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Titaniferous clinohumite from Gardiner Plateau Complex, East Greenland

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SUMMARY. Titaniferous clinohumite occurs as a major constituent in the centres of late magmatic veins in the Tertiary ultramafic, strongly alkaline Gardiner Plateau Complex in East Greenland (69° N. and 32° W.). The complex is briefly described and an electron microprobe analysis of titaniferous clinohumite is presented. This gives the following: 38·44% SiO_2, 2·99% TiO_2, 4·87% FeO, 51·89% MgO, 1·3% F, $H_2O_{calc.}$ 1·50%, and total 100·44%. Optical data, density, and unit cell dimensions are also presented. Of magmatic occurrences, titaniferous clinohumite has otherwise only been reported in certain kimberlites and carbonatites.

THE ring-shaped Gardiner Plateau Complex (Frisch and Keusen, 1975; Brooks and Nielsen, in press) intrudes Tertiary plateau basalts beyond the head of Kangerdlugssuaq fjord, 69° N. and 32° W., in East Greenland. Unpublished fission track ages on apatite and sphene give a weighted mean of $54{\cdot}3 \pm 2{\cdot}4$ Ma (1 σ) (A. G. W. Gleadow, pers. comm. to C. K. Brooks), which conforms with the age of 60-55 Ma for the plateau basalts obtained by K-Ar methods (Beckinsale *et al.*, 1970).

The complex has a diameter of around 6 km, and is composed of two major generations of ultramafic rocks and associated ring dikes and radial dike swarms of strongly alkaline basic to salic rock types. Most of the complex is composed of an early generation of ultramafic rocks, which are probably all cumulates. These form a succession of rings inwards from the contact in the following order: hornblende-bearing peridotites, olivine pyroxenites, dunites, and pyroxenites. Hereafter followed dikes and sheets consisting of pyroxenitic, tawitic, and undersaturated salic rocks. The second generation of ultramafic rocks includes two bodies of uncompahgrite, an ultramafic coarse-grained rock composed mainly of melilite with perovskite, melanite, Ti-rich magnetite, apatite, phlogopite, diopside, calcite, and minor cebollite. These rocks are best exposed in a ring dike that is up to 700 m wide and occurs approximately 1·5 km from the centre of the complex. A second body can be seen at the edges of a circular icecap, with a diameter of 2 km, that covers the centre of the complex. Dikes and sheets of søvite are believed to be related to the uncompahgrites (Frisch and Keusen, 1975). Late sheets of apatite-, magnetite-, and perovskite-rich pyroxenites and nepheline syenites form the closing magmatic events. The emplacement of the uncompahgrites was followed by strong metasomatism of the earlier ultramafic rocks expressed largely by the development of phlogopite.

The titaniferous clinohumite-bearing veins occur in the south-western part of the complex on a plateau at the altitude of 1600 m and approximately 2 km from the centre. The veins intrude dunite and are related to an 8-m thick pyroxenitic ring dike with a westerly dip, which is well exposed in the southern escarpment of the plateau. The outer parts of the dike are composed of pyroxenite, which is followed inwards by a phlogopite-rich transitional zone. The centre is rather inhomogeneous and is composed of phlogopite, magnetite octahedra, felt-like apatite, antigorite, forsteritic olivine, diopside, and hornblende. The dike is believed to belong to a group of dikes related to the emplacement of the uncompahgrites. In the upper part of the escarpment, veins up to 20 cm wide split off from the dike. These veins are composed of Ti-rich magnetite, phlogopite, apatite, antigorite, and minor diopside. The dike continues on the plateau as an apatite-, magnetite-, and perovskite-bearing diopside-hornblende dike. The titaniferous clinohumite is reddish-brown and forms aggregates up to 10 cm in size in the centres of the veins that are exposed on the plateau. It is also found on joints in the neighbouring host dunite.

The centres of the veins are dominated either by magnetite octahedra, up to 10 cm in size, or by the Ti-clinohumite, which is the last-crystallizing magmatic phase of the paragenesis. The size of the Ti-clinohumite grains, which mostly are anhedral, decreases from approximately 1 cm in the centre to less than 1 mm at the margins of the aggregates.

The bulk of the veins is composed of apatite felt, antigorite, phlogopite, diopside, Ti-poor magnetite, and alkali-amphibole. These minerals are also present in accessory amounts within aggregates. Sparse forsteritic olivine can be found in all parts of the veins.

Physical and chemical properties of the titaniferous clinohumite. In thin section the Ti-clinohumite is strongly pleochroic from golden-yellow parallel to α to pale yellow parallel to β and γ. Lamellar twinning is common. Optical data are shown in Table I. The grains in the marginal parts of the aggregates are often poikilitic and enclose Ti-poor magnetite and richterite, and a few grains of primary hematite.

