occur together in approximately equal proportions, indicating an original Fe–Ti oxide of the composition Usp$_{85}$Mt$_{15}$. Graphical pyroxene thermometers (e.g. Saxena *et al.*, 1986) suggest a very wide range of crystallisation temperatures (around 1350 to 1000 °C) for the S.E. Greenland dykes, for which the late-stage precipitation of near end member ulvöspinel indicates f_{O_2} conditions of $-\log f_{O_2} = 13$ (cf. Lindsley, 1976).

In contrast to the Proterozoic dolerites, the pyroxenes in the Tertiary olivine-dolerite dykes of S.E. Greenland are relatively chemically uniform pigeonite–augite pairs (Fig. 1*f*), which suggest a crystallisation temperature of between 1100 and 900 °C. These dykes contain early precipitated titanomagnetite, and their chilled margins carry microphenocrysts of ilmenite and magnetite. The combination of this pyroxene assemblage and the composition and early precipitation of the Fe–Ti oxide phases in these Tertiary rocks clearly indicate that they crystallised under slightly higher f_{O_2} conditions than did the neighbouring Proterozoic dykes.

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KEYWORDS: pyroxene, dolerite, S.E. Greenland.

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First occurrence of dalyite in extrusive rock

THE potassium-zirconosilicate dalyite, K$_2$ZrSi$_6$O$_{15}$, has so far been described from four localities: in peralkaline granites from Ascension Island (Van Tassel, 1952; Roedder and Coombs, 1967; Harris *et al.*, 1982) and from Antarctica (Harris and Rickard, 1987); in peralkaline quartz syenites from the Azores (Cann, 1967), and from Western Norway (Robins *et al.*, 1983). This is the first account of dalyite from an extrusive rock. It was found in the Sierra de Cabras, two km W of Cancarix in the Province of Albacete, SE Spain. Here, by processes of selective erosion, the remnants of a lava-filled crater rise above their surroundings of alpine deformed Mesozoic and Tertiary sediments (Fuster *et al.*, 1967). The volcanic body extends 1100 m NS and 800 m EW. Layers of breccias, lithic tuffs and glassy flows mark the conically inclined contacts with the country-rock. The mass of the body—several tens of millions of m^3—is composed of holocrystalline

Table 1.
XRF analyses and norm of a dalyite-bearing cancalite from Cancarix

SiO_2	55.168
TiO_2	1.520
ZrO_2	0.105
Al_2O_3	8.834
Cr_2O_3	0.103
Fe_2O_3	1.870*
FeO	3.160*
NiO	0.067
MnO	0.075
MgO	12.477
CaO	3.501
SrO	0.107
BaO	0.243
K_2O	8.848
Na_2O	1.036
P_2O_5	1.225
Total	98.340
Z	0.16
Or	49.11
Ac	5.51
Ks	1.14
Ns	0.62
Di	8.10
Hy	24.32
Ol	4.99
Cm	0.15
Il	2.94
Ap	2.95
Total	99.99

* Ratio based on average calculated from eleven analyses of cancalites by Fuster et al. (1967).

Table 2. Electron microprobe analyses and structural formulae of dalyite from Cancarix and dalyite analyses from the literature

