II.

ON THE MINERALOGY OF PYROCHLORE FROM THE ILÍMAUSSAQ ALKALINE INTRUSION, SOUTH GREENLAND

CONTRIBUTION TO THE MINERALOGY OF ILÍMAUSSAQ No. 11

BY

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Abstract

Niobium-bearing minerals such as pyrochlore, igdloite (= lueshite) and epistolite are of widespread occurrence in the Ilímaussaq Intrusion, South Greenland. Furthermore, rock-forming minerals such as eudialyte and rinkite contain one percent or more of Nb_2O_5. Pyrochlore occurs mainly in rocks of supposed hydrothermal origin and is associated with analcime, natrolite, polylithionite, sphalerite, and a number of other minerals. Four types of pyrochlore are described:

1. Brown pyrochlore which is associated with analcime in aggregates several centimetres across. $a_0 = 10.39$ Å, $n = 2.02 \pm 0.01$, sp. gr. = 4.12. $Nb_2O_5 = 60.85$, $Ta_2O_5 = 0.09$, $TiO_2 = 0.69$, $SiO_2 = 2.00$, $TR_2O_3 = 13.03$, $CaO = 6.30$, $Na_2O = 2.97$, $U_3O_8 = 0.35$ weight percent, etc.
2. Grey pyrochlore forming irregular areas. $a_0 = 10.35$ Å, $Nb_2O_5 = 42.06$, $Ta_2O_5 = 3.63$, $TiO_2 = 4.09$, $SiO_2 = 14.14$, $TR_2O_3 = 6.14$, $CaO = 9.23$, $Na_2O = 5.34$ weight percent, etc. (impure material).
3. White earthy pyrochlore which probably forms pseudomorphs after epistolite.
4. Yellow siliceous pyrochlore associated with analcime and neptunite. $a_0 = 10.39$ Å, sp. gr. = 3.69, $Nb_2O_5 = 59{,}91$, $Ta_2O_5 = 0.11$, $TiO_2 = 2.66$, $SiO_2 = 10.26$, $TR_2O_3 = 2.45$, $CaO = 8.31$, $Na_2O = 7.46$, $U_3O_8 = 0.20$ weight percent, etc.

It has not been possible to decide whether the silica content is due to mechanical admixture or to isomorphic substitution. As long as this problem is not solved the Ilímaussaq pyrochlore should most properly be termed siliceous pyrochlore.

РЕЗЮМЕ

Ниобиевые минералы, такие как пирохлор, игдлоит (луешит) и эпистолит, широко распространены в Илимауссакской интрузии (Ю. Гренландия). Кроме того, породообразующие минералы, как эвдиалит и ринкит, содержат один процент и больше Nb_2O_5. Пирохлор характерен главным образом для пород предположительно гидротермального происхождения и ассоциирует с анальцимом, натролитом, полилитионитом, сфалеритом и многими другими минералами. Описаны четыре разновидности пирохлора:

1. Коричневый пирохлор, ассоциирующий с анальцимом в агрегатах величиной до нескольких сантиметров. $a_0 = 10.39$Å, $n = 2.02 \pm 0.01$, уд.вес = 4.12. $Nb_2O_5 = 60.85$, $Ta_2O_5 = 0.09$, $TiO_2 = 0.69$, $SiO_2 = 2.00$, $TR_2O_3 = 13.03$, $CaO = 6.30$, $Na_2O = 2.97$, $U_3O_8 = 0.35$ весовых процентов, и т.д.
2. Серый пирохлор, образующий неправильные участки. $a_0 = 10.35$Å, $Nb_2O_5 = 42.06$, $Ta_2O_5 = 3.63$, $TiO_2 = 4.09$, $SiO_2 = 14.14$, $TR_2O_3 = 6.14$, $CaO = 9.23$,$Na_2O = 5.34$ вес. $^0/_0$ и т.д. (примеси).
3. Белый землистый пирохлор, образующий, повидимому, псевдоморфозы по эпистолиту.
4. Желтый кремнистый пирохлор, ассоциирующий с анальцимом и нептунитом. $a_0 = 10.39$Å, уд.вес = 3.69, $Nb_2O_5 = 59.91$, $Ta_2O_5 = 0.11$, $TiO_2 = 2.66$, $SiO_2 = 10.26$, $TR_2O_3 = 2.45$, $CaO = 8.31$, $Na_2O = 7.46$, $U_3O_8 = 0.20$ $^0/_0$ и т.д.

