Hiortdahlite II from the Ilímaussaq alkaline complex, South Greenland, the Tamazeght complex, Morocco, and the Iles de Los, Guinea

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At Ilímaussaq hiortdahlite has only been known from a dyke located immediately to the south-east of the complex. This mineral has now been found in a pegmatite horizon in the sodalite-rich rock naujaite of the complex. It appears to be earlier than eudialyte and is regarded as having been formed at low alkalinity at an early stage of naujaite formation. The optical and X-ray parameters are identical to the data for hiortdahlite from Kipawa, Quebec, and indicate that the Ilímaussaq mineral is type II hiortdahlite.

Minerals from the Iles de Los, Guinea, and the Tamazeght complex, Morocco, have been examined by optical and X-ray methods and chemical analysis, and are shown also to be hiortdahlite II.

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Hiortdahlite, $(Ca,Na)_3(Zr,Ti)Si_2O_7(O,F)_2$, is a relatively rare mineral, only known from alkaline rocks. It is a sorosilicate belonging to the cuspidine–låvenite–wöhlerite group. It was first mentioned in a preliminary way by Brögger in 1888 and described in detail by the same author in 1890 from Arø in Langesundsfjord in the south-western part of the Oslo igneous province, Norway, where it occurs in a medium-grained, trachytoid nepheline syenite dyke. Neumann (1985) reports a few other occurrences of hiortdahlite in the Langesundsfjord area and in a granite near Skien to the north of Langesundsfjord.

Hiortdahlite is known from a few other localities. Lacroix (1910) expressed the view that hiortdahlite most probably also occurs in the nepheline syenites of the Iles de Los, Guinea, which has been confirmed by our studies (see below). Di Franco (1942) reported the mineral from Mt. Etna, Sicily, and Kapustin & Bykova (1965) reported it from the Korgeredaba alkaline complex, Sangilen Upland, SE Tuva, Russia. Kempe & Deer (1970) identified the mineral in the Kangerdlugssuaq alkaline complex, East Greenland, and Larsen & Steenfelt (1974) from an iron-rich peralkaline phonolite dyke immediately to the south-east of the Ilímaussaq complex, South Greenland; no chemical analyses or other information about the mineral were reported.

Aarden & Gittins (1974) presented chemical and X-ray data for hiortdahlite from the Kipawa River complex, Quebec, Canada, where it sometimes occurs in almost monomineralic veinlets in pyroxenite and amphibolite belonging to a regionally metamorphosed alkaline complex. Chemical and X-ray data have also been reported for hiortdahlite found in a phonolite dyke from the Jingera Rock syenite complex, New South Wales, Australia (Eggleton *et al.* 1979). The mineral X described by Kadar (1984) from the Tamazeght nepheline syenite complex in the High Atlas Mountains at Midelt, Morocco, has been found to be hiortdahlite (see below).

Merlino & Perchiazzi (1985, 1987) determined the crystal structure of hiortdahlite and distinguished hiortdahlite I and II, which co-exist at Kipawa River. Both

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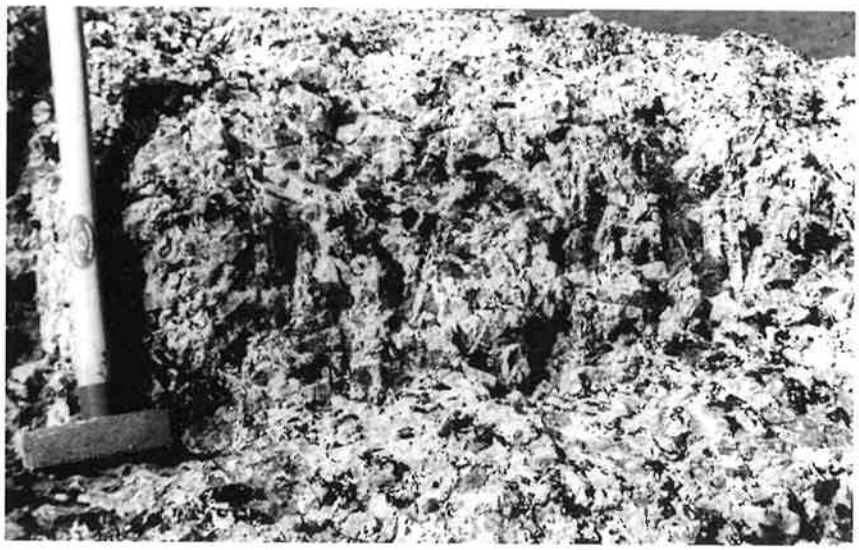


