Age and origin of the Klokken Gabbro-Syenite Intrusion, South Greenland: Rb-Sr study

ALAN B. BLAXLAND and IAN PARSONS

DGF

Blaxland, A. B. & Parsons, I.: Age and origin of the Klokken Gabbro-Syenite Intrusion, South Greenland: Rb-Sr study. *Bull. geol. Soc. Denmark.* Vol. 24, pp. 27–32. Copenhagen, November, 17th., 1975.

A Rb-Sr whole-rock isochron age of 1159±11 m.y. for the small Klokken intrusion suggests that it may well be the youngest of a series of central complexes in the Gardar Igneous Province. Chronologically, Klokken appears to represent an extension of the magmatic episodes which produced the larger, undersaturated, intrusive centres of Igaliko to the north. An initial $^{87}Sr/^{86}Sr$ ratio of 0.7031 ± 0.0003 suggests an origin from primitive mantle material with little or no contamination by older crust.

Alan B. Blaxland, Isotope Geology Division, Scottish Universities Research and Reactor Centre, East Kilbride, Glasgow G75 OQU, Scotland. Ian Parsons, Department of Geology and Mineralogy, University of Aberdeen, Aberdeen AB9 1AS, Scotland. *December 2nd, 1974.*

The Klokken intrusion is a small (3 × 2 km), oval, layered gabbro-syenite intrusive complex situated at 60°56'N, 45°05'W in the Gardar igneous province of south-west Greenland. It reaches (fig. 1) to within 1 km of the SE margin of the Igdlerfigssalik centre, the most southerly of the series of large plutons which comprise the Igaliko nepheline syenite complex (Emeleus & Harry, 1970). The several intrusive centres making up this complex are seen, on the basis of field relationships, to become progressively younger in an anticlockwise direction beginning with the Motzfeldt centre and terminating in Igdlerfigssalik. Rb-Sr isotopic studies (Blaxland et al., in preparation) confirm this progression and suggest that the four centres were emplaced at about 1310 m.y., 1295 m.y., 1185 m.y. and 1167 m.y. respectively (based on a value $\lambda = 1.39 \times 10^{-11} y^{-1}$ for the decay constant of ^{87}Rb). Geographically, the Klokken body would be the next and final point in this progression, but in contrast to the Igaliko centres Klokken is chemically slightly over-saturated, and its most fractionated members are aplites and pegmatites of alkali granite composition. Like the Igaliko centres, Klokken intrudes the basement Julianehåb Granite of Ketilidian age, about 600 m.y. older than the major Gardar activity (van Breemen, Aftalion & Allaart, 1974; Blaxland *et al.*, in preparation). However, there is no contact between Klokken and the Igaliko intrusions and so age relationships between these later bodies cannot be determined by field evidence.

Despite its small size, the Klokken intrusion contains a great diversity of readily distinguishable rock types which cover a wide spectrum from gabbro, through syeno-ferrodiorites to strikingly layered ferrosyenites. The geology has been briefly described by Parsons (1972) and detailed mineralogical work is in preparation. The body has sharp contacts with the surrounding Julianehåb Granite and there exist substantial protrusions, roof pendants and rotated xenoliths, suggesting that stoping may have been important during intrusion. Although the transition from a marginal gabbro to syenite takes place over a short distance, there is no intrusive junction between these two units, and all intermediate types may be found. The existence of a basic syenitic liquid intermediate between gabbro and the more fractionated syenites is amply demonstrated by a late discordant biotite-syenite which cuts (and is chilled against) the ferrosyenites, but is cut by acid aplites. Fractionation of gabbro to syenite was demonstrably a single, continuous event, if not wholly in situ. In this respect, Klokken differs from other Gardar gab-