Невозможно было решить относится ли кремнезем к механическим примесям или к изоморфным замещениям. До тех пор, пока эта проблема не разрешена, было бы правильнее называть илимауссакский пирохлор кремнистым пирохлором.

CONTENTS

PREFACE

Since 1964, when two of the authors (E.I.S. and H.S.) together visited the Ilímaussaq intrusion in South Greenland, an intimate scientific cooperation has been established between the Institute of Mineralogy, Geochemistry and Crystallo-chemistry of Rare Elements (IMGRE), Moscow and the Institutes of Mineralogy and Geology of the University of Copenhagen. This paper is one of many resulting from this cooperation.

The authors wish to express their gratitude to the Rask-Ørsted Foundation which covered the travelling expenses of one of the authors (E.I.S.) in 1964.

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Mr N. HESSELBJERG, the Research Laboratories of the Danish Atomic Energy Commission, has kindly placed a number of partial chemical analyses at our disposal and Mr T. C. R. PULVERTAFT has kindly read the English of the manuscript.

Mrs A. DEMIN translated the Russian part of the manuscript into English.

INTRODUCTION

The Ilímaussaq alkaline intrusion in South Greenland, which is mainly composed of agpaitic nepheline syenites, is characterized by a high content of niobium and a very low content of titanium, especially when compared to the Lovozero alkaline intrusion of the Kola peninsula which, with respect to structure, petrology and mineralogy, is strikingly similar to the Ilímaussaq intrusion.

Ussing (1912) mentioned small cubes of (?) pyrochlore in the arfvedsonite lujavrite of Ilímaussaq and also in the alkali granite of the uppermost part of this intrusion. Ussing (1912, p. 175) also reported that the arfvedsonite lujavrite may contain as much as $0.45^{0}/_{0}$ Nb_2O_5. Epistolite was described by Bøggild & Winther (1901).

In later years igdloite (Danø & Sørensen, 1959), widespread pyrochlore (Sørensen, 1962), minerals of the group epistolite-murmanite (unpublished observations), niobophyllite (unpublished observations), nenadkevichite, gerassimovskite and tundrite (Semenov, Aleksandrova & Kazakova, 1967) and ilimaussite (Semenov, Kazakova & Bukin, 1968) have been found.

Contents of one percent or more of Nb_2O_5 have been found in astrophyllite, eudialyte, rinkite and vudjavrite (unpublished data).

A detailed study of the niobium mineralization of the northernmost part of the intrusion is now in progress. Preliminary reviews of this work have been published by Hansen (1966 a & b).

A preliminary examination of the distribution of niobium in the rocks of the Ilímaussaq intrusion was undertaken by Hamilton (1964, p. 95); his results were as follows:

augite syenite	6– 18	ppm Nb
alkali granite	447– 837	—
chill of alkali granite	1040–1110	—
naujaite	880	—
sodalite foyaite	1115	—
foyaite	1076	—
lujavrite	555–1400	—
sodalite	75	—
eudialyte	1342	—

In the present paper some varieties of pyrochlore will be described.

MODE OF OCCURRENCE

Pyrochlore is of widespread occurrence in Ilímaussaq. It occurs as earthy or granular masses of light yellow (sometimes white) to brown colour. The masses are up to 10 centimetres across and often have irregular or rounded shapes.

Pyrochlore has so far been found in the central zones of pegmatites, in hydrothermal veins composed of analcime and natrolite, in lenticular masses of analcime-natrolite, and disseminated in the lujavrite and alkali granite.

1. **Pegmatites:** In the poikilitic sodalite syenite (naujaite) and in the sodalite foyaite there are several types of pegmatites among which are zoned bodies with marginal zones composed of microcline, green sodalite, arfvedsonite, eudialyte and ægirine and central zones of analcime and natrolite. Pyrochlore is confined to these central zones which also contain polylithionite, sphalerite, neptunite and other minerals.

In the southernmost part of the intrusion the agpaitic nepheline syenite named kakortokite is separated from the marginal miascitic augite syenite by a zone rich in pegmatites containing microcline, albite, nepheline, arfvedsonite, eudialyte, tundrite, and other minerals including earthy pyrochlore.