Fig. 1. The pegmatite at Tupersuatsiaat showing prismatic grains of sodalite (**white**) growing downwards from the contact against the overlying naujaite. Hammer head measures 12 cm.

are triclinic, but hiortdahlite II differs from type I in being pseudomonoclinic. They found that the type material from the Langesundsfjord and the Jingera Rock mineral is hiortdahlite I.

Hiortdahlite from the Ilímaussaq complex

Hiortdahlite has recently been found occurring as a subordinate mineral in a horizon of naujaite pegmatite (Fig. 1) in the NW corner of the bay Tupersuatsiaat on the south coast of the fjord Tunulliarfik (see Sørensen 2001, fig. 1, this volume, for the locality names mentioned in the text). These horizons are characterised by up to 10 cm long prismatic crystals of sodalite which have grown downwards from the hanging wall of the pegmatites at right angles to the horizontal contacts against the overlying naujaite (Sørensen & Larsen 1987). The sodalite crystals are partially replaced by analcime with preservation of their crystal forms. Interstitial to the sodalite are plates of microcline, crystals of nepheline, eudialyte and rinkite, and irregular grains of aegirine which often have cores of arfvedsonite in parallel growth, and aenigmatite. Small flakes of biotite and aggregates of natrolite are late minerals. The biotite flakes grow on the faces of the aegirine grains, whereas the natrolite occurs interstitially and as fracture fillings in analcime secondary after the elongated crystals of sodalite.

Hiortdahlite occurs as yellow-brown crystals associated with eudialyte and with aggregates of aegirine (Figs 2, 3). It is separated from the eudialyte by powdery reaction zones which, using the Debye–Scherrer method, have been identified as mixtures of hiortdahlite and catapleiite. There are no reaction zones against the aegirine.

Optical properties. The mineral is weakly pleochroic: γ = amber yellow, α = β = pale yellow or colourless. There is a strong dispersion: r < v, 2V (+) ~ 60°, α =

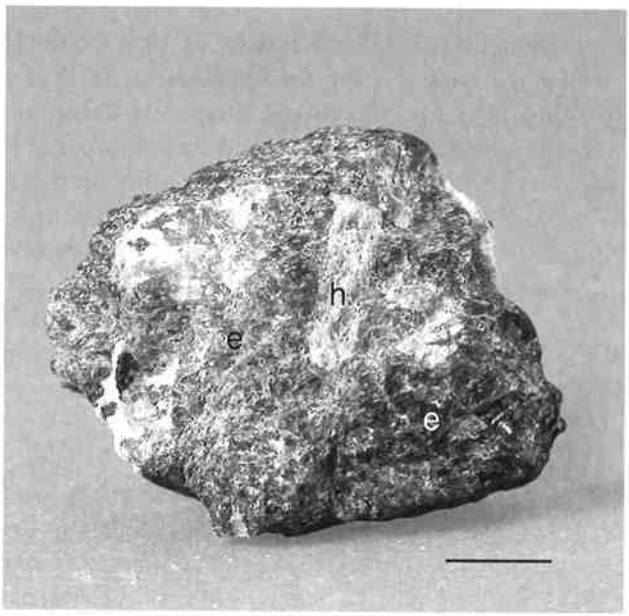


Fig. 2. Hand specimen (sample 104378, Geological Institute, University of Copenhagen) showing crystal of hiortdahlite (**h**) enclosed in eudialyte (**e**), scale = 1 cm. Photo: Ole Bang Berthelsen.

