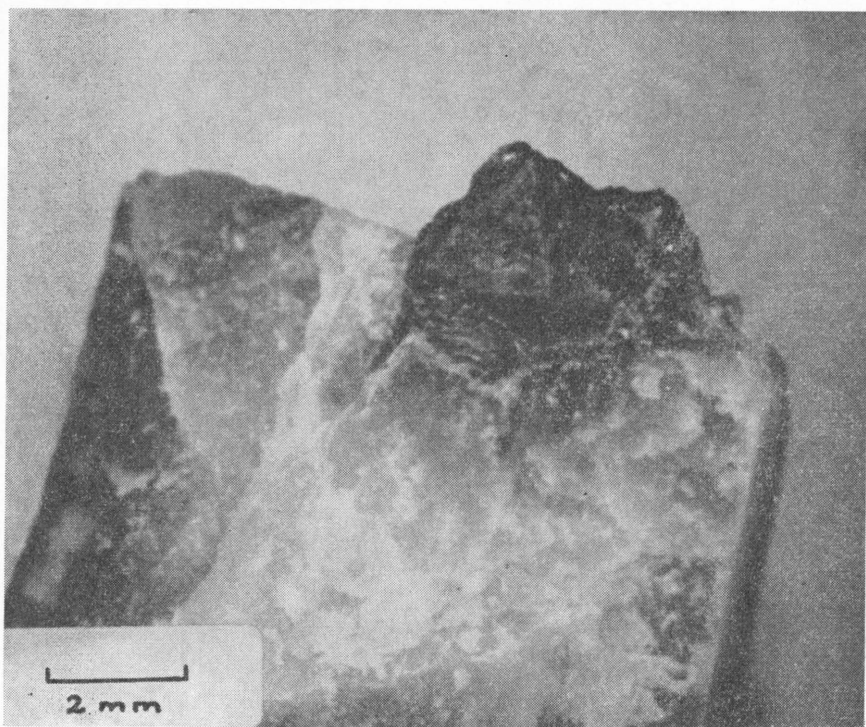


Fig. 3. Complex titanium mineral showing octahedral form.

a crosslike form (Fig. 4). Usually, however, this growth is rudimentary and deeply serrate, and completely surrounds the center portion.

Microscopically it is seen that the center portion is essentially homogeneous, bluish white in plain light, and isotropic. The surrounding material is banded parallel to the edges of the quadratic center and consists of two phases: a predominant phase creamy white in plain light and markedly anisotropic, interbanded with a phase similar to the center portion (Fig. 5). Microhardness and maximum reflectivity measurements vary somewhat because of the banding, but resemble the values for rutile, the isotropic phase being somewhat harder than the anisotropic phase.

Although in well-developed grains the center portion usually appears quadratic in section, the centers of other grains are more irregular as is the banding of the envelopment. In addition to banding parallel to the sides of the quadratic center, oblique banding (apparently twinning)

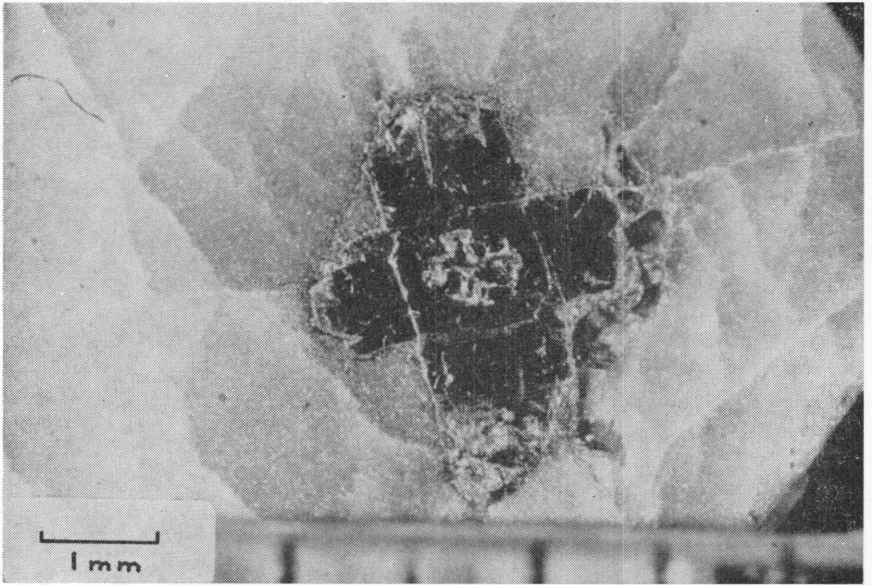


Fig. 4. Complex titanium mineral with cross-like development.