2. **Hydrothermal veins:** In naujaite and sodalite foyaite there are hydrothermal veins composed of coarse-grained analcime, natrolite and sodalite which often have thin marginal zones composed of ægirine/acmite and/or arfvedsonite. In the marginal zones there are crystals of eudialyte (and also pseudomorphs after eudialyte), steenstrupine, britholite, neptunite and biotite.

The coarse-grained zones of analcime etc. also contain schizolite, monazite, neptunite, chkalovite, lithium mica, pyrochlore and igdloite. The igdloite and pyrochlore associated with neptunite and a red micaceous mineral often form fine-grained lamellar masses.

Veins of this type have been described by Sørensen (1962) and by Oen & Sørensen (1964).

In the naujaite of the Taseq plateau there are veins of fine-grained albitite containing fluorite, analcime, neptunite, allanite, lithium mica, schizolite, sphalerite, biotite and lamellar masses of igdloite, pyrochlore and neptunite (SEMENOV & SØRENSEN 1966).

In the alkali granite of Nákâlâq pyrochlore has been found in hydrothermal veins composed of quartz, microcline, riebeckite, polylithionite, eudidymite, monazite and neptunite.

3. In the Kvanefjeld area in the northernmost part of the intrusion there are small patches and lenticular bodies attaining lengths of a few metres composed of **coarse-grained analcime.** These bodies occur in a coarse-grained to medium-grained variety of lujavrite which represents the latest phase of intrusive agpaitic activity in Ilímaussaq. The bodies are often zoned with thin marginal zones composed of microcline, arfvedsonite and steenstrupine, and central zones of analcime, sodalite, albite, natrolite, pyrochlore, neptunite, blue apatite, igdloite, monazite, sorensenite, chkalovite and beryllite. The pyrochlore occurs i) as compact masses up to 2 centimetres across associated with neptunite, arfvedsonite and a strongly birefringent mineral which may be altered epistolite; ii) as small skeletal aggregates in association with igdloite; iii) as elongated aggregates of igdloite, neptunite, arfvedsonite and pyrochlore with small patches of epistolite. These aggregates have been regarded as pseudomorphs after epistolite (SEMENOV *et. al.*, 1965, p. 9).

On the Kvanefjeld plateau there are also veins of fine-grained albitite intersecting naujaite and augite syenite. The veins further contain analcime, natrolite, chkalovite, tugtupite, sphalerite, neptunite, igdloite, pyrochlore, epistolite, Li-mica, beryllite and ægirine. Pyrochlore occurs partly as small grains, partly as "fracture fillings" together with neptunite. These fractures cut all the other minerals of these veins which indicates that the pyrochlore was of late formation.

4. In **arfvedsonite lujavrite** small grains of pyrochlore have been found, especially in lujavrite rich in analcime or natrolite. This type of pyrochlore has not yet been examined mineralogically.

5. FERGUSON (1964) and HAMILTON (1964) have mentioned minute grains of pyroclore in **the alkali granite** of Ilímaussaq. Other accessories of this granite are elpidite, astrophyllite, epididymite, leucosphenite, fluorite, zircon and neptunite.

6. **Association and genesis:** As is apparent from this survey of the mode of occurrence of the pyrochlore in Ilímaussaq, this mineral is first of all associated with analcime, natrolite, albite, neptunite, igdloite, Li-mica and sphalerite. A number of other minerals which are characteristic for the late pneumatolytic or hydrothermal phases in Ilímaussaq,

also occur in the pyrochlore-bearing rocks, but mainly in their marginal zones. When these minerals occur in rocks rich in analcime and/or albite, they were probably formed prior to the crystallization of the latter minerals which, as demonstrated by Sørensen (1962), often are the results of replacement processes.

According to Sørensen (1962, p. 205) the late pneumatolytic or hydrothermal mineralizations of Ilímaussaq may be genetically connected with the lujavrite. Alkaline fluids expelled from the consolidating lujavrite magma have percolated fractures in the naujaite, sodalite foyaite and augite syenite. During field work carried out in 1962 and 1964 a late intrusive phase of rather coarse-grained lujavritic rocks was found in the Kvanefjeld area near the top of the northernmost part of the Ilímaussaq intrusion. This phase was accompanied by extensive mineralizations in the adjacent rocks (Sørensen, 1966). The lenticular bodies of analcime etc. mentioned on p. 16 were formed at this stage.