	1	2	3	4	5	6	7		8		9
SiO_2	62.6	62.4^5	62.6^5	62.9^5	62.6^5	63.0	62.72		63.07		61.85
Al_2O_3	0.1	0.1	0.1	0.0^5	0.0^5	0.0^5	0.08		0.06		-
TiO_2	1.2^5	1.1	1.1	0.7^5	1.1^5	0.8^5	1.03		1.23		-
ZrO_2	19.1	19.2	19.3^5	19.4	19.6	19.7	19.39		19.37		21.70
Fe_2O_3	0.2*	0.2*	0.2*	0.2*	0.1^5*	0.2*	0.19*		-		0.37*
FeO	-	-	-	-	-	-	-		0.28**		-
MnO	n.d.	-	-	-	-	-	-		0.02		-
MgO	n.d.	n.d.	-	0.0^5	n.d.	0.0^5	0.02		0.10		-
BaO	0.4^5	0.3	0.4	0.1^5	0.2^5	0.3^5	0.32		0.11		-
CaO	n.d.	-	-	-	-	-	-		0.02		-
Na_2O	0.1^5	0.1^5	0.1^5	0.1	0.1^5	0.1^5	0.14		0.04		1.75
K_2O	15.7^5	16.1	16.1	15.9^5	16.2^5	16.1	16.04		15.60		14.60
P_2O_5	-	-	-	-	-	-	-		0.04		-
Total	99.6	99.6	100.0^5	99.6	100.2^5	100.4^5	99.93		99.94		101.91$^+$
Ions on the basis of 15(O)											
Si	6.00	6.00	5.99^5	6.02	5.98^5	6.00	6.000		6.006		5.95
Al	0.01	0.01	0.01	0.01	0.01	0.01	0.010	1.004	0.007	0.994	-
Ti	0.09	0.08	0.08	0.0^5	0.08^5	0.06	0.074		0.088		-
Zr	0.89^5	0.90	0.90^5	0.90^5	0.91^5	0.90^5	0.905		0.899		1.01
Fe^{3+}	0.01^5	0.01^5	0.01^5	0.01^5	0.01^5	0.01^5	0.015		-		-
Fe^{2+}	-	-	-	-	-	-	-		0.022	1.951	-
Mg	-	-	-	0.00^5	-	0.00^5	0.002	1.997	0.015		-
Mn	-	-	-	-	-	-	-		0.002		-
Ca	-	-	-	-	-	-	-		0.002		-
Ba	0.01^5	0.01	0.01^5	0.00^5	0.01	0.01	0.011		0.004		-
Na	0.02^5	0.02^5	0.03	0.02	0.03	0.03	0.026		0.007		0.32
K	1.93	1.97	1.96^5	1.95	1.98^5	1.96	1.958		1.896		1.79
P	-	-	-	-	-	-	-		0.003		-

* Total iron as Fe_2O_3.
** Total iron as FeO.
\+ Includes 0.64% H_2O.
n.d. Not detected.

1 - 6 Point analyses of dalyite from Cancarix.
7 Arithmatic mean of analyses 1-6.
8 Dalyite from Sunnfjord (Robins et al., 1983).
9 Dalyite from Ascension (Van Tassel, 1952).

homogeneous rock without any apparent directed structures other than columnar cooling joints running without interruption throughout the whole height of the exposed walls (up to 60 m). This suggests that the volcanic body was formed by a single extrusion of a huge volume of magma filling a previously blown-out crater. The volcanite has a K–Ar age of 7.2–7.6 Ma (Nobel *et al.*, 1981). The sheer volume makes it highly feasible that cooling and solidification of the bulk of the magma took place rather slowly and uniformly, which explains the coarse and rather plutonic structure of this volcanite. The rock, an alkali trachyte following the IUGS Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1978), can be grouped with the lamproites, as defined by Niggli (1923), because of its high K_2O and MgO contents and relatively low Al_2O_3 content (Table 1). As the norm features forsterite but lacks leucite, the lava is a cancalite (after Cancarix) in the classification of Spanish lamproites by Fuster *et al.* (1967).

Sanidine forms *c.* 50 vol. % of the rock, building euhedral skeletal subradiating aggregates (up to four mm in size), intergrown with abundant (*c.* 25 vol. %) interstitial crystals (up to three mm in size) of titanian potassium-richterite. Most other components occur mainly as inclusions in the poikilitic sanidine crystals. Olivine is thus present as fresh anhedral crystals and peridotitic xenoliths that may attain 2.5 mm in diameter. Corroded inclusions of phlogopite with sagenitic exsolutions are also present in the sanidine crystals, as are numerous euhedral short (±0.2 mm) prisms of diopside, apatite needles and scarce opaque grains. Where not enclosed by sanidine, olivine relics are corroded by interstitial orthopyroxene whereas relics of diopside and phlogopite are replaced by titanian potassium-richterite. These relations indicate SiO_2 saturation of the post-sanidine residual melt. Quartz, however, is not found. Scarce subhedral dalyite crystals (*c.* 150 μm) occur in close association with titanian potassium-richterite, often bordering the voids of druses (Fig. 1) in which tiny euhedral prisms of aegirine can be found also.

