A new volcanic province: evidence from glacial erratics in western North Greenland

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Mapping and regional geological studies in northern Greenland were carried out during the project *Kane Basin 1999* (see Dawes *et al.* 2000, this volume). During ore geological studies in Washington Land by one of us (B.T.), finds of erratics of banded iron formation (BIF) directed special attention to the till, glaciofluvial and fluvial sediments. This led to the discovery that in certain parts of Daugaard-Jensen Land and Washington Land volcanic rocks form a common component of the surficial deposits, with particularly colourful, red porphyries catching the eye. The presence of BIF is interesting but not altogether unexpected since BIF erratics have been reported from southern Hall Land just to the north-east (Kelly & Bennike 1992) and such rocks crop out in the Precambrian shield of North-West Greenland to the south (Fig. 1; Dawes 1991). On the other hand, the presence of volcanic erratics was unexpected and stimulated the work reported on here.

This report deals with the finds and distribution of the volcanic erratics and on their provenance; petrological and chemical work, including isotopic age determination, is in progress.

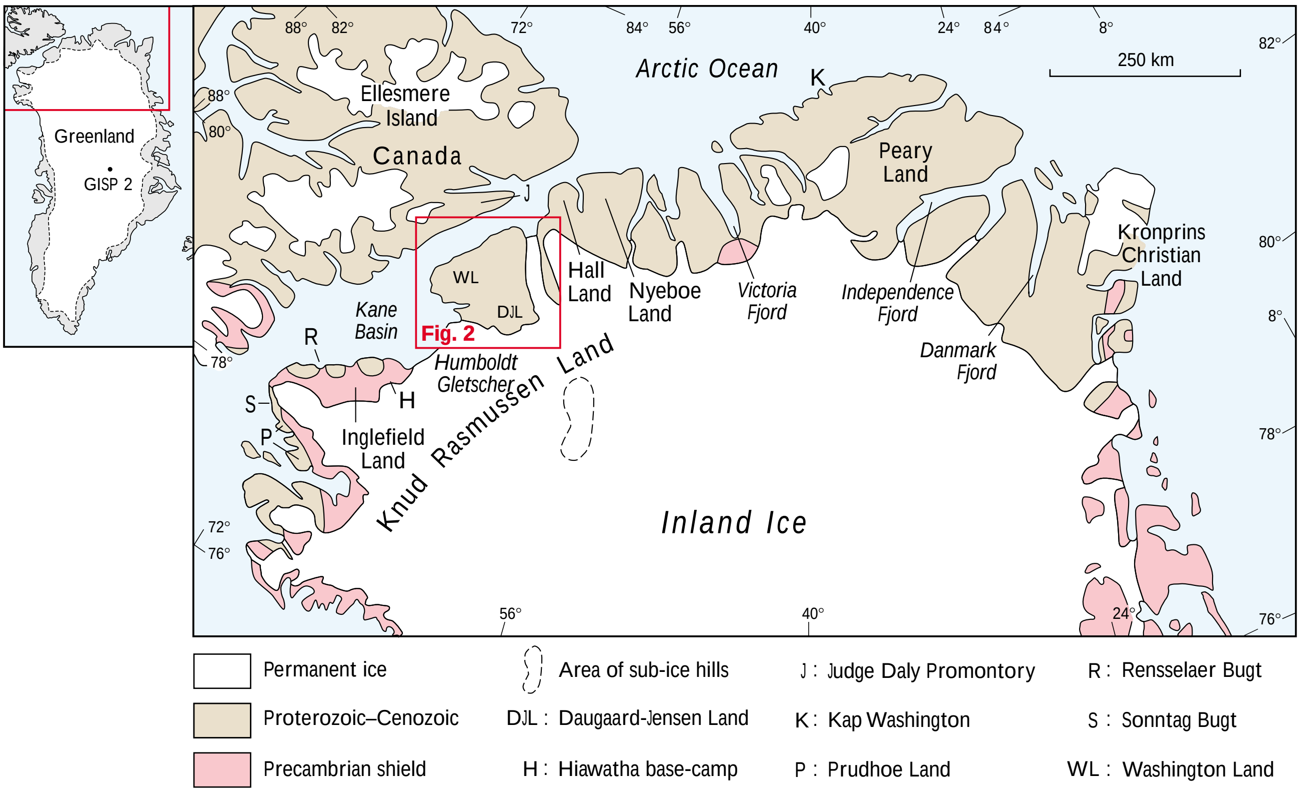

Fig. 1. Locality map of northern Greenland and adjacent Canada showing the study region (frame Fig. 2), Precambrian shield outcrops and the position of the sub-ice hills in Knud Rasmussen Land. The eastern outcrops of the shield southwards from Kronprins Christian Land are reworked complexes within the East Greenland Caledonides. The site of the GISP 2 drill hole from which bedrock has been sampled is shown on the small map.