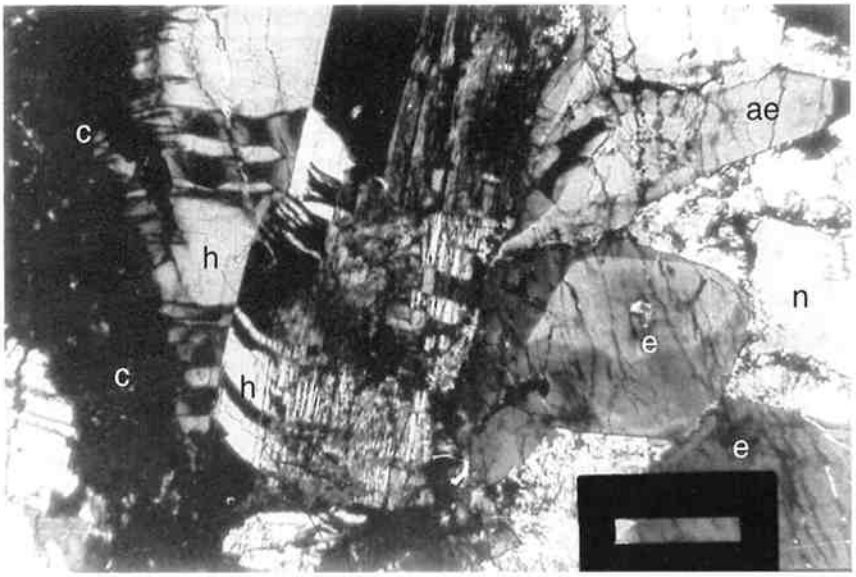


Fig. 3. Crystal of hiortdahlite (**h**) showing complex twinning. It is covered and intergrown by aggregates of fine-grained catapleiite (**c**, black area near left margin of photograph). Right part of photograph: an aegirine crystal (**ae**) and two crystals of eudialyte (**e**) showing zonation; centre right nepheline (**n**). Matrix is made up of fine-grained natrolite. Sample 104378 Geological Institute (same as Fig. 2), crossed polars, scale bar 0.6 mm.

Table 1. X-ray powder diffraction data for hiortdahlite

Ilímaussaq		Tamazeght		Iles de Los	
d	I/I_0	d	I/I_0	d	I/I_0
10.319	5	10.280	30	10.283	30
7.322	2	7.196	15	7.256	5
5.093	12	5.126	10	5.185	30
4.577	3	4.599	10	4.623	5
3.544	10	3.534	5	3.534	20
3.270	46	3.278	100	3.279	70
3.198	3				
3.020	86	2.998	100	2.999	100
2.882	100	2.858	100	2.867	90
2.727	1			2.691	10
2.592	7				
2.515	10	2.508	30	2.522	20
2.445	17	2.442	2	2.449	20
2.306	4	2.338	5	2.312	5
2.258	12	2.259	5	2.254	10
2.113	1				
2.067	9	2.067	30	2.076	10
2.030	33	2.027	30	2.032	40
1.956	11	1.953	10	1.957	5
1.844	15	1.845	20	1.845	30
1.803	27	1.801	20	1.801	20
1.777	17	1.749	10		
1.702	27	1.710	40 vb	1.698	40
1.624	3	1.648	10		
1.595	13	1.595	10 b	1.663	10 vb
1.543	36	1.543	30 b	1.549	20 vb
1.481	5				
1.460	7				
1.418	8				

Ilímaussaq: diffractometer, Geological Inst. (Copenhagen) sample 104040 deposited at Université Paul Sabatier, Toulouse.
Tamazeght: Debye-Scherrer method (Cu$K\alpha$, 360 mm), sample XT 15, Université Paul Sabatier, Toulouse.
Iles de Los: Debye-Scherrer method (Cu$K\alpha$, 360 mm), Lacroix sample MNHN n° 119-115.
b = broad, vb = very broad.