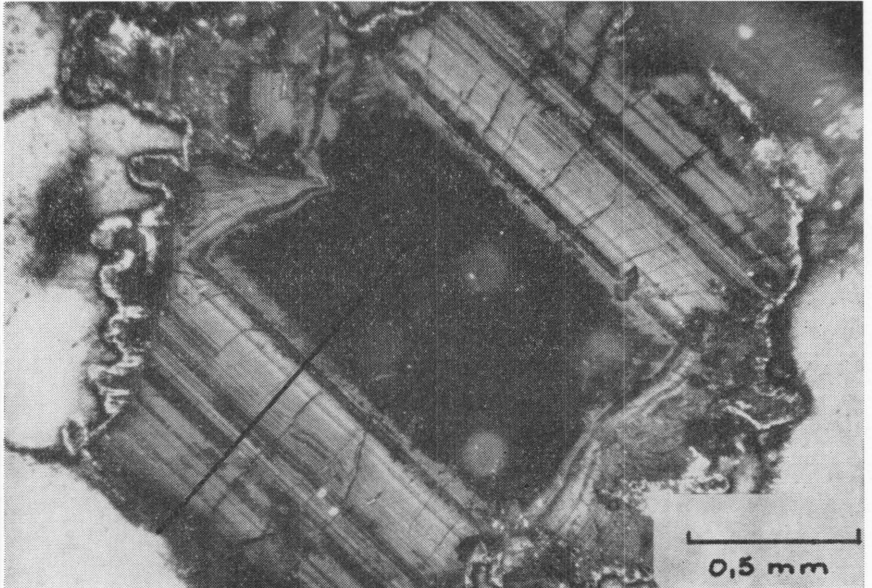


Fig. 5. Polished section of complex titanium mineral in polarized light, oil immersion.

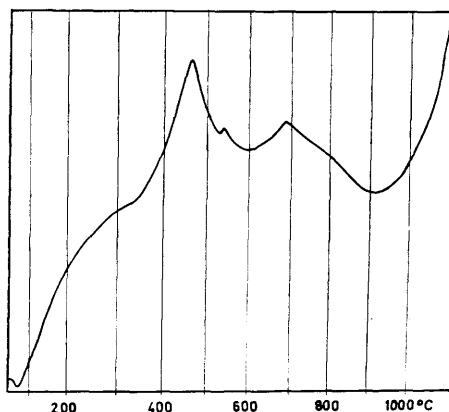


Fig. 6. *Differential thermal analysis of complex titanium mineral.*

may also be present, especially in the corners. Sometimes also the banding is distorted as seen in the NW and SE quadrants of Fig. 5. The banded portion of the mineral shows long traversal cracks not seen in the center portion, and the individual anisotropic bands show fine traversal cracks that do not extend into neighbouring isotropic bands. The anisotropic phase has thus apparently a greater coefficient of contraction than the isotropic phase, and it must be this phenomenon which causes the friability of the banded envelopment.

Within the mineral some inclusions of secondary rutile, quartz, chalcocopyrite, marcasite, and malachite have been found. Leaching has taken place. Along the irregular periphery of the mineral a rim of leucoxene has developed. Secondary open spaces often occur between the mineral and the fels. Within the fels adjacent to the mineral hematite has accumulated.

Separation of the mineral as previously described did not provide narrow limits for specific gravity measurement. Values vary from about 4.0 to 4.2, with increase in magnetic susceptibility parallel to specific gravity.

Differential thermal analysis of the mineral shows exothermal reactions at 470° and 690°C and an endothermal reaction at 900° before sintering begins at 1000° (Fig. 6). The reaction at 470° appears to be due to the contamination of a small amount of sulphides. (Note sulphur content, Table 1.) Polished sections heated to 500° show no apparent change in comparison to unheated sections. At 700°, however, the mineral has

recrystallized to a myriad of extremely tiny grains of rutile, though banding and anisotropy are still recognizable. At 900° the banding and anisotropy has completely disappeared and the recrystallization is slightly coarser. Near the periphery some grains of a grey unidentified mineral have also formed.

X-ray data on microscopically selected fractions of the mineral are presented in Table 2. The first column are the measured $d\text{\AA}$ values for the banded phase of the mineral and the second column the $d\text{\AA}$ values for the central isotropic phase. Subtracting the values of the second column from the first gives the values in column three which presumably represent the anisotropic phase. Identical films were obtained for each of the phases on unheated material and material heated up to 600°. At 700°, however, both phases gave a typical rutile film. (Material heated to 1300° also gave a rutile film.) This transition corresponds to the D.T.A. exothermal reaction at 690° and the observed recrystallization of heated polished specimens. Attempts to obtain X-ray single-crystal data on tiny fragments were not successful.