TABLE I. *Composition, cell dimensions, density, and optical properties of titaniferous clinohumite from the Gardiner Plateau Complex*

SiO_2	38·44 wt %	Formula normalized to 4 Si:	
TiO_2	2·99	$[(Mg_{0\cdot95}Fe_{0\cdot05})_{7\cdot7}Si_4O_{16}]$.	
FeO	4·87	$[Mg_{0\cdot77}Ti_{0\cdot23}OH_{1\cdot04}F_{0\cdot42}O_{0\cdot54}]$	
MnO	trace		
MgO	51·89		
F*	1·30		
$H_2O_{calc.}$	1·50		
	100·99		
O ≡ F	0·55		
Total	100·44	α	1·638
a	13·6819 Å	β	1·654
b	4·7436 Å	γ	1·685
c	10·2655 Å	$\gamma-\alpha$	0·047
β	100·9271°	$2V\gamma$	73°
V	654·10 Å^3	α:[001]	9°
$\rho_{calc.}$	3·21 g/cm^3	$\rho_{meas.}$	3·23(2) g/cm^3

* Uncorrected.

The chemical analysis was carried out on a Hitachi XMA-5B electron microprobe at 15·0 kV and 20 nA sample current. Six grains from different parts of the veins were investigated and no significant variations have been observed. A complete analysis is presented in Table I and was performed using the following standards: wollastonite (Si), anatase (Ti), hematite (Fe), periclase (Mg), and fluorite (F). Data, except for F, were processed by EMSKOR2A (J. G. Rønsbo, Institute of Mineralogy), which is a modified version of the programme of Springer (1967), in accordance with the scheme of Sweatman and Long (1969). The formula is normalized to 4 Si (Table I), while the water content is calculated by the method proposed by Jones *et al.* (1969). In addition to the main elements Mn, Ca, Al, Na, Zr, and Nb were searched for, but only traces of Mn were found.

Density was determined by suspension in heavy liquids, and measurements of four grains at 24 °C gave $\rho_{meas.}$ 3·23(2) g/cm^3, which is in good agreement with the $\rho_{calc.}$ 3·21 g/cm^3.

Powder patterns were taken with a Guinier–Hägg focusing camera, Cu-K_α radiation, and quartz as internal standard. Least squares refinements of thirty-four d-values gave the unit cell dimensions shown in Table I.

Discussion. Titaniferous clinohumite has been recorded from a number of localities of different parageneses. Among the earliest descriptions is that of Brugnatelli (1904), who reviewed occurrences in the Alps, where Ti-clinohumite is found in metamorphosed basic and ultrabasic rocks. The parageneses include olivine and its alteration products (e.g. antigorite), magnetite, diopside pyroxene, and calcite.

Huang (1957) has reported the mineral from metasomatic reaction zones between gabbros and supposed F-rich granitic veins. Another common occurrence of Ti-clinohumite is in metamorphosed limestones: skarns (Sahama, 1953; Barsanov, 1941; Muthuswami, 1958). The parageneses of these occurrences often include phlogopite, tremolite, magnetite, and calcite.

A number of magmatic occurrences have also been described. Gasparrini *et al.* (1971) have reported the mineral from the Cargill Lake carbonatite, Ontario, and a crystal structural analysis of this Ti-clinohumite has been presented (Kockman and Rucklidge, 1973). A similar occurrence is known in Siberia (Voskresenskaya *et al.*, 1965). Melcher (1966) reported clinohumite in the carbonatite of the Jacupiranga complex, Brazil, but no details have been published. Kimberlite diatremes in Utah and Arizona also contain Ti-clinohumite (McGetshin *et al.*, 1970), which here have been proposed as a possible mantle phase, occurring in nodules of mantle peridotite.

None of these occurrences can be compared with that of East Greenland and, to our knowledge, the Ti-clinohumite from the Gardiner Plateau Complex is the first recorded occurrence where the mineral is found as a primary phase in late magmatic veins.

The small number of complete descriptions of Ti-clinohumites do not justify any attempts to correlate chemistry and paragenesis or physical properties with any certainty. Compared to the analyses in the quoted references the composition of the Ti-clinohumite from the Gardiner Plateau Complex is low in FeO (total) and has a moderate TiO_2 content, probably correlated with the low α and high birefringence. Thus, our sample has the highest recorded birefringence. The lack of correlation between modes of origin and chemistry is apparent by the fact that the closest resemblance to our specimen is shown by a Ti-clinohumite from skarns, Bhandara, India, described by Muthuswami (1958). The only major difference is found in the values of β and γ, which are higher in our specimen, giving the higher birefringence.

Our analysis also confirms the statement made by Jones *et al.* (1969) that clinohumites with a high content of Ti are not deficient in Si as suggested by Machatschki (1930).

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