Table 2. Unit cell parameters of hiortdahlite calculated by the least squares method

	Ilímaussaq	Tamazeght	Iles de Los
a	10.979 Å	10.913 Å	11.008 Å
b	10.303 Å	10.427 Å	10.315 Å
c	7.340 Å	7.217 Å	7.335 Å
α	90.01°	90.31°	90.28°
β	109.28°	108.38°	109.36°
γ	90.28°	89.74°	90.11°

Ilímaussaq, Geological Institute (Copenhagen) sample 104040 deposited at Université Paul Sabatier, Toulouse.
Tamazeght, sample XT 15, Université Paul Sabatier, Toulouse.
Iles de Los, Lacroix sample MNHN no. 119-115.

1.643, β = 1.645 and γ = 1.656. The mineral shows polysynthetic twinning (Fig. 3).

Crystallography. The Ilímaussaq hiortdahlite was identified by its X-ray diffractogram (Table 1) which is identical to that of the hiortdahlite from Kipawa River (Aarden & Gittins 1974). The unit cell parameters were calculated by the least squares method (Table 2) and are very similar to the data on the Kipawa River hiortdahlite presented by Aarden & Gittins (1974).

The cell parameters and the refractive indices indicate that the Ilímaussaq hiortdahlite belongs to type II of Merlino & Perchiazzi (1987).

Infra-red spectroscopy and thermogravimetric analysis. The infra-red absorption spectrum recorded on a tablet of hiortdahlite and KBr shows a sharp band at 3430 cm^{-1} corresponding to (OH) in the H_2 vibration field.

The thermogravimetric analysis shows a loss of weight of 0.70% between 200 and 400°C. X-ray diffraction analysis of the powder after heating to 1000°C shows no significant structural change.

Chemical analysis. The hiortdahlites from the Ilímaussaq, Iles de Los and Tamazeght complexes were chemically analysed by electron microprobe (Table 3). The chemical analyses of the hiortdahlite from Ilímaussaq, Iles de Los and Tamazeght show that the Ilímaussaq mineral has the highest contents of Nb and F and that the inverse relation between Nb and F proposed by Mellini & Merlino (1979) for wöhlerite does not exist in any of these samples of hiortdahlite.

Hiortdahlite from Iles de Los and Tamazeght

Iles de Los, Guinea. Lacroix (1910) presented a partial description of a mineral which is abundant in a biotite-eudialyte-låvenite nepheline syenite. It shows various shades of yellow to brown colours and a glassy lustre on the crystal faces, but greasy on fracture surfaces. There is polysynthetic twinning, a weak pleochroism, γ = like yellow wine, β = clear yellow, α = colourless. These properties led Lacroix (1910) to suggest that this mineral may be related to the hiortdahlite described by Brögger (1890). G.C. Parodi and J. Skrok, Muséum d'Histoire Naturelle, Paris, France, kindly made available to us the material examined by Lacroix (MNHN n° 119-115). The X-ray powder diagram (Table 1) clearly indicates that the mineral is hiortdahlite, and the parameters presented in Table 2 show that it is hiortdahlite II. The electron microprobe analysis (Table 3) shows contents of ZrO_2 and F similar to those of the Ilímaussaq hiortdahlite, whereas Nb_2O_5 and REE_2O_3 are absent; their place is taken by MnO and FeO.

The Tamazeght complex, Morocco. Kadar (1984) described a grey-white mineral with conchoidal fracture and greasy appearance from a thin microsyenite dyke near the summit of Bou Tichlilt, where it is associated with nepheline, zircon, alkali feldspar and låvenite. It has γ = 1.652 and α = 1.646 and shows polysynthetic twinning but the data obtained were insufficient for the identification of the mineral, which was mentioned as mineral X. We have managed to obtain an X-ray powder diagram by the Debye–Scherrer method (Table 1) according to which this mineral is hiortdahlite II (Table 2). The electron microprobe analysis (Table 3) shows higher contents of ZrO_2 than in the Ilímaussaq hiortdahlite, and the absence of REE_2O_3 and Nb_2O_5. H_2O was not determined.