In order to determine the distribution of various elements in the mineral, investigation by microprobe was undertaken. Several grains were studied with very similar results. The grain described below is shown in Fig. 5. In this case the banding is well developed in one direction and poorly in the other. The probe path runs normal to the banding from near the midpoint of the grain in the quadratic center portion, through the banding, and into the surrounding fels. The distribution of six elements, V, Cr, Fe, Ti, U, and Ce, is shown in Fig. 7. The left side of the figure is a composite of oscilloscope photographs of inverse electron images and shows the probe path, with the mid-point of the grain at the top. Approximately 30 % of the path traverses the isotropic center (0–0.29 mm) before the first band is met. The distribution of V, Cr, Fe, and Ti is given in percent. As standards for Ce and U were not available at the time, the distribution of these elements is relative.

It is seen that the contents of V, Fe, and Ti show no apparent gradient across the mineral, whereas the content of Cr in the central area is approximately twice that of the banded area. None of these elements show correlation with the banding, although the distribution of V is more erratic in the banding. Ce is high in the central area, and in the banded area it slavishly follows the banding, with minimal concentration in the dark (anisotropic) bands and maximal concentration in the lighter (isotropic) bands. (In an inverse electron image the lighter the

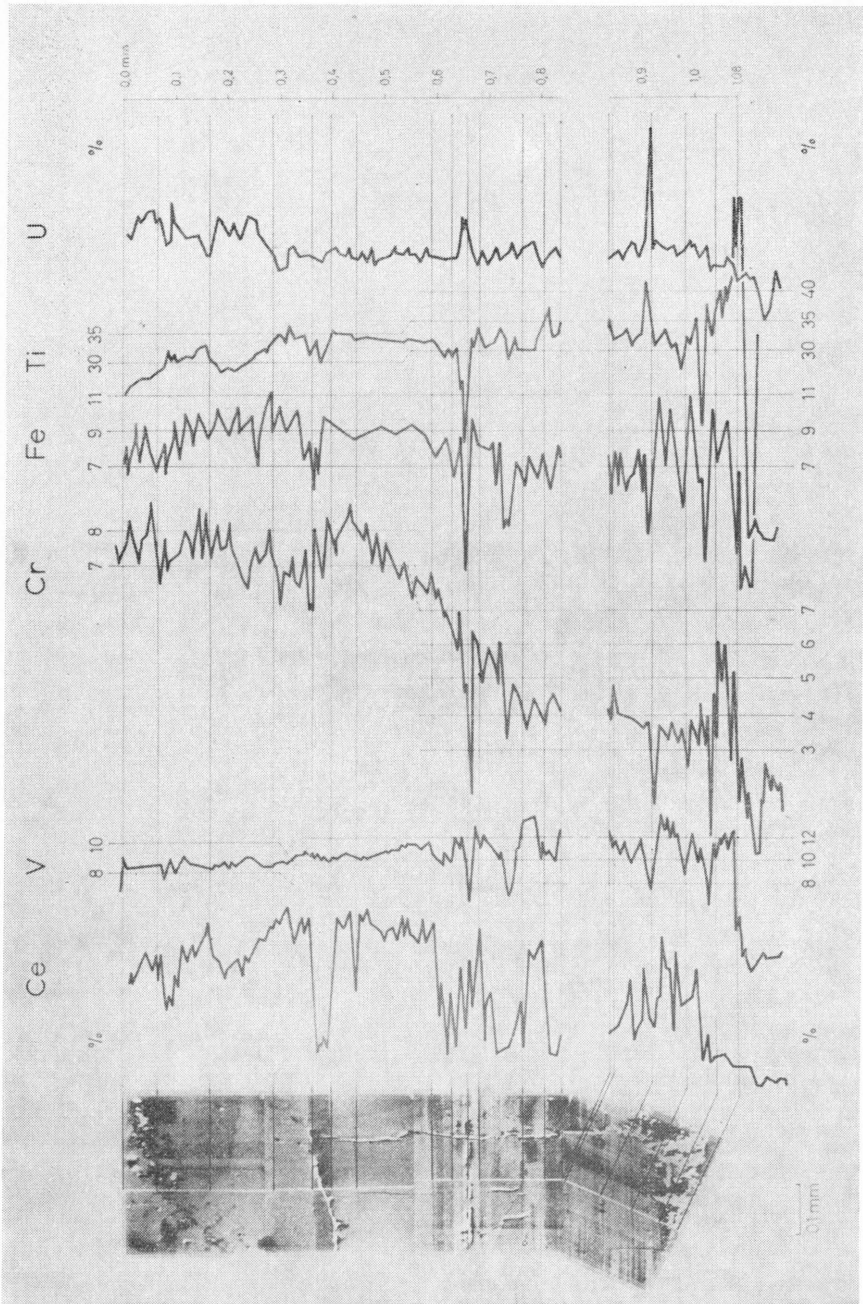


Fig. 7. Distribution of Ce, V, Cr, Fe, Ti, and U in complex titanium mineral as determined by microprobe.