With the possible exception of the pyrochlores of the lujavrite (and also that of the alkali granite) all the pyrochlore found so far in Ilímaussaq is of very late formation and may even occur on fractures and as networks in late analcime. This indicates, as emphasized by Sørensen (1962, p. 206), that Nb may have been held in solution by strong sodium halide complexes after the precipitation of thorium and rare earth metals.

The niobium of the pyrochlore may have been either expelled from the lujavrite magma or derived by leaching from the naujaite adjacent to the fractures through which the late fluids percolated. The eudialyte and rinkite of the naujaite and sodalite foyaite have been strongly altered along the fractures in which the hydrothermal veins have been formed. A part of the niobium of these veins may therefore have been derived from eudialyte or rinkite. In cases where the pyrochlore occurs in epistolite-bearing rocks the pyrochlore has been formed partly at the expense of pegmatitic epistolite.

MINERALOGY

Four varieties of pyrochlore will be described in the present paper, namely a brown, a grey, a white and a yellow type.

1. **Brown Pyrochlore:** The brown pyrochlore examined was found in a pegmatite on the north-east slope of Nákâlâq (sample no. 77301). This pegmatite occurs in sodalite foyaite near the contact with the underlying naujaite. The marginal parts of the pegmatite are composed of microcline, eudialyte and arfvedsonite; the central part is composed of analcime with a net-work of pyrochlore veinlets. The pyrochlore is associated with polylithionite and sphalerite. Equidimensional aggregates of analcime with abundant pyrochlore are up to 10–15 centimetres in size. Irregular aggregates of pyrochlore are up to one cm in size. An electron micrograph (plate 1, fig. 1) demonstrates that the aggregates are composed of isometric, pseudohexagonal or collomorphous pyrochlore. The X-ray powder diagram of the mineral was produced without heating and has $a_0 = 10.39$ Å and a great number (over 20) of distinct lines.

The refractive index determined in liquids containing phosphorus was found to be 2.02 ± 0.01.

The chemical composition and the specific gravity of the brown pyrochlore are presented in table 1. Be (0.0X–0.X$^0/_0$), Sn and Zn were found spectrographically by N. V. Lizunov. This variety of pyrochlore is rich in rare earth metals: $TR_2O_3 = 13^0/_0$.

The La-Ce group of rare earth metals has been found to occur in the following proportions:

$$La_{30}Ce_{55}Pr_{4.5}Nd_{8.6}Sm_{0.9}Gd_{0.1}Dy_{0.1}$$

(determined in the X-ray spectrographic laboratory of R. L. Barinsky). The chemical formula as calculated from the chemical analysis, assuming Nb = 2, is:

$$(Na_{0.66}Ca_{0.48}Ce_{0.35})\ (Fe_{0.11}Al_{0.14}Si_{0.14})\ Nb_2\ (0,0H)\ _{x}F_{1.45}$$

The total amount of all the cations, with the exception of niobium, is 1.88. Thus, even if Al and Si are placed in the A group, the deficiency of this group will remain.

Table 1. *The chemical composition of pyrochlore from the Ilímaussaq intrusion.*

(Z. T. Katajeva, analyst).

	1. Brown		2. Grey (impure sample)		3. Yellow		4. Lueshite (igdloite)
	Weight percent	Number of atoms	Weight percent	Number of atoms	Weight percent	Number of atoms	Weight percent
Nb_2O_5	60.85	0.457	42.06	0.316	59.91	0.451	58.53
Ta_2O_5	0.09	–	3.63	0.016	0.11	–	0.15
TiO_2	0.69	0.009	4.09	0.051	2.66	0.033	3.75
ZrO_2	0.30	0.002	–	–	–	–	–
SiO_2	2.00	0.033	14.14	0.236	10.26	0.171	–
ThO_2	–	–	0.74	0.003	0.68	0.002	–
TR_2O_3	13.03	0.080	6.14	0.037	2.45	0.015	6.13
Fe_2O_3	2.06	0.026	1.22	0.015	0.69	0.008	–
Al_2O_3	1.69	0.033	2.21	0.043	1.32	0.026	–
BaO	–	–	–	–	0.39	0.002	–
SrO	–	–	–	–	0.22	0.002	–
CaO	6.30	0.113	9.23	0.165	8.31	0.149	2.20
Na_2O	2.97	0.096	5.34	0.172	7.46	0.241	9.74
K_2O	2.79	0.059	2.77	0.059	2.80	0.059	2.42
H_2O	3.39	0.377	7.57	0.840	1.76	0.196	3.50
U_3O_8	0.35	0.001	–	–	0.20	–	–
F	6.46	0.340	–	–	2.84	0.149	–
$O = F_2$	2.71	–			1.19	–	–
Total	100.06				100.87		
Sp. gravity	4.12				3.69		