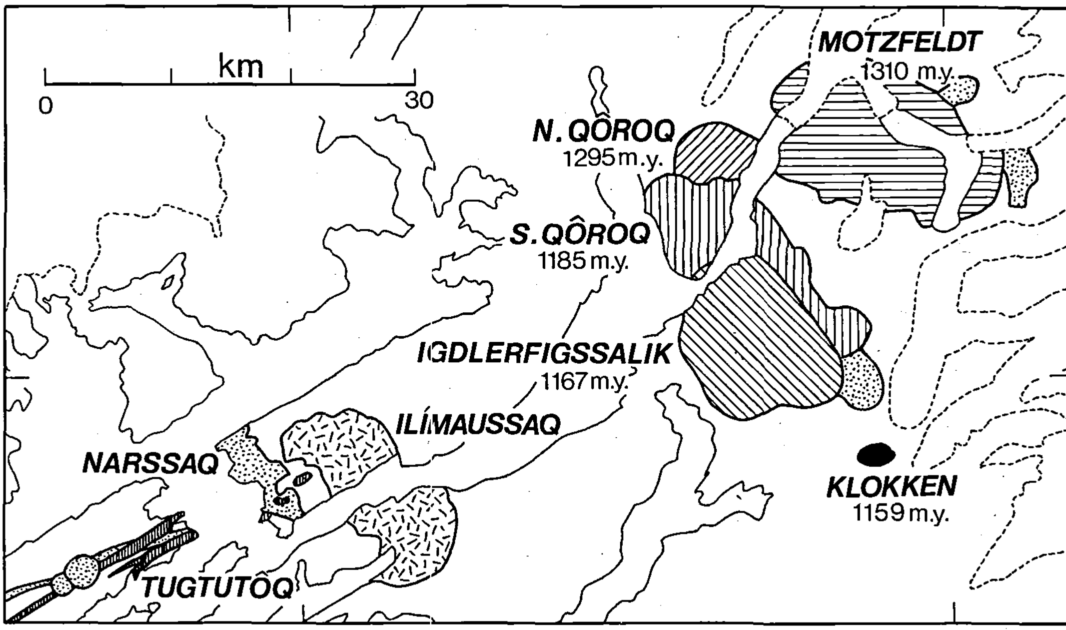

Fig. 1. Sketch map showing relationship of the Klokken intrusion to other intrusive centres in the eastern part of the Gardar Province. The four Igaliko centres (from Emeleus & Harry, 1970) are shown with cross-hatching. Approximate ages for these complexes are from data given by Blaxland et al. (in preparation).

bro-syenite-alkali granite central complexes, where sharp breaks are observed between gabbro and other members. At Alángorssuaq in the Nunarssuit (western Gardar) complex (Harry & Pulvertaft, 1963) the layered gabbro is truncated by granite (and by implication predates the syenites), while at Kûngnât (Upton, 1960), gabbro forms a late ring-dyke structure. Both in bulk composition and in fractionation trends observed, Klokken more resembles the large composite dykes occurring in the Gardar province, such as the Hviddal Dyke on Tugtutôq Island (Upton, 1962). It has been proposed (Upton, 1974) that there may be a progression from simple dilational basic dykes, which are widespread in the Gardar, to major central complexes. Perhaps significantly, the Klokken intrusion lies well away from basic dyke swarms.

Outline of geology and sample descriptions

Sample localities and simplified geology are given in fig. 2. The Klokken body is well exposed and most rock-types readily afford fresh specimens. Slight iron-staining may occur on the surfaces of some samples, but deuteric alteration of feldspar is negligible in all but three cases, the micro- or crypto-perthitic alkali feldspars being free of alteration. In hand-specimen such feldspars are transparent and dark green in colour. In some leucosyenite layers the feldspar is cloudy and translucent white in colour. As this type of alteration is restricted to certain layers and also associated with more advanced unmixing and ordering in the feldspars, it seems likely to have been immediately post-magmatic. Samples 140122 and 140026 show alteration of this type; the former lies on, the latter off. the isochron (fig. 3). All specimens of gabbro show alteration in the plagioclase (ca. An_{50}) from which the selected sample (140053) is almost free. Finer-grained gabbros near contacts with the Julianehåb Granite also frequently show evidence of contamination in the form of rounded inclusions showing granophyric quartz-feldspar intergrowths; such material was absent in 140053.