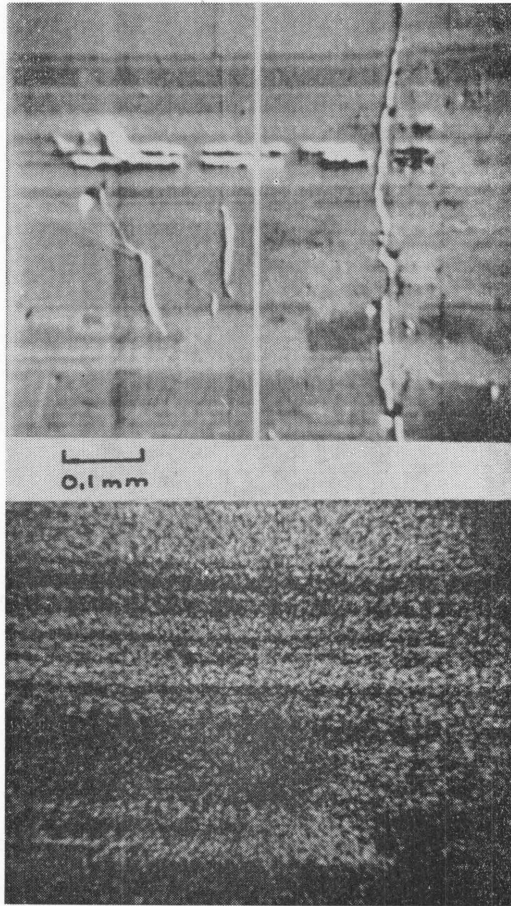


Fig. 8. Distribution of Ce in complex titanium mineral as determined by microprobe. The upper photo is an inverse electron image, the lower a Ce scan.

shade the higher the median atomic number.) Fig. 8 shows an inverse electron image of a portion of the banding (third photo from the top in Fig. 7) and a Ce scan for the same area. The distributions of Y and Sc was determined to closely parallel that of Ce.

In order to obtain quantitative values for Ce, Y, and Sc, standards were prepared using measured quantities of the oxides of these elements in $\text{Li}_2\text{B}_4\text{O}_7$ flux. Microprobe analyses were made at 0.38 and 0.43 mm (Fig. 7), in and outside the banding respectively. Reconnaissance showed these areas to be quite representative of the two phases. The results are

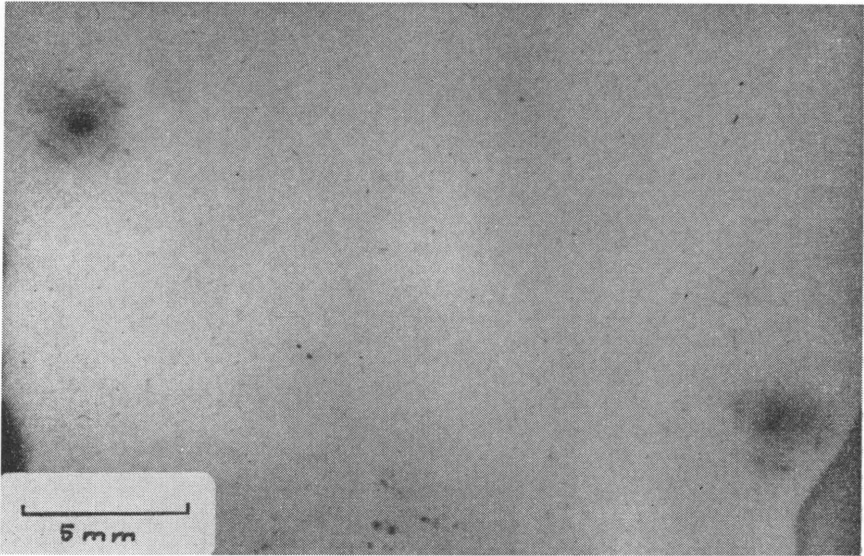


Fig. 9. Auto-radio exposure of polished fels containing two grains of complex titanium mineral.

shown in Table 3, and are compared to the general analysis taken from Table 1. The totals are low, at least in part because not all constituents were measured.