The margins of the yellow-brown resinous pyrochlore aggregates are often altered into a greenish grey nontransparent substance with dull lustre. As is apparent from the X-ray powder diagram and from the incomplete chemical analysis (table 1, analysis no. 4), this substance represents igdloite (lueshite), which is orthorhombic pseudocubic $NaNbO_3$ with perovskite structure (Danø & Sørensen, 1959). The replacement of pyrochlore by igdloite can be observed only at high magnification (plate 1, fig. 3). The electron micrograph (plate 1, fig. 2) demonstrates the heterogeneity of the replacement. By comparing the chemical analyses and the formulae it is seen that, during the alteration of pyrochlore into igdloite (lueshite), there is a removal of calcium and an addition of sodium. This process is the contrary of the large-scale process of fersmitization of pyrochlore and of the process of pyrochlorization of loparite which have been observed in Lovozero (SEMENOV *et al.*, 1963.)

2. **Grey Pyrochlore:** The occurrence of areas up to 1.5 centimetres wide of irregular outline composed of dull brownish grey pyrochlore has been observed in a huge pegmatite which occurs along the contact between kakortokite and augite syenite in the south-western part of the massif (Kringlerne). The pyrochlore of this pegmatite (sample no. 77351) is associated with polylithionite and tundrite. According to the chemical analysis of a not completely pure sample (table 1, no. 2), this pyrochlore is enriched in Ta, Si and H_2O. The size of the unit cell (a_0 = 10.35 Å) is smaller than that of the more widespread varieties of pyrochlore in Ilímaussaq.

3. **White Earthy Pyrochlore:** An unusual white earthy pyrochlore, which is easily ground with the fingers, has been found in pseudomorphs after an elongated (up to one centimetre) obscure mineral (epistolite ?, nenadkevichite ?, gerassimovskite ?). Similar pyrochlore occurs in the eastern part of Nákâlâq in hydrothermal veins in the alkali granite and in naujaite. In the first case the mineral is associated with quartz, microcline, polylithionite, riebeckite, eudidymite, monazite and neptunite (no. 77365); in the second case with analcime, schizolite, chkalovite and polylithionite (no. 77382).

The X-ray powder diagram of the white earthy pyrochlore is distinct and has a great number of lines. Judging from the low refractive index (about 1.75) this pyrochlore is a secondary epithermal, or perhaps hypergenic, mineral which is intensively hydrated. It may therefore represent hydropyrochlore.

4. **Yellow Siliceous Pyrochlore:** A yellow siliceous pyrochlore is often found in hydrothermal veins in the naujaite at Nákâlâq and elsewhere. It forms masses of irregular shape measuring up to 0.5 cm or elongated masses measuring 3×0.5 cm (pseudomorphs after epistolite ?). It is associated with analcime and neptunite (no. 77385).

The mineral is light yellow, with conchoidal fracture and dull lustre. The specific gravity (3.69) and the hardness are lower than in the varieties mentioned above.

The X-ray powder diagram is distinct and has a great number of lines, a_0 = 10.39 Å.

The remarkable feature of this pyrochlore is an unusually high content of silica ($10.26^0/_0$, see Table 1). Assuming Nb + Ti = 2 the following formula is deduced:

$$Na_{1.24}Ca_{0.63}Ce_{0.07}Al_{0.14}Si_{0.71}\,(Ti_{0.14}Nb_{1.86})\,(O,OH)_{x}F_{0.61}$$