Table 3. Electron microprobe analyses of hiortdahlite

	Ilímaussaq		Tamazeght		Iles de Los	
	wt%	atoms*	wt%	atoms*	wt%	atoms*
SiO_2	29.96	1.919	30.08	1.930	30.32	1.945
TiO_2	0.94	0.046	0.36	0.019	0.93	0.046
ZrO_2	15.24	0.475	20.43	0.639	14.93	0.470
La_2O_3	0.11	0.003	n.d.	-	n.d.	-
Ce_2O_3	0.25	0.005	n.d.	-	n.d.	-
Y_2O_3	0.51	0.008	n.d.	-	n.d.	-
FeO	2.64	0.142	0.44	0.023	1.57	0.085
MnO	0.40	0.023	0.65	0.035	2.67	0.146
CaO	32.69	2.244	35.14	2.411	35.72	2.453
Na_2O	6.76	0.839	6.34	0.790	5.41	0.678
K_2O	n.d.	-	0.02	-	0.10	0.008
Nb_2O_5	2.24	0.032	n.d.	-	n.d.	-
H_2O†	0.70	0.231	n.a.	-	n.a.	-
F	11.05	2.233	9.47	1.918	10.41	2.103
	103.49		102.93		102.06	
– O for F_2	4.64		3.98		4.37	
	98.85		98.95		97.69	

Each analysis given is the average of 9 point analyses.
Ilímaussaq, Geological Institute (Copenhagen) sample 104040 deposited at Université Paul Sabaiter, Toulouse.
Tamazeght, sample XT 15, Université Paul Sabatier, Toulouse.
Iles de Los, Lacroix sample MNHN no 119-115.
n.a. = not analysed, n.d. = not detected.
* Calculation of the structural formula for Ilímaussaq material based on (O,OH,F) = 9.000; for Tamazeght and Iles de Los based on (O,F) = 9.000.
† Thermogravimetric analysis.
Camebax SX 50 electron microprobe at the Laboratoire de Minéralogie, Université Poul Sabatier, Toulouse. Standards used: wollastonite (Ca, Si), albite (Na), zircon (Zr), $MnTiO_3$ (Ti), YPO_4 (Y), hematite (Fe), topaz (F), $NbLiO_3$ (Nb), Al_2O_3 (Al). For the REE, the standards of Jarosewich & Boatner (1991) were used.

Paragenesis

In the Ilímaussaq complex, hiortdahlite has so far been identified at only one locality within the complex and in a dyke immediately to the south-east of the complex. In contrast to this, the rinkite group minerals, which are also Na-Ca-Zr-Ti-Nb sorosilicates, are of widespread occurrence in the complex. The rinkite group minerals differ from hiortdahlite in having distinctly higher contents of Na, Ti, Nb, Y and REE, and lower contents of Zr, Ca and F. At Tupersuatsiaat, hiortdahlite occurs in a sodalite-rich naujaite pegmatite which forms a distinct horizon in the naujaite. The naujaite in this horizon contains scattered grains of fayalite, hedenbergite, apatite and titanomagnetite, which were formed at low alkalinity at an early stage of formation of the naujaite (Larsen 1976). The hiortdahlite at this locality is associated with eudialyte (Figs 1, 2) and aegirine and separated from the eudialyte by a fine-grained zone of catapleiite, which is interpreted as a zone of reaction indicating that the hiortdahlite crystallised earlier than the eudialyte. Rinkite is generally formed after eudialyte in the naujaites. The succession hiortdahlite – eudialyte – rinkite may then be interpreted as an expression of increasing alkalinity during the crystallisation of the naujaite.