As may be seen, the values for Ce and Sc lie considerably above those obtained in the general analysis. A control spectrographic analysis of a fraction of the original material made at the Institute for Atomic Energy at Kjeller showed 1.6 % Ce, 0.23 % Y, and 0.56 % Sc (0.61 % Sc by neutron activation), and is included in Table 3 as oxides. The values for Ce and Y here obtained compare favorably with the microprobe results. A divergence, however, exists with respect to Sc, especially since Sc is also involved in the thortveitite to be described. It is possible that the content of Sc in the well-developed grains examined is not completely representative for all grains. Although the general analysis, Table 1, shows some Sr, interference prevented determination of the distribution of this element.

U is dispersed in small quantity throughout the mineral and as well occurs as discrete grains. These grains are concentrated mainly at the center of the mineral (small white spots at the top of Fig. 7 not traversed by the probe path), but also between certain bands near the edge of

the mineral as at 0.92 mm. (A slow traverse speed was used to achieve the peak at 0.92 mm. Reduced speed at 0.65 mm would likely have produced a similar peak.) Fig. 9 is an auto-radio exposure on X-ray film of a surface containing two grains of the complex titanium mineral. The grain on the left is the same as that shown in Fig. 4. Due apparently to the concentration of U in the centers of grains these centers are often pitted, as seen in Fig. 3 and less clearly in Fig. 5. It was determined that Pb closely follows U of which it is likely a decay product. Th accompanied by a little U is found to be concentrated in the walls of radial cracks near the periphery of the mineral. (The walls of these cracks thus appear white in inverse electron images.) It is apparently because of the effects of U and Th that bleached haloes occur around grains of the mineral, as seen in Fig. 2.

The complex titanium mineral described above defies simple classification. It is evident that the mineral comprises two phases, an isotropic phase enriched in Ce, Y, and Sc, and an anisotropic phase containing less of these elements. The X-ray data obtained was not identifiable for either phase. It is also evident that both phases invert to rutile at about 700°C. A relationship between this mineral, especially the isotropic phase, and davidite (which is also isotropic in reflected light) may be considered. But, aside from a certain resemblance in chemical composition, the accumulated data does not convincingly indicate this to be the case. A relationship to the vanadio-rutile in the surrounding fels, described subsequently, is, however, distinct.

Thortveitite.

While examining by microprobe other grains of the complex titanium mineral for consistency of results, thortveitite (Schetelig, 1922) was discovered. It occurs as a thin discontinuous shell along the periphery of grains of the titanium mineral, and is secondary to the development of its host (Fig. 10). Since this deposition is no more than a few hundredths of a mm in thickness it was not possible to obtain material for X-ray powder determination. Table 4 presents two microprobe analyses (Analysis 1 relates to the zone seen in Fig. 10) and compares them with an analysis from Eptevann, South Norway (Marble and Glass, 1942). It is seen that the rare earth content of the Eptevann thortveitite is higher than that of the Bidjovagge variety in which the cerium lanthanides were not detectable. Vlasov (1964) cites Zr and Hf analyses

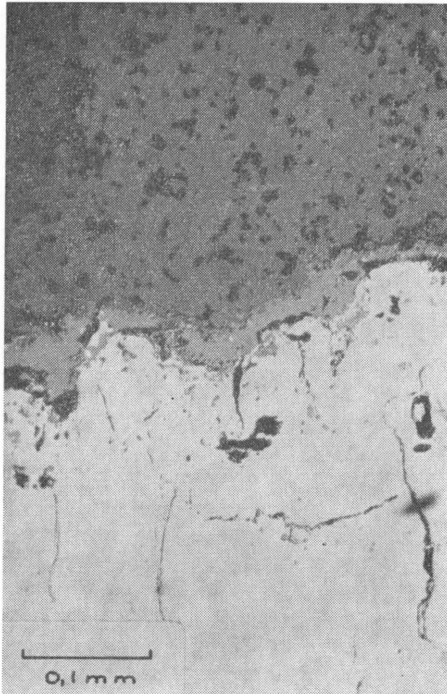


Fig. 10. Polished section of complex titanium mineral with rim of thortveitite.

from Norway and Madagascar of about 1 % for each of these elements. Neither Zr nor Hf were detectable in the Bidjovagge variety. Several tenths of a percent Zr may nevertheless be present, since the presence of Sc and Fe interferes with this determination.

Vanadio-rutile.