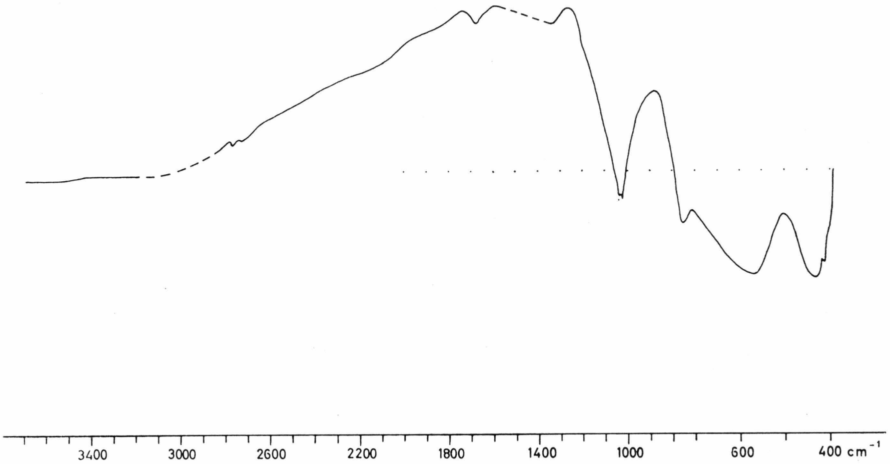

Fig. 1. Infrared absorption spectrum of yellow siliceous pyrochlore. Laboratory of L. S. SOLNTSEVA (VIMS).

The total amount of the cations, excluding niobium, is higher than two (2.79), the excess being almost exactly the amount of silicon present.

As in the case of the brown and grey pyrochlores it is not clear whether the content of SiO_2 is due to isomorphic substitution or to mechanical admixture. There is no indication of obvious mechanical admixture of other minerals in the pyrochlore, neither under the microscope nor in the X-ray powder diagram. In reflected light unidentified areas of lower reflectivity are seen.

It is characteristic that the siliceous pyrochlore is poor in aluminium, even though it is associated with the alumino-silicates analcime, microcline and sodalite, and not with quartz. This pyrochlore is also very rich in sodium.

Silicon has now been demonstrated to occupy octahedral coordination positions not only in stishovite but also in the low temperature silicate thaumasite. This suggests that silicon may enter the structure of pyrochlore. To substantiate this suggestion the infrared absorption spectrum of the siliceous pyrochlore has been determined (fig. 1). This diagram demonstrates the presence of molecular water (1640 cm^{-1}) and the maximum at 1000 cm^{-1} may indicate a Si-O band. However, until now this method has not produced any satisfactory answer to the problem of how silicon is combined in the mineral.

The yellow siliceous pyrochlore sometimes occurs as elongated aggregates. These aggregates may possibly be pseudomorphs after the lamellar hydrous niobium silicate epistolite or perhaps after other niobium minerals. It is therefore possible that the silicon in the pyrochlore is related to remnants of primary niobium silicates. However, the low water content in the yellow siliceous pyrochlore is not in agreement with this idea.

CLASSIFICATION

In the present paper three chemical analyses of pyrochlore from Ilímaussaq are presented. In addition four partial chemical analyses have been made in the chemical laboratories of the Danish Atomic Energy Commission in connection with the examination of the niobium mineralizations of Ilímaussaq (see table 2).

Table 2. *Partial chemical analyses of pyrochlore.*

	63/16	77523	77524	MJ 3
SiO_2	12.4	2.0	10.3	15.7
Nb_2O_5	40.9	58.5	43.6	35.7
Ta_2O_5	0.2	1.3	0.3	
TiO_2	1.3	0.9	2.3	3.6
Fe_2O_3	1.1	3.4	0.8	0.8
TR_2O_3	8.5	10.9	16.9	17.9
Al_2O_3, CaO, etc.	6.3	7.9	4.5	7.1
Na_2O	9.2			
K_2O	0.4			
P_2O_5	1.6			
U_3O_8	0.07			
ThO_2	0.19			
not dissolved	8.9	3.9		1.8

Analyst: N. Hesselbjerg.

The samples analysed were not completely pure. Ta was determined by activation analysis, Nb and Ti were determined spectrophotometrically.

All availbale analyses display the following features in common:

1. The B-group of the chemical formula $A_2B_2(O,OH,F)_7$ is dominated by Nb; Ta and Ti are of subordinate importance.

2. The A-group is dominated by Na and Ca but contains considerable amounts of rare earth metals which may make up almost half of the cations of the group.

