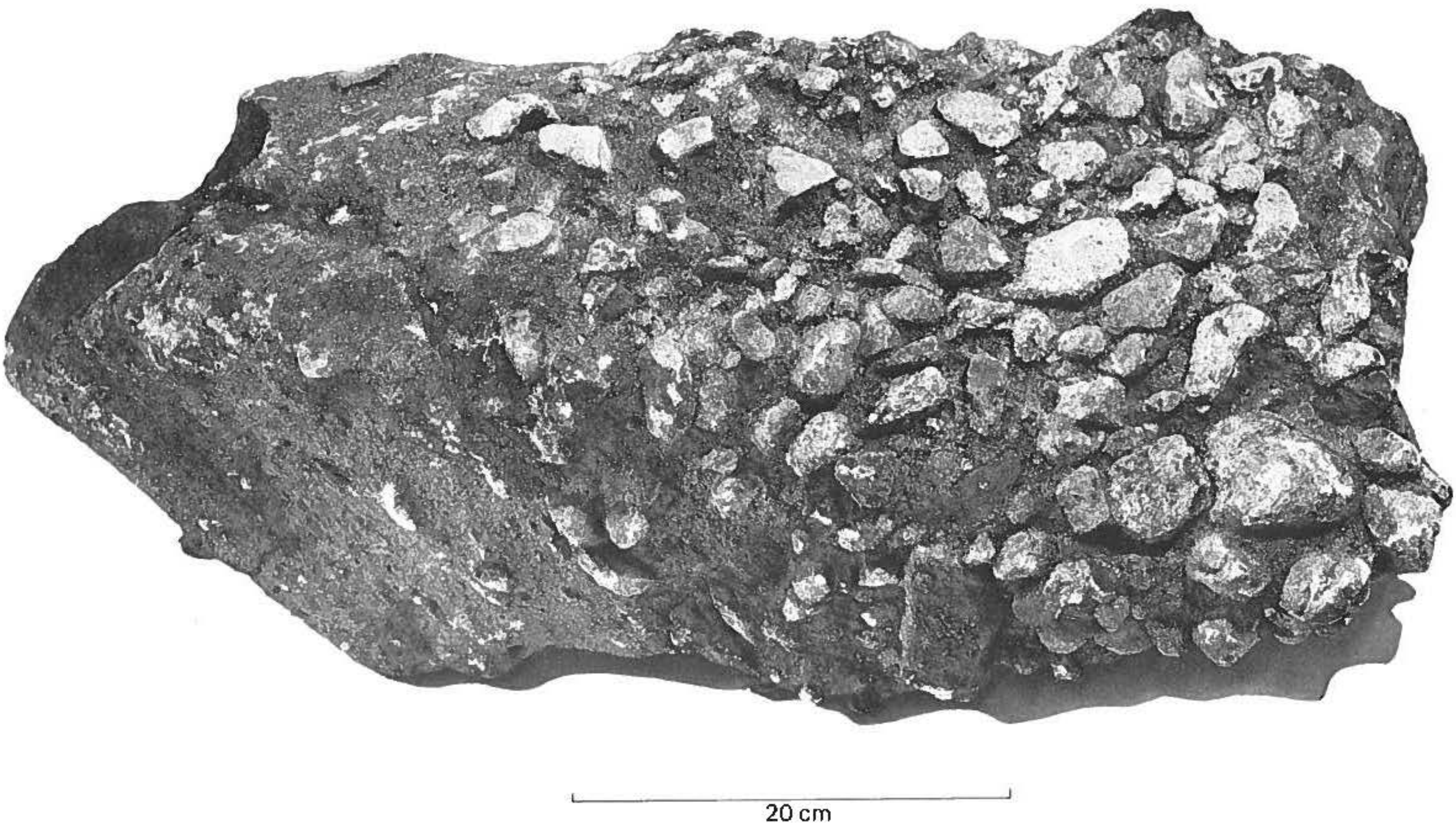
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Kimberlites of West Greenland