The outer gabbro ring gives way gradation-

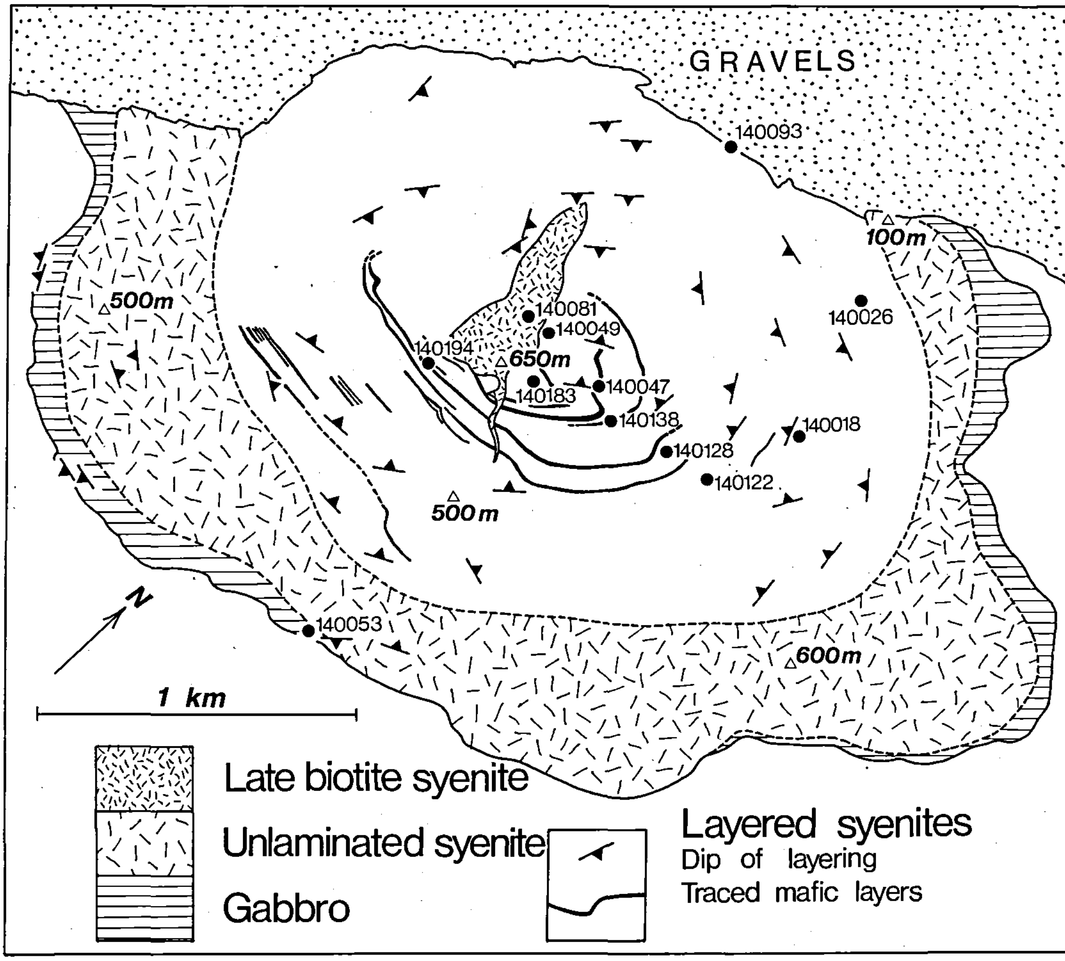

Fig. 2. Geological map of the Klokken complex showing the localities of specimens used in the present study. Only mafic horizons which have been traced on the ground are shown in the layered series; many more layers actually exist.

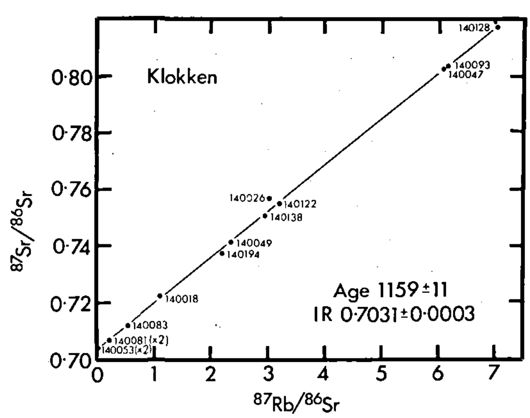

Fig. 3. Rb-Sr whole-rock isochron for Klokken. Samples 140194 and 140026 are not included in the regression treatment.

ally inwards, via a restricted suite of types in which alkali feldspar occurs as continuously zoned rims to plagioclase, to unlaminated, alkali feldspar-augite syenites forming a zone up to 750 m wide. This coarse-grained type is relatively susceptible to weathering, poorly exposed, and has not been included in this study.

The central part of the intrusion comprises a remarkable layered syenite series, in the form of downward pointing cones with inward dips of 30–50°. Two main interleaved rock types form this series; a sequence of granular syenite layers from 0.1–30 m thick (140183 and 140018) is interleaved with a series of coarser, well laminated syenites. The granular layers form about 15 % of the 600 m thickness of exposed layered series and all major mineral species show that they are slightly less fractionated than the enclosing laminated syenites. The latter show mineral layering of an unusual type, in which the content of mafic minerals increases gradually upwards, over ca 2 m, before rapidly decreasing or being truncated by a granular layer (see fig. 4 in Parsons, 1972). The main type of mafic layer shows upward increase in hedenbergite-rich clinopyroxene (electron microprobe data, Parsons, in preparation) at the expense of alkali feldspar followed in some complete examples by a narrow horizon of an ultramafic fayalite-magnetite rock. The latter types were low in both Rb and Sr and are not included in this study. Specimens 140138, 140194, 140047, 140128, 140049, 140122, 140026 and 140093 represent members of the laminated series varying largely in the hedenbergite to alkali feldspar ratio and, as listed, represent a series becoming increasingly leucocratic (140138 contains 30 %CIPW normative feldspar, 61 % clinopyroxene; 140093 contains 80 % and 10 % of these components, respectively).

The layered series is cut by the fine-grained feeder of a late augite-biotite syenite (140081) which forms a coarser grained sheet-like body near the topographic summit of the intrusion. This represents a less fractionated phase of injection intermediate between the unlaminated syenites and the gabbros; the specimen 140081 is perfectly fresh with clear green alkali feldspars and conspicuous poikilitic biotites in hand specimen.