The Inland Ice and glacial erratics

The central ice sheet of Greenland – the Inland Ice – covers about 80% of the subcontinent (Fig. 1). Although in the last decade interpretations about the geology and structure of central Greenland have been made on the basis of geophysical measurements from ice-based stations, aircraft and satellites, the geological mapping of the sub-ice surface is still in its infancy. Drilling through the Inland Ice to sample bedrock has to our knowledge only been achieved once: in 1993 in the GISP 2 bore-hole (Fig. 1; Weis *et al.* 1997). Thus, the only tangible regional indicators of the hidden geology beneath the Inland Ice are the surficial deposits covering the surrounding ice-free land.

More often than not, glacial erratics in Greenland can be referred to known geological provinces. However, in some regions, erratics indicate the existence of rock units that are not known in outcrop. In cases where glacial flow directions are unequivocal, the erratics can be taken to indicate a source under the Inland Ice. The best known example is the presence of *Skolithos*-bearing quartzite erratics that are common along the entire length of the East Greenland Caledonides (Haller 1971, fig. 48), indicating an extensive source to the west. Such rocks have since been discovered in outcrop (e.g. Strachan *et al.* 1994; Leslie & Higgins 1998). Another example is in North-West Greenland between 72° and 75°N, where the common and widespread erratics of undeformed, red clastic rocks reported by several geologists (e.g. J.C. Escher and M. Kelly, personal communications 1980; Thomassen *et al.* 1999) point to an important redbed depocentre under the ice to the east. As noted by the latter authors some of the lithologies resemble strata of the Proterozoic Thule Basin, the nearest exposures of which are to the north-west at 76°N.

The volcanic erratics from Daugaard-Jensen Land and Washington Land reported on here provide another example of provenance from a sub-ice source but in this case the occurrence is particularly interesting since some rocks of the erratic suite – red porphyries – are hitherto unknown from northern Greenland.

The volcanic erratics

Observations and collection sites

Following the initial report of volcanic erratics in Washington Land (see introductory paragraph), geolo-