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Introduction

Kimberlites were first found in Greeenland during primary mapping of the Ivigtut and Frederikshåb areas by the Geological Survey of Greenland (Andrews & Emeleus, 1971) and it is now known that this rare ultrabasic rock occurs sporadically on the west coast at least as far north as Holsteinsborg (fig. 469). A considerable number of localities in the Holsteinsborg–Søndre Strømfjord region have been pinpointed during the recent investigations of the Nagssugtoqidian boundary (Escher & Watterson, 1973) and a kimberlite dyke at Søndre Isortoq has been studied in detail by Goff (1973). As 1:20 000 mapping of the west coast proceeds northwards, further discoveries seem likely as immediate identification has proved elusive during reconnaissance mapping. Extensive petrological and structural studies of the South-West Greenland kimberlites have recently been completed (Emeleus & Andrews, 1975; Andrews & Emeleus, 1975).

South-West Greenland kimberlites

The three areas in which kimberlites have been reported, Nigerdlikasik (62° 02′N, 48° 51′W), Midternæs (61° 33′N, 48° 10′W) and Pyramidefjeld (61° 33′N, 48° 10′W) have been mapped in great detail during prospecting operations. Eight microscopic diamonds have been recovered from four rock samples (Prast, 1973). All kimberlites so far located are massive mica-rich types which petrographically and geochemically closely resemble the Benfontein sill in South Africa (Dawson & Hawthorne, 1973)

Fig. 468. Kimberlite with abundant rounded xenoliths of mantle material, from 2 m dyke. Nanîtsorssuaq, Holsteinsborg district.

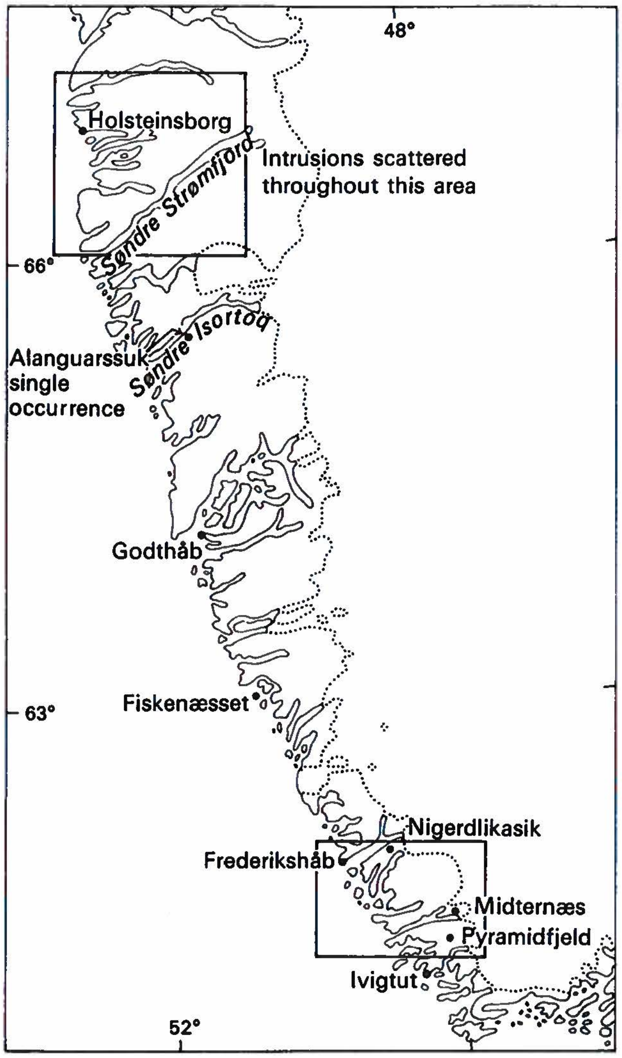

Fig. 469. Localities of kimberlite intrusions in West Greenland.

and hardebank porphyritic kimberlite from Pipe 200, Lesotho (Kresten & Dempster, 1973). Xenoliths of olivine-rich peridotite are frequently encountered and in addition fragments of acid and basic pyroxene granulites occur in the Nigerdlikasik dyke (fig. 470).