Within the fels containing the complex titanium mineral described above are observed in polished specimens sinuous stringers of a finely divided dark mineral (Fig. 2). From a screened fraction of the crushed fels a quantity of material was collected by pincette, which under a binocular showed no trace of the complex mineral or its reaction halo. This material was ground and subject to magnetic separation. The concentrate was finely pulverized and centrifuged in heavy liquid, sp. gr. 4. The heavy fraction, whose specific gravity was determined to be 4.3, gave an X-ray powder film typical of rutile. A combination of ordinary spectrographic and microprobe analyses gave the results shown

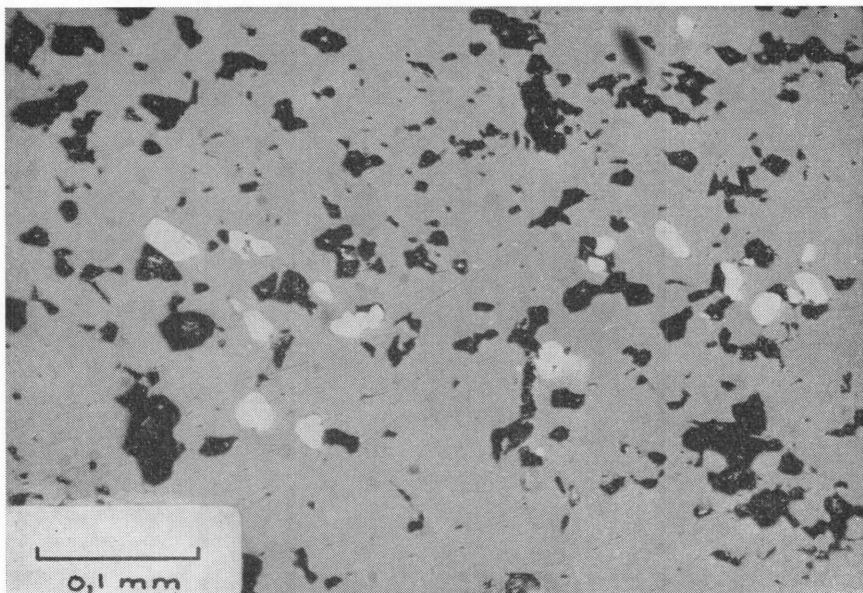


Fig. 11. Polished section of fels with vanadio-rutile.

in Table 5. (Microprobe analyses are given in parantheses.) Contamination of iron in the crushing process may explain the divergence between the spectrographic and microprobe analyses for this element.

Microscopically this mineral is seen to be completely opaque and subhedral to anhedral in form (Fig. 11). The colour of the mineral resembles closely the anisotropic bands of its complex companion, as does the anisotropy and bireflection. Under higher magnification the inner reflex characteristic of rutile is conspicuous. Minute inclusions of higher reflectivity appear to be chalcopyrite, as the spectrographically determined copper would also indicate.

As may be seen from Table 5 this rutile is of unusual composition. (Cases in which vanadium has been reported in rutile the content is never more than a few tenths of a percent.) Aside from the physical relationship between this rutile and the complex mineral described previously and the optical similarity to the anisotropic phase of that mineral, there is also a distinct chemical similarity though the contents of V, Cr, Fe, and the rare earths are considerably less.

It is observed that the rutile stringers, which are abundant in the fels, do not extend into the halo zones surrounding the complex mineral

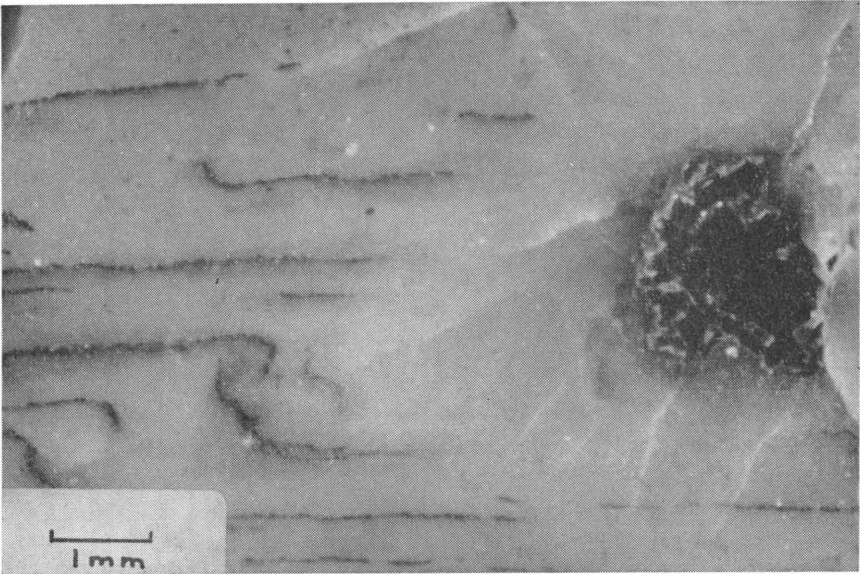


Fig. 12. Polished specimen of fels with complex titanium mineral. The vanadio-rutile stringers do not extend into the halo zone surrounding the complex mineral.