According to Larsen & Steenfelt (1974), hiortdahlite in the dyke locality to the south of the complex is restricted to alkali-poor parts of the dyke, where it is associated with zircon. This part of the dyke is made up of perthitic alkali feldspar, nepheline, sodalite, aegirine-hedenbergite, biotite, magnetite, apatite, fluorite and pyrrhotite. The alkali-rich parts of the dyke are made up of an agpaitic mineral assemblage corresponding to the early stages of the roof-series of the Ilímaussaq complex (Larsen & Sørensen 1987). Phenocrysts of fayalite, diopside-hedenbergite, nepheline, alkali feldspar and minor magnetite are set in a

matrix of microcline and albite in separate grains, nepheline, sodalite, aegirine, arfvedsonite, eudialyte, aenigmatite, apatite, fluorite, pyrite and late analcime and natrolite. The alkali-poor parts of the dyke are found close to the Ilímaussaq complex and its mineral assemblage is interpreted to have formed as a result of loss of alkalis because of heat from the adjacent intrusion.

This interpretation is in accordance with the description of the Langesundsfjord occurrence of hiortdahlite (Brögger 1890). There, hiortdahlite is restricted to a suite of medium-grained dykes made up of microperthitic alkali feldspar, lepidomelane and nepheline. These dykes are poor in mafic minerals and sodalite and without eucolite (eudialyte), mosandrite (rinkite), astrophyllite, catapleiite and leucophanite, minerals which are important in pegmatites in other parts of this contact zone of the Oslo igneous province. Brögger (1890) mentions that the medium-grained dykes containing the hiortdahlite also contain homilite, erdmannite, löllingite, zircon, fluorite, molybdenite, titanite, Y-garnet, rare wöhlerite, analcime and zeolites. According to this description hiortdahlite is restricted to alkali-poor nepheline syenite dykes.

The Kipawa River hiortdahlite, according to Aarden & Gittins (1974) and Gittins *et al.* (1976), occurs in almost monomineralic veins in alkaline amphibolite and is associated with zircon, britholite, fluorite, albite, nepheline and calcite. It is not clear from the descriptions how these veins are related to the occurrences of eudialyte, wöhlerite, agrellite, miserite, rinkite and vlasovite in this complex.

The Tamazeght hiortdahlite is also associated with zircon.

The Iles de Los hiortdahlite appears from the description of Lacroix (1910) to be associated with nepheline, eudialyte, låvenite and biotite. According to Lazarenkov (1975) hiortdahlite is an accessory mineral in foyaites, which also contain wöhlerite.

The hiortdahlite from Jingera Rock occurs in a metre-wide phonolite dyke made up of aegirine, alkali feldspar and interstitial sodalite and nepheline. The hiortdahlite contains inclusions of magnetite and apophyllite(?) (Eggleton *et al.* 1979).

The description of the occurrences of hiortdahlite at Kangerdlugssuaq, Mt. Etna and Korgeredaba, Tuva referred to above do not supply sufficient information about the paragenetic relations to allow a comparison with the data from Langesundsfjord, Ilímaussaq, Kipawa River, Iles de Los and Tamazeght.

Conclusions

This survey of the mineral associations, in which hiortdahlite is reported to occur, does not lead to a clear picture. An environment relatively poor in alkalis, Ti, REE and Nb and rich in Zr, Ca and F appears to favour the formation of this mineral rather than the rinkite group minerals. The relation to låvenite is uncertain. Hiortdahlite and eudialyte may occur in the same rock, as described from Ilímaussaq and Iles de Los; in Ilímaussaq hiortdahlite appears to be earlier than the eudialyte and not formed in equilibrium with that mineral. The Ilímaussaq occurrence of hiortdahlite is controversial because it occurs in an alkali-rich environment. It appears, however, to have been formed at low alkalinity at an early stage of the evolution of the naujaite. Other chemical parameters may, however, also contribute to the formation of hiortdahlite. It is interesting in this connection to note that hiortdahlite has not been reported from the Khibina and Lovozero alkaline complexes of the Kola peninsula, which are characterised by the occurrence of a wealth of minerals rich in Ti, Nb and REE (cf. Khomyakov 1995; Semenov 1997).

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