Due to its low to moderate relief and weak birefringence in most orientations, the colourless dalyite is not conspicuous in transmitted light. Dalyite crystals, however, are easily detected on the backscattered electron monitor (Fig. 1) and the Zr–$L\alpha$ X-ray image. The estimated 2Vα of *c.* 70° and observed twinning are in accord with data given for the original Ascension Island dalyite by Van Tassel (1952). Electron microprobe analyses were performed with a Cambridge Instruments

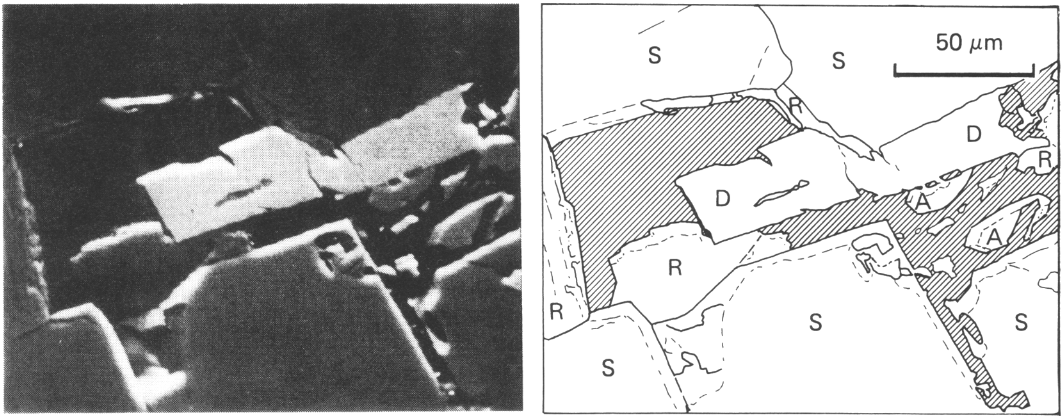

FIG. 1. Backscattered electron image of polished thin section of cancalite from Cancarix and drawing showing crystals of dalyite (D), titanian potassium-richterite (R) and aegirine (A) in a druse, among crystals of sanidine (S).

Microscan 9 using an accelleration voltage of 15 kV; for qualitative work we used a Geoscan equipped with a Link energy-dispersive system. The following standards were used: diopside (Si), corundum (Al), ilmenite (Ti), zircon (Zr), fayalite (Fe), foresterite (Mg), baryite (Ba), jadeite (Na), orthoclase (K). The results were ZAF-corrected with the Microscan-9 on-line correction program. Formulae based on electron microprobe analyses of six points in four grains are close to $K_2ZrSi_6O_{15}$ (Table 2). The Spanish dalyite shows a mere 2% replacement of K (by Na, Ba, and Mg), 10% replacement of Zr (mainly by Ti) and has the tetrahedral sites fully occupied by Si.

Lamproites, like most other peralkaline rocks, are relatively rich in Zr. Our sample contains 0.105 wt. % ZrO_2, which is equivalent to 777 ppm Zr. Values from the literature for other lamproites vary from 520 to 3110 ppm Zr (Wade and Prider, 1940; Carmichael, 1967; Sheraton and Cundari, 1980; Kuehner *et al.*, 1981). Yet the mineral zircon has not been reported from any of the lamproite occurrences. Instead, wadeite ($K_2ZrSi_3O_9$) is the Zr-phase found in the leucite-bearing lamproites from West Kimberley (Prider, 1939) and Leucite Hills (Carmichael, 1967).