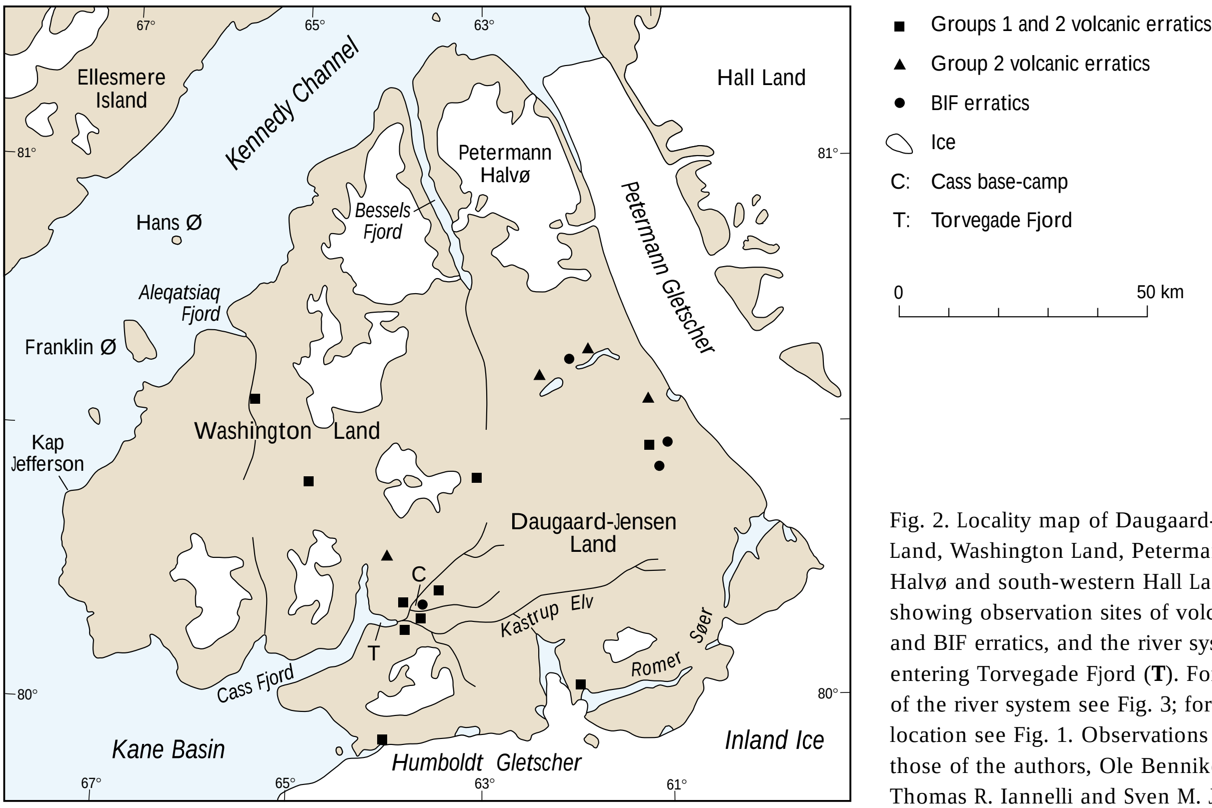

Fig. 2. Locality map of Daugaard-Jensen Land, Washington Land, Petermann Halvø and south-western Hall Land showing observation sites of volcanic and BIF erratics, and the river system entering Torvegade Fjord (**T**). For view of the river system see Fig. 3; for general location see Fig. 1. Observations are those of the authors, Ole Bennike, Thomas R. Iannelli and Sven M. Jensen.

Fig. 3. View of part of the river terrace system east of Torvegade Fjord, Daugaard-Jensen Land showing Cass base-camp with landing strip (*c*. 400 m long). Volcanic erratics were collected in all water courses shown and on the terraces. View is to the north with Kastrup Elv in the right foreground. Middle–Upper Cambrian strata of the Kastrup Elv, Telt Bugt and Cass Fjord Formations form the bedrock. The relief shown is about 500 m; the distant hills and local ice caps are over 600 m above sea level.

gists working north of the Humboldt Gletscher, were asked 'to keep an eye open' for volcanic erratics. This resulted in some information but unfortunately no systematic observations. It also brought to light an earlier report of volcanic erratics in an area south of Aleqatsiaq Fjord, where red porphyritic rocks had attracted attention in 1997 (Sven M. Jensen, personal communication 1999; see Fig. 2).

Volcanic rocks were mainly collected by two of us: T.I.H.A., who for much of the season resided at the Cass base-camp in Daugaard-Jensen Land (Figs 2, 3) made a large collection in the fluvial, delta and kame terraces around the camp, south-west of it down to Torvegade Fjord and up the major valleys north and north-east of the camp, while P.R.D. sampled selected lithologies during several day trips to Daugaard-Jensen Land and Washington Land from Hiawatha base-camp in Inglefield Land. The collection and observation sites are shown on Fig. 2, including the 1997 locality. No systematic mapping or stone counting of erratics were carried out.

The highest concentration of erratics noted was in the area at the head of Torvegade Fjord in gravels of the prominent terrace system; an upper terrace level at 45 m is the site of the Cass base-camp (Fig. 3). This terrace system has four main rivers draining a large catchment area of central Daugaard-Jensen Land; the eastern river, Kastrup Elv, has its source in central Daugaard-Jensen Land in the Romer Søer area (Fig. 2). Volcanic erratics occur both in the material making up the terraces and also in the river beds. Erratics are also present in some areas in the ground moraine that drapes the homoclinal Palaeozoic bedrock and that is particularly thick on the plateau surfaces.