Field relationships

Thin (0.1–2 m) sheets of kimberlite at all three localities were intruded along zones of pronounced platy jointing which because of preferential erosion under recent glacial conditions form one of the most prominent field indications of their presence. Exposures are frequently concealed beneath rubble derived from the closely jointed host granite, gneiss or metasediment. Dyke intrusion in the Nigerdlikasik area follows an *en echelon* pattern maintaining a constant (140°) trend for over 3 km through pre-Ketilidian gneisses. Selective erosion of the adjacent shattered gneisses has developed shallow gullies commonly 5–10 m wide. Impersistent flat-lying sheets in the Pyramidefjeld granite complex outcrop at 20–50 m vertical intervals between altitudes of 400 and 900 m. Distinct systems of interconnected sills are centred about Grydesø, Safirsø–Blokpass, Østvoldgrav–Vestvoldgrav, and the west and south-west side of Pyramidefjeld (see Andrews & Emeleus, in press, fig. 2). The sheets extend for up to 2 km beyond the granite contact into pre-Ketilidian gneisses. On Midternæs kimberlite sheets dip gently westward rising from sea level at Sioralik Bræ to about 600 m, passing from pre-Ketilidian gneisses into the Ketilidian succession.

Contacts are microscopically sharp (fig. 471) but often manifested by small scale mechanical shattering with thermal effects restricted to sericitisation of calcic cores of plagioclase. A rare occurrence of associated carbonate metasomatism can be seen on Midternæs where complete calcification of part of a banded siltstone in the Ketilidian succession takes place for up to 2 m from a kimberlite sheet where it becomes confined beneath a thick gabbro sill. Extensive serpentinisation adjacent to the margins enables identification of internal contacts as green weathering zones in both dykes and sheets, and accumulation of sedimented nodules and xenocrysts from successive pulses of magma may impart a layered appearance to the base of sheets (fig. 472). Layering due to 3–10 mm thick concentrations of opaque minerals and perovskite is seen in kimberlites on Midternæs and is similar to, though not so impressive as, the excellent structures in the Benfontein sill (Dawson &

Fig. 470. Apparent alignment of peridotite and granulite inclusions perpendicular to the walls in the Nigerdlikasik dyke.

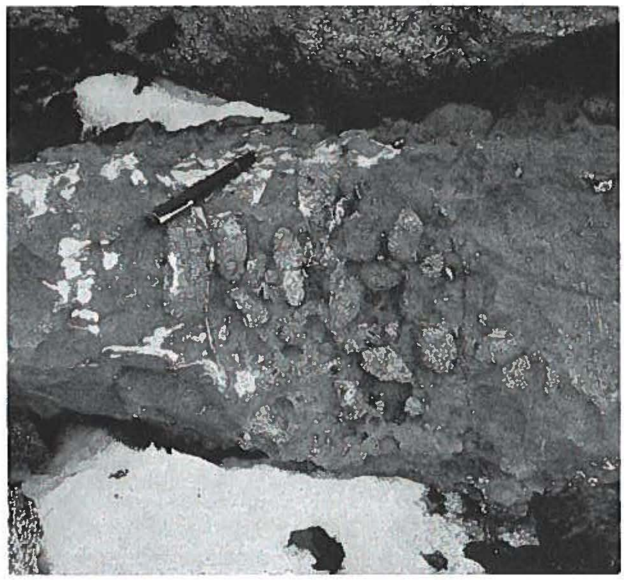

Fig. 471. Thin section of kimberlite in contact with granite-gneiss (left), showing good size-sorting parallel to the contact, and indications of alignment of the kimberlite minerals parallel to the contact. Plane polarised light, × 6.

Hawthorne, 1973). Strong associated preferred orientation of micas together with truncated contacts imply that flow differentiation is important here, a process also suggested by a diminution in megacryst size at margins and around nodular inclusions. Fibrous calcite fills internal systems of veins formed at a late stage after consolidation of the magma.