3. The Ce-group of rare earth metals predominates.

4. U and Th are inconspicuous. In accordance with this the Ilímaussaq pyrochlore is not metamict.

5. Ba and Sr are scarce.
6. The A-group is deficient in cations.
7. SiO_2 is present in considerable amounts.

As stressed above it has not yet been possible to explain the high SiO_2 content. If this problem is disregarded at the moment the analysed samples, according to the proposal by Bonshtedt-Kupletskaya (1966), should be classified as pyrochlore and as the variety marignacite which is rich in the Ce-group of the rare earth metals. However, as long as the content of silica is not accounted for we prefer to term the Ilímaussaq pyrochlore siliceous pyrochlore.

The high contents of Na, Nb, F, Si and Ce and the low contents of Ta, Ti, Sr and Ca distinguish the Ilímaussaq pyrochlores from the minerals of the pyrochlore group in other alkaline massifs (*e.g.* Lovozero, Vishnevi Gori and Kovdor).

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Færdig fra trykkeriet den 13. juni 1968.

PLATE

Plate 1.

Fig. 1. Electron micrograph of pyrochlore. Replica of fracture surface. × 6650. Photo: I. D. Beliaeva (IMGRE).

Fig. 2. Electron micrograph showing igdloite-lueshite replacing pyrochlore. Replica of surface. × 6600. Photo: I. D. Beliaeva.

Fig. 3. Igdloite-lueshite (light grey) replacing pyrochlore (dark). × 450, 1 nic. Photo: S. A. Gorzhevskaja (VIMS).

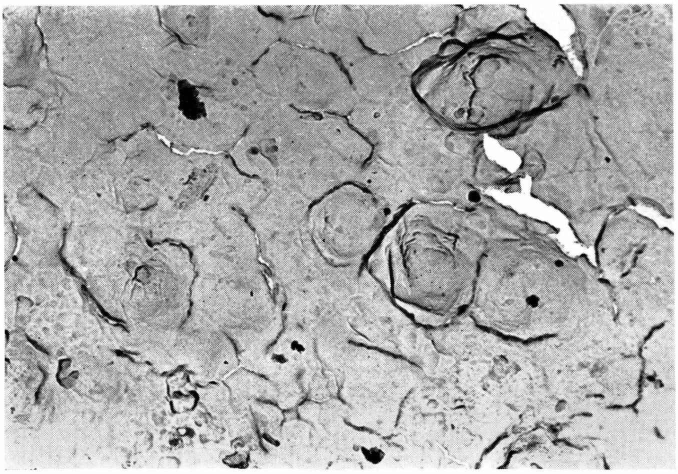

Fig. 1.

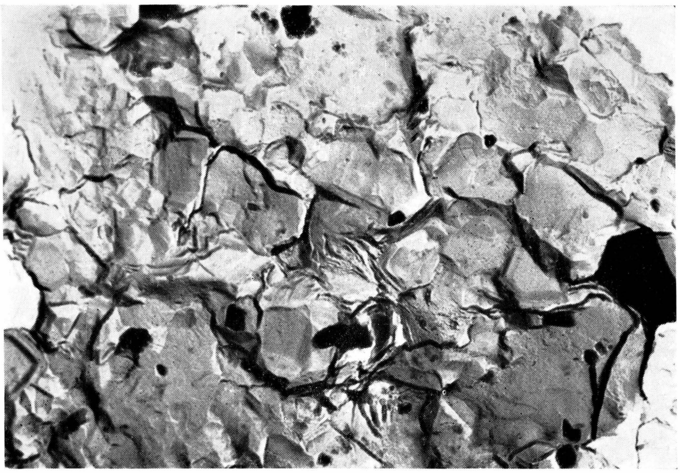

Fig. 2.

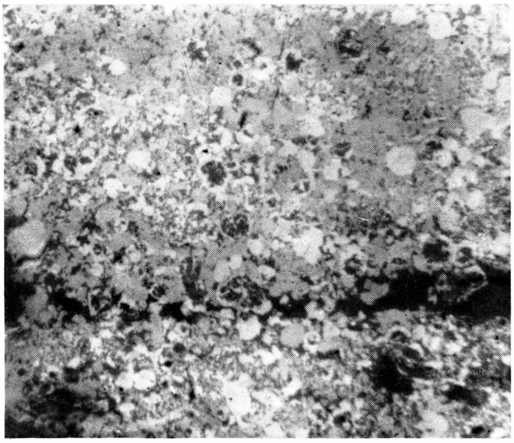

Fig. 3.