(Fig. 12). It is possible that grains of the complex were formed by the migration of ground mass rutile to certain loci, but this process would require supplementary V, Cr, Fe, rare earths and U. It seems more probable that secondary processes have removed the rutile from these radioactively affected and more porous zones as well as leaching the periphery of the complex mineral itself.

Vanadiochrome spinel.

Within the fels in the section containing the grain of the complex titanium mineral seen in Fig. 5 was found a small area with tiny (c. 0.01 mm) grains of a mineral giving the microprobe analysis shown in Table 6. Microscopically the mineral has the grayish color of magnetite, is isotropic, and exhibits edges characteristic of the isometric system. Indeed, it would have been taken for magnetite had not its chemical composition been determined. In the table Fe is calculated as Fe_3O_4 as the proportion $\text{Fe}^{2+}:\text{Fe}^{3+}$ was not determinable, and V is calculated as V_2O_3 . The mineral occurs in what appears to be a crack filling, together with rutile and probably albite and quartz.

The data would seem to indicate this mineral to be a variety of spinel, but no such composition has been found in the literature. The variety of magnetite, coulsonite, contains up to about 7 % V_2O_3 , but with negligible Cr. Chromite contains but scant V.

Gadolinite and euxenite.

In the concentrate obtained by Carpco separation described previously a small amount of a black mineral, bottle-green on thin edges, with conchoidal fracture and vitreous luster was observed, and a number of these grains were collected by pincette. X-ray powder analysis showed the mineral to be gadolinite. Insufficient material was found for a chemical analysis, but meticulous spectrographic analysis on the small amount available provided the results shown in Table 7. The values in parentheses were determined by microprobe, Tb, Ho, Tm, Lu, and Hf being determined by interpolation. The relatively high proportion of cerium lanthanides more exactly define the mineral as a cergadolinite, with a Ce-Nd maximum.

Several dark grains with conchoidal fracture and vitreous luster, but with a deep reddish color on thin edges, were determined by X-ray powder analyses to belong to the series euxenite-blomstrandine. The amount of material available, however, did not permit closer identification.

These grains of gadolinite and euxenite (as well as apatite and antigorite) were obtained through a process designed to concentrate the complex titanium mineral. It is likely that they occur in the host rock in greater quantity than the small amount observed would indicate.

Acknowledgements.

Determinative tests were performed at the following institutions. Microprobe analyses:

Central Institute for Industrial Research, Oslo
Technical University of Norway, Trondheim

Chemical and spectrographic analyses:

Geological Survey of Norway, Trondheim
Institute for Atomic Energy, Kjeller

X-ray powder data:

Geological Survey of Norway, Trondheim
Technical University of Norway, Trondheim

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Table 1.

Analysis of complex titanium mineral. The remaining 0.1 % R.E. consist mainly of La and Yb.

Small amounts of Pr, Nd, Gd, Dy, and Er are also present.

Comp.	wt. %	Comp.	wt. %
TiO ₂	54	U	0.5—2
V ₂ O ₅	17.7	Sr	0.2
Cr ₂ O ₃	7.4	Zn	0.00x
FeO	4.5	Ni	0.0x
Fe ₂ O ₃	6.6	Pb	0.x
ZrO ₂	0.4	Th	0.0x
Al ₂ O ₃	1	Sc	0.0x
SiO ₂	1.5	Tot. R.E.	0.91
MgO	0.5	(Ce)	(0.6)
MnO	0.06	(Y)	(0.2)
Cu	0.2		
S	1.5	SUM c.	98

Table 2.

Complex titanium mineral. X-ray powder data (copper radiation).

Both phases		Isot. phase		Anisot. phase	
dÅ	Int.	dÅ	Int.	dÅ	Int.
3.80	6			3.80	6
3.47	10			3.47	10
2.81	6			2.81	6
2.61	7			2.61	7
2.47	6	2.46	4		
2.42	1			2.42	1
2.37	2			2.37	2
2.18	6	2.17	7		
2.14	6			2.14	6
1.89	5			1.89	5
1.80	2			1.80	2
1.68	9	1.69	10		
1.66	8			1.66	8
1.63	1			1.63	1
1.60	1			1.60	1
1.48	1			1.48	1
1.44	2			1.44	2

Table 3.