Petrology and mineralogy

The kimberlites are fresh, tough, porphyritic peridotites in which the dominant mineral phase, olivine, is set in a groundmass of carbonate, serpentine, phlogopite mica and often diopside. Modal mineral proportions vary considerably (Emeleus & Andrews, 1975, table 1). Both phenocrystal and xenocrystal olivine show a considerable compositional range (Mg_{76-92}), exhibit slight (1–2 % Mg) normal zoning to iron-rich margins and occasional more extreme reverse zoning to magnesium-rich margins (ibid., fig. 1) converging on a compositional band about Mg_{87-91}. Slight zoning has also been detected in groundmass diopside which is very abundant in the Midternæs sheets. Mica, rare as xenocrysts but common in the groundmass, is magnesium-rich phlogopite. Red rims of tetraferriphlogopite characterised by reverse pleochroism are well developed in parts of the Pyramidefjeld sheet system and frequently seen elsewhere. Serpentine is an important late crystallising, pale green or grey *primary* mineral of an unusually iron-rich composition (ibid., table 2) occurring as interstitial fibrous or structureless patches. Secondary serpentine is usually abundant as a pale green or colourless alteration product after olivine. Many groundmass opaque minerals are composite grains of chromite and titaniferous magnetite (ibid., figs 4, 5). Ever present perovskite is usually surrounded by a black frill of opaque material. Apatite is also prominent among minor kimberlitic minerals which include a wispy amphibole in the Pyramidefjeld sheets and very occasional xenocrysts of garnet. Diamond was only recovered after careful crushing of large amounts of material.

Textural relations indicate that the kimberlite magma crystallised olivine, opaque oxides and perovskite at an early stage before emplacement to its present levels. Crystallisation of clinopyroxene and phlogopite was accompanied and outlasted by carbonate (both calcite and ferroan dolomite) and serpentine which fill the interstitial spaces. Zoning in olivine

Fig. 472. Loose boulder from kimberlite sheet at Safirsø, Pyramidefjeld. The boulder is shown in its original orientation. Note (a) the rough weathered surface caused by protruding olivine meagcrysts, (b) the concentration of nodules and megacrysts into distinct zones parallel to the edge of the sheet, and (c) the concentration of nodules towards the base of the sheet. Hammer shaft 25 cm.

and diopside results from differentiation prior to emplacement and/or crystallisation over a temperature interval. Residual pockets of liquid were somewhat iron-enriched and depleted in alumina as evidenced by interstitial ferroan dolomite, iron-enriched serpentine and the alumina-deficient tetraferriphlogopite rims to micas.

Xenoliths

All the kimberlite bodies carry a suite of rounded inclusions, dominantly olivine-rich periodotites with occasional pyroxene granulites. The most spectacular concentrations occur in sheets on the north side of Pyramidefjeld where poorly sorted basal accumulations of nodules and xenocrysts superficially resemble conglomerates. Elsewhere xenoliths are more sparsely distributed, especially on Midternæs, though not totally absent. Most peridotites are lherzolites with an aluminous phase (garnet, spinel or phlogopite) and secondary reaction products which include phlogopite and serpentine. Some nodules from Pyramidefjeld have textures which can be classified as granular (porphyroclastic) and sheared (mosaic) following Boullier & Nicolas (1973), who interpret them as evidence of high temperature deformation.