The occurrence of dalyite intergrown with late-stage titanian potassium-richterite in this leucite-free Spanish lamproite adds evidence to the empirical findings (for references see Linthout, 1984) that: in peralkaline rocks alkali-zirconosilicates are likely to be formed and not zircon; dalyite occurs in peralkaline feldspathoid-free rocks, whereas wadeite is found in feldspathoid-bearing types; and dalyite crystallizes in close association with late-stage alkali-Mg-Fe-Ti-silicates.

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The structural behaviour of the nepheline family: (3) Thermal expansion of kalsilite

THE published structures of $SrAl_2O_4$ and $BaAl_2O_4$ (Schulze and Müller-Buschbaum, 1981; Hörkner and Müller-Buschbaum, 1979) and the change in the cell parameters of their solid solution series as a function of temperature and composition (Henderson and Taylor, 1982; Paper 1 of this series) indicated that their structural behaviour could be pictured in terms of two tilt systems. One (tilt 1) is a cooperative rotation of the framework tetrahedra about the three-fold axes which lie parallel to the *c*-axis, and the other (tilt 2) is a cooperative tilting of the framework tetrahedra relative to the 0001 plane. Both increasing temperature and increasing the size of the cavity cation were deduced to cause partial removal of both tilt systems. Distance Least Squares (DLS) modelling of the monoclinic $(Ba,Sr)Al_2O_4$ solid-solution series has confirmed significant changes in both tilt systems for compositional effects, but smaller changes for thermal effects (Taylor *et al.*, 1985; Paper 2 of this series). It was not possible to explore the behaviour of the two tilt systems for the hexagonal $(Ba,Sr)Al_2O_4$ solid-solution series by the DLS method because of severe problems in modelling their structures. For compositions close to, and including, $BaAl_2O_4$ the decreasing rate of thermal expansion of the *c*-axis indicated that removal of the second tilt system was reaching a limit (Henderson and Taylor, 1982). Unfortunately, it was not possible to explore this effect by further increasing the size of the cavity cation because Ba is the largest of the divalent, alkaline earth cations. However, the structures of the subcells of $BaAl_2O_4$ (Do Dinh and Bertaut, 1965; Uchikawa and Tsukiyama, 1966; Perrotta and Smith, 1968) and kalsilite, $KAlSiO_4$ (Perrotta and Smith, 1965), show that they are in a similar state of structural collapse. Moreover, there is scope for increasing the cavity cation size in kalsilite by replacing some K by Rb. If sufficient replacement

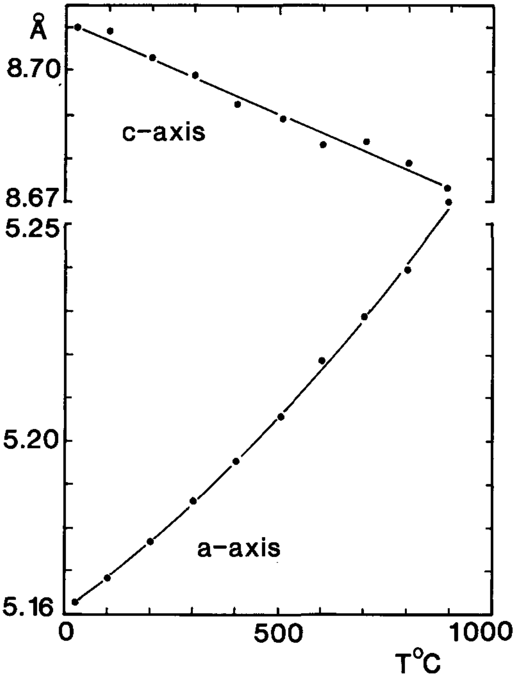

FIG. 1. Thermal expansion curves and observed data for synthetic kalsilite, $KAlSiO_4$.