Although our survey is cursory and the precise regional distribution of volcanic erratics unknown, it seems clear that the erratics are more common in the south-eastern areas towards the Inland Ice, i.e. relatively more abundant in Daugaard-Jensen Land than in Washington Land. At several localities, for example in eastern Washington Land, volcanic erratics were searched for but not found. The 1997 observation south of Aleqatsiaq Fjord is the most distant from the Inland Ice and that closest to Kennedy Channel (Fig. 2). The notes and map of Prest (1952) infer that there is nothing unusual in the erratic assemblage at his landings in Washington Land on the plateau overlooking Kennedy Channel, north-east of Kap Jefferson and south-west of Bessels Fjord.

Rock collection

The collection of volcanic rocks consists of 54 samples (GGU 425202–55), varying from pebbles and cobbles to boulder-size blocks; the largest is about 25 cm on its longest side. Several of the samples weigh more than 5 kg. The samples vary from being sub-rounded to rounded; those samples collected from active water courses can be extremely well rounded, with some almost spherical (Fig. 4).

Fig. 4. Porphyry erratics from Daugaard-Jensen Land collected in the neighbourhood of Cass base-camp. **Left**: from fluvial sediments (GGU 425202); **right**: from till (GGU 425220). The scale is 2 cm. Photo: Jakob Lautrup.

From megascopic characteristics the rocks appear to be undeformed and unmetamorphosed, with unstrained phenocrysts. They can be placed into two main groups.

1. Brick red to brownish red, brown and mauve rocks that vary from feldspar and quartz porphyries (Fig. 4) to fine- to medium-grained porphyritic and aphyric types. Some types contain rock fragments, some are vesicular. The rocks of this group are of extrusive origin.

2. Grey to greenish grey, fine- to medium-grained basaltic rocks; many are aphyric, but porphyritic and vesicular types occur. One aphyric sample in the collection is a basalt column (GGU 425244). The group is taken to contain both effusive basalts and hypabyssal dolerites.

Regional distribution of volcanic erratics

The volcanic erratics occur in the region bordered by Humboldt Gletscher, Petermann Gletscher, Kennedy Channel and the Inland Ice (Fig. 1). Without more observations, it is premature to state categorically that the volcanic erratics are restricted to this region but it does seem likely. The Quaternary geology of the two adjacent regions, i.e. Hall Land and Nyeboe Land to the north-east and Inglefield Land to the south-west, are relatively well known from the work of Davies *et al.* (1959), Malaurie (1968), Nichols (1969), Tedrow (1970), Dawes (1987) and Kelly & Bennike (1992). One of us (P.R.D.) has worked in both these adjacent regions and studied glacial erratics; the only undeformed magmatic rock component of the drift in both regions is dolerite as sporadic erratics of pebble size.

For completeness, it should be said that the Daugaard-Jensen Land and Washington Land erratic suite is not known from the Canadian side of Kennedy Channel. Diabase and gabbro erratics were recorded in north-eastern Ellesmere Island by Christie (1967, p. 8), but his nearest locality to our study area in Judge Daly Promontory (Fig. 1) showed no basaltic component in his stone counts. Our literature search uncovered no reports from Ellesmere Island of the distinctive red porphyries so characteristic of the Daugaard-Jensen Land – Washington Land erratic suite.

Bedrock geology and glacial erratics in northern Greenland

The bedrock of northern Greenland adjacent to the Inland Ice between Inglefield Land in the west and Kronprins Christian Land in the east is dominated by sediments of the Palaeozoic Franklinian Basin, with in the east outcrops of Proterozoic sediments and basaltic rocks. The Precambrian crystalline shield, is exposed in three regions: (1) in Inglefield Land in the west, (2) at the head of Victoria Fjord in central North Greenland, and (3) as Caledonian-reworked complexes in coastal areas of Kronprins Christian Land in eastern North Greenland (Fig. 1). Throughout the entire region the drift covering the Proterozoic–Palaeozoic rocks contains, in addition to local bedrock lithologies, a strong component of shield rocks, i.e. granites and gneisses with metabasites and ultramafic rocks (Davies 1972; Kelly & Bennike 1992). It is interesting that the latter authors also record in Hall Land erratics of banded iron formation (BIF), an observation that ties in with the observations of BIF erratics in our study region (Fig. 2; see also comments in the introduction of this paper).