In peridotite xenoliths olivine shows only rarely slight compositional variation around Mg_{91}. An exception is a nodule (GGU 126738) with porphyroclastic texture in which large strained olivines (Mg_{77}) are set in a fine-grained recrystallised matrix of magnesian olivine (Mg_{86}) and rare mica. Clinopyroxenes are chrome-rich diopsides showing a limited range of solid solution towards enstatite, largely within field 'A' of Boyd & Nixon (1972). Chromium, aluminium and titanium contents show significant variations in distribution between diopsides from the three peridotite types resulting from differing partition of these elements with either garnet, spinel or phlogopite (Emeleus & Andrews, 1975, fig. 6). Orthopyroxene is the second most common mineral after olivine and has a very uniform composition of about Mg_{91}. The pattern of minor element variation in orthopyroxenes follows clinopyroxene. Lamellar inclusions of brown spinel and probable clinopyroxene occur occasionally in the central parts of crystals probably as a result of exsolution. Garnets are chrome-pyrope with up to 16 % uvarovite, 71 % pyrope and 4 % knorringite molecules. They are commonly more or less altered with rims of chrome-spinel, orthopyroxene, minor clinopyroxene and often phlogopite; the phlogopite frequently forms a marginal zone between the reaction coronas and adjoining olivine or pyroxene suggesting disequilibrium between the two aluminous phases (op. cit., fig. 7). Phlogopite in this textural setting is primary in contrast to that which occurs interstitially along fracture zones penetrated by kimberlite, carbonate and serpentine. Large plates of primary mica in phlogopite peridotites are sometimes spaced randomly through the rock and frequently grouped into ill-shaped aggregates. In some xenoliths they occur in complex intergrowth with clinopyroxene and skeletal opaque minerals. The xenolith mica compositions have higher Mg/Fe and Si/Al ratios than those in the kimberlite groundmass but Ti and Cr are somewhat variable (Emeleus & Andrews, 1975, fig. 2). Characteristic alternation of large primary mica plates to dark rims or even red rims occurs in cases of extensive kimberlite penetration. Spinel peridotites are notably fresh, the chrome-rich spinel occurring interstitially as deep golden grains between olivine and pyroxene. In one periodotite (GGU 72501 G2) chrome-spinel forms part of an equilibrium assemblage with garnet. Opaque inclusions within garnet are chromites whilst those in the reaction coronas around garnet are of similar composition to primary chrome-spinels (op. cit. fig. 4).

Peridotite xenoliths are fossil representatives of the upper mantle beneath the continental crust at the time of kimberlite emplacement, probably during the early Mesozoic in South-West Greenland. In general garnet-bearing peridotites came from greater depths than spinel-bearing peridotites. The role of peridotites in which large phlogopite plates represent the aluminous phase is less certain; some evidence points to their possibly being derived from higher mantle levels where garnet and spinel are unstable. However, occasionally xenoliths contain both garnet and phlogopite which may originally have been in stable co-existence. Recently, attempts have been made to use the compositions of co-existing mineral phases to estimate equilibration pressures and temperatures of peridotites. Using the data of Boyd (1973) and MacGregor (1974) for assemblages containing clinopyroxene and orthopyroxene with pyrope garnet, a garnet peridotite nodule (GGU 126732) from Pyramidefjeld containing clinopyroxene ($Ca_{46.8}Mg_{49.2}Fe_{4.0}$) and orthopyroxene ($Ca_{0.6}Mg_{91.8}Fe_{7.6}$; Al_2O_3 = 0.94 wt. %) gives a temperature of 900°C and a pressure of about 38 kb (*c.* 120 km) while a garnet lherzolite from Nigerdlikasik (GGU 59200) with clinopyroxene ($Ca_{44.7}Mg_{51.1}Fe_{4.2}$) and orthopyroxene ($Ca_{1.3}Mg_{91.1}Fe_{7.6}$; Al_2O_3 = 1.49 wt. %) gives 980°C and 38 kb.

Some peridotites in the Pyramidefjeld sheets have an unusually ferriferous composition as shown by olivine compositions (Fo_{77-86}) in GGU 126738 and orthopyroxene (Fe:Mg:Ca = 18:80:2) in an olivine-orthopyroxene fragment in GGU 126744. Emeleus & Andrews (1975) suggested they might have a crustal source but ferriferous granular garnet-peridotites have recently been reported from the Matsoku pipe, Lesotho (Cox *et al.*, 1973) in which olivine (Fo_{83}) is in equilibrium with orthopyroxene (Fe:Mg:Ca = 14:85:1) and iron-rich clinopyroxene. The deduced equilibrium pressures and temperatures for these nodules lie within the upper mantle.

Pyroxene granulite xenoliths occur in the Nigerdlikasik dyke as dark grey nodules if rich in mafic minerals, and eye-catching glittering shapes if biotite mica is abundant. The collective assemblages (Andrews & Emeleus, 1971) are characteristic of high grade granulite facies metamorphic rocks found in Southern India (Subramanium, 1967) and are clearly derived from deeper levels of the continental crust. Similar inclusions are a common feature of kimberlite intrusions from other continental shield areas (Dawson, 1967).