*Complex titanium mineral.
Analyses of the anisotropic and isotropic phases.*

Comp.	Anisot. phase	Isot. phase	Gen. anal. Table 1	Anal. Kjeller
TiO ₂	50.29	51.17	54	
V ₂ O ₅	14.42	13.15	17.7	
Cr ₂ O ₃	8.91	9.43	7.4	
Fe ₂ O ₃	8.58	10.19	10.1	
Al ₂ O ₃	0.60	0.86	1	
SiO ₂	2.39	not anal.	1.5	
MgO	0.05	0.26	0.5	
CeO ₂	0.70	4.12	0.7	2.0
Sc ₂ O ₃	1.00	2.89	0.0x	0.9
Y ₂ O ₃	not anal.	0.36	0.3	0.3
SUM	86.94	92.43	93.2	

Table 4.
*Thortveitite. Bidjovagge analyses compared with thortveitite
 from Eptevann.*

Comp.	Anal. 1	Anal. 2	Ave.	Eptevann
MgO	1.76	2.87	2.31	0.17
Al ₂ O ₃	3.13	3.53	3.33	4.95
SiO ₂	44.71	45.09	44.90	45.79
CaO	0.24	0.20	0.22	0.24
Sc ₂ O ₃	39.07	38.18	38.62	34.32
TiO ₂	0.68	0.85	0.76	< 0.01
V ₂ O ₅	1.30	1.37	1.33	
Cr ₂ O ₃	0.37	0.83	0.60	
MnO	0.24	0.22	0.23	0.53
Fe ₂ O ₃	4.63	6.10	5.36	2.95
Y ₂ O ₃	2.73	2.87	2.80	
Dy ₂ O ₃	0.18	0.20	0.19	
Er ₂ O ₃	0.11	0.13	0.12	
Yb ₂ O ₃	0.26	0.40	0.33	
ThO ₂				0.09
ΣLa ₂ O ₃				1.48
ΣY ₂ O ₃				9.52
U ₃ O ₈				0.00
Pb				0.00
ZrO ₂				0.00
H ₂ O—				0.07
H ₂ O+				0.00
SUM	99.48	102.89	101.16	100.11

Table 5.
Analysis of vanadio-rutile.

Comp.	wt. %	Comp.	wt. %
TiO ₂	(94.3)	U	trace
V ₂ O ₅	3.8 (3.5)	Y	trace
Cr ₂ O ₃	0.6 (0.4)	Sr	not detect.
Fe ₂ O ₃	1.0 (0.2)	Zn	0.00x
FeO	< 0.1 (chem. det.)	Ni	0.0x
Al ₂ O ₃	< 0.1	Pb	0.01
SiO ₂	1.5	Th	0.0x
MgO	not detect.	Na	not detect.
MnO	not detect.	Nb	0.1
ZrO ₂	0.3	Sc	trace
Cu	0.2	Ce	not detect.
S	not anal.	Ta	not detect.
SUM	c. 102		

Table 6.
Microprobe analysis of vanadiochrome spinel.

Comp.	wt. %
Fe ₃ O ₄	66.28
V ₂ O ₃	16.98
Cr ₂ O ₃	15.09
TiO ₂	0.52
Al ₂ O ₃	1.14
SiO ₂	0.19
MnO	0.x
SUM	100.2+

Table 7.
Analysis of gadolinite.

Comp.	wt. %	Comp.	wt. %
La ₂ O ₃	0.7		
CeO ₂	5.4 (2.4)		
Pr ₂ O ₃	1.1		
Nd ₂ O ₃	4.8		
Sm ₂ O ₃	2.3		
Eu ₂ O ₃	10 p. p. m.		
Gd ₂ O ₃	2.3		
Tb ₂ O ₃	(0.3)		
		ΣCe ₂ O ₃	16.7
Y ₂ O ₃	c. 30 (31.7)		
Dy ₂ O ₃	1.7		
Ho ₂ O ₃	(1.0)		
Er ₂ O ₃	0.8		
Tm ₂ O ₃	(0.1)		
Yb ₂ O ₃	1.4		
Lu ₂ O ₃	(0.5)		
HfO ₂	(0.03)		
		ΣY ₂ O ₃	35.5
		SiO ₂	(22.5)
		FeO	9.5
		BeO	9.0
		CaO	(0.3)
		MnO	(0.2)
		B ₂ O ₃	0.0x
		SUM	93.7