Following the initial observations on the regional distribution of crystalline erratics (Koch 1920, 1928), there is consensus that they have a southern provenance representative of the Greenlandic shield that underlies much of northern Greenland under the Inland Ice (e.g. Davies 1963, 1972; Christie 1975; Weidick 1976; Kalsbeek & Jepsen 1980; Funder 1989; Kelly & Bennike 1992). Only the crystalline erratics on the north coast of Peary Land are considered to have been derived from elsewhere; a northern offshore source (Dawes 1986).

For a literature review on the Quaternary of the Kane Basin region the reader is referred to Dawes (1999). Apart from the little-publicised find from 1997 mentioned above, nothing unusual had been previously reported about the composition of the glacial drift of the Daugaard-Jensen Land – Washington Land – Petermann Halvø region and the erratics, like those other areas of northern Greenland flanking the Inland Ice, were regarded as representatives of provinces known to crop out locally or elsewhere in northern Greenland.

Outcrops and potential sources

The *nearest* volcanic rocks to our study region are in Ellesmere Island, Canada (Fig. 1). However, there is no evidence that the Innuitian Ice Sheet of northern Canada extended across Greenland (Blake 1992; England 1999), and in any case a source of the Daugaard-Jensen Land – Washington Land erratics from either the small components of basaltic rocks in the Tertiary Eureka Sound Formation on Judge Daly Promontory, 30 km away on Kennedy Channel (Miall 1982), or from the Cretaceous basaltic flows of the Sverdrup Basin in northern Ellesmere Island some 200 km distant (Embry & Osadetz 1988), is not credible.

The *nearest volcanic outcrops in Greenland* are about 300 km distant at the northern margin of the Thule Basin at Sonntag Bugt in northern Prudhoe Land (Fig. 1). These outcrops are basaltic lavas of the Mesoproterozoic Cape Combermere Formation of the Nares Strait Group (Dawes 1997). Coeval basaltic sills in western Inglefield Land occur as far east as Rensselaer Bugt. Much farther east, both intrusive and extrusive basaltic rocks occur in another Mesoproterozoic basin flanking the Inland Ice and exposed from southern Peary Land to Danmark Fjord (Fig. 1) – the Midsommersø Dolerite and Zig-Zag Basalt Formations (Kalsbeek & Jepsen 1984; Sønderholm & Jepsen 1991).

For physiographical and glaciological reasons derivation of the volcanic erratics from either of these Proterozoic basins is not viable, but the presence of another Mesoproterozoic basin under the Inland Ice would be a potential source. Such a basin falls naturally into the distribution of Proterozoic basins situated along the northern margin of the Canadian–Greenland shield (e.g. see Young 1979, fig. 1; Sønderholm & Jepsen 1991, fig. 1). However, militating against such a basin as a source are: (1) sediments form the dominant component of the Mesoproterozoic basins yet none have been found in the erratic assemblage, and (2) red porphyries are not a known part of the Mesoproterozoic magmatic assemblage.

The only other undeformed volcanic province in northern Greenland is the Cretaceous Kap Washington Group (Soper *et al.* 1982; Brown *et al.* 1987) that from its position on the northern coast of Peary Land around Kap Washington (Fig. 1) is clearly not a viable source.

Conclusions on provenance

We conclude that the volcanic rocks in the surficial deposits of Daugaard-Jensen Land and Washington Land represent a province situated somewhere to the southeast beneath the Inland Ice in Knud Rasmussen Land (Fig. 1). Of particular relevance here is that the region in focus is anomalous from the point of view of subice topography. Radar measurements have pin-pointed the region as being characterised by several physiographic highs with a relief of 600 m or more (Chuah *et al.* 1996; Legarsky *et al.* 1998; see Fig 1); it is a region that also corresponds to low gravity anomalies (Rene Forsberg, personal communication 1999). As pointed out in the above-cited papers relief of this magnitude is unusual and requires explanation; elsewhere in northern Greenland the topography of the sub-ice surface is subdued due to glacial erosion.

The origin of the sub-ice hills in Knud Rasmussen Land is unknown but one explanation is that they are of volcanic origin and relatively young since their topography has been sustained, i.e. late Phanerozoic. Whether there is a direct relationship between the volcanic erratic suite and the sub-ice hills can only be speculated on at this stage; similarly, the tectonic/magmatic significance of the volcanic province must await the results of petrological and chemical work.

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