Kimberlite from southern Søndre Isortoq

An isolated kimberlite dyke cutting the Archaean basement occurs at Alánguarssuk, near Sukkertoppen. The dyke consists of an olivine and dolomite-rich alkaline matrix in which are embedded megacrysts of ilmenite (MgO:7.9 %) and olivine (Fo_{92}) of primary origin, and orthopyroxene (En_{89}) together with two suites of pyrope crystals (one Cr-rich, the other Ti-rich), all of which are considered to have been derived from the disruption of garnet lherzolite and eclogite. Using Ca/Ca + Mg and Al_2O_3 in pyroxenes, preliminary temperatures and pressures of equilibration of garnet lherzolite fragments have been made (970°C, *c.* 30 kb; 1050°C, 40 kb, for two samples examined) (S. P. Goff, personal communication).

Kimberlites in the Holsteinsborg – Søndre Strømfjord region

The kimberlites, only recently found in the region (Escher *et al.*, 1970) are typically thin dykes with a NW-SE strike in the Holsteinsborg area, but varying to NE-SW in the south and east. Detailed mapping of the swarm awaits execution but known bodies are distributed over an area of some 6000 km^2 (Escher & Watterson, 1973). Some of the dykes are petrographically remarkably similar to the South-West Greenland kimberlites as they are micaceous, highly carbonaceous and mostly unaltered. The dyke in Holsteinsborg harbour contains many garnet xenocrysts. Carbonatites found in a different tectonic unit of the basement approximately 20 km south-east of Holsteinsborg are apparently related to the suite (J. Watterson personal communication, and Escher & Watterson, 1973). Numerous rounded ultramafic inclusions characterise the dykes including dunite, harzburgite, wehrlite, lherzolite and high grade garnetiferous pyroxene granulites. Garnetiferous inclusions are abundant in the Holsteinsborg harbour dyke. Preliminary studies show that many olivine-rich xenoliths have flaser or sub-mylonitic textures similar to those seen in some Pyramidefjeld nodules and elsewhere, and regarded in southern Africa as deriving from the low velocity zone (Boyd, 1973). Further comprehensive investigation of the nodule suite is in progress.

Structural setting of the West Greenland kimberlite province

All the kimberlites so far discovered are sheets intruded as dykes or sills. It seems that the age of emplacement differs considerably and that those in the Søndre Strømfjord–Holsteinsborg region are considerably older than those in South-West Greenland. Initial K-Ar ages reveal a spectrum of dates between 200 and 600 m. y. (Bridgwater, 1970, 1971) but because of the difficulties in interpretation, especially of whole rock determinations, further work involving both K-Ar and Rb-Sr isotopic measurements has been undertaken (Andrews, McIntyre & Pringle, unpublished). This supports an older age (very late Precambrian) for the Holsteinsborg dyke and Mesozoic ages for the South-West Greenland occurrences. The emplacement of the latter bodies is linked to the development of rifting in the Davis Strait. The Nigerdlikasik dyke has a coast-parallel attitude departing by just ten degrees from the average trend of the Jurassic dolerite swarm (Watt, 1969). Pyramidefjeld and Midternæs sheets are located inland outside the limits of the Jurassic dolerites. The regional stress pattern evoked by pre-drift updoming and rifting would conform to that necessary to explain the distribution of coastal dykes and hinterland sheets (Andrews & Emeleus, 1975).

Interpretation of the late Precambrian activity further north is not so straightforward. Dykes in the western part of the Søndre Strømfjord area trend 100–120° (Escher & Watterson, 1973) and some of these persist for at least 1–2 km. In the eastern districts trends differ, with dykes in Søndre Strømfjord running north by north-west and those south of Søndre Strømfjord, north-east (J. Watterson, personal communication). The age relationships between different trends is not known and the intrusions cannot be readily reconciled with one simple prevailing stress field. Possibly these kimberlite intrusions are a part of the North Atlantic early Cambrian alkaline carbonatite activity said to be associated with the development of the St. Lawrence graben and other major fractures (Doig, 1970). African kimberlite magmatism is considered to be controlled by deep seated fractures related to epeirogenic uplift (Dawson, 1970).

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