Analytical Procedures and Results

Analytical procedures were similar to those used by van Breemen *et al.* (1974). After dissolution, the sample is transferred to a teflon beaker containing "double spike" aliquots of Rb and Sr spike solutions. Such beakers are previously prepared in batches of about 75, giving a suitable range of Rb/Sr ratios, and this procedure eliminates many problems associated with calibration during individual sample spiking. Isotope dilution analyses were performed using a AEI-GEC MS-12 solid-source mass spectrometer with a 12" radius and 90° sector, and using a Faraday cup and a Cary 401 vibrating reed electrometer. Values obtained for Rb and Sr concentrations, Rb/Sr ratios and ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr ratios are shown in table 1. Values obtained for Eimer and Amend standard $SrCO_3$ were 0.70813 ± 0.00013 (one standard deviation), based on an average of 11 analyses made over the general period of study.

Table 1. Rb-Sr Isotopic Data

Sample No.	Rb (ppm)	Sr (ppm)	Rb/Sr (weight)	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
140053	12.2	1340.7	0.009	0.0263	0.70339
140053(r)	13.6	1352.7	0.010	0.0290	0.70353
140081	57.3	755.1	0.076	0.2194	0.70668
140081(r)	52.3	700.4	0.075	0.2160	0.70652
140183	69.6	373.1	0.186	0.5397	0.71196
140018	70.7	180.5	0.392	1.1352	0.72213
140194*	20.5	26.8	0.765	2.2203	0.73720
140049	50.2	61.7	0.813	2.3599	0.74128
140138	38.3	37.5	1.022	2.9697	0.75068
140122	86.2	78.2	1.102	3.2039	0.75477
140026*	103.4	99.4	1.040	3.0249	0.75676
140047	52.5	25.2	2.086	6.0910	0.80270
140093	118.1	55.8	2.114	6.1748	0.80374
140128	57.5	23.9	2.409	7.0438	0.81771

All sample numbers refer to Grønlands Geologiske Undersøgelse sample files.
(r) = repeat analysis
* sample lies off isochron and is not included in regression treatment

The ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr results shown in table 1 were regressed by the least squares method developed by York (1969) using a decay constant value $\lambda = 1.39 \times 10^{-11}y^{-1}$. For the purposes of the regression analysis, the duplicate analyses of samples 140053 and 140081 were averaged to yield single values. Samples 140194 and 140026 clearly fall off the isochron (shown in fig. 3) and were not included in the regression treatment. Analytical errors on ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr were taken to be 0.5 % and 0.02 % respectively (based on previous replicate analyses). The regression parameters obtained were as follows:

Age: 1159±11 m.y.
Initial ^{87}Sr/^{86}Sr ratio: 0.7031±0.0003
Number of points on isochron: 10
$[SUMS/n\text{–}2)]^{1/2}$: 1.66

All uncertainties are shown at the 2σ (95 % confidence) level. The value of $[SUMS/(n-2)]^{1/2}$ was found to be 1.66 indicating, within the applicable certainty limits, that a true isochron exists (see Brooks, Hart & Wendt, 1972, for discussion of the value $[SUMS/(n-2)]^{1/2}$.)

Discussion

Previous age determinations on Gardar intrusions have been summarised by Bridgwater (1965) and by Emeleus & Upton (in press). The early work referred to in these summaries consisted of K-Ar determinations and Rb-Sr mineral ages and these suggested that that Gardar activity was spread over an interval of time, 1400–1000 m.y. before present. More recently, van Breemen & Upton (1972) showed a much more restricted range of 1245 ± 16 – 1180 ± 37 m.y. for three intrusions at Kûngnât, Hviddal Dyke and Tugtutôq Central Complex, based on the much more reliable Rb-Sr isochron method. More detailed isochron work (Blaxland, van Breemen & Steenfelt, in press; Blaxland et al., in preparation) on 10 other Gardar central complexes has revealed that Gardar activity did indeed occur in a more restricted time interval of 1325–1150 m.y. before present. Moreover, this word suggests that magmatism may not have been a continuous process over that time period but that two relatively discreet periods of activity (at about 1300 and 1160 m.y.) were separated by a period of relative quiescence. There are thus Early and Late Gardar stages.

The Igaliko complex (fig. 1) lies at the easternmost edge of the Gardar province and consists of 4 distinct centres (Emeleus & Harry, 1970). Isotope data support field evidence that the centres were emplaced in an anticlockwise direction and show, moreover, that the two oldest centres (Motzfeldt and North Qôroq) belong to the Early Gardar period whereas the younger centres (South Qôroq and Igdlerfigssalik) belong to the Late Gardar. As mentioned earlier, the age relationships between the Igaliko group and Klokken cannot be determined on the basis of field evidence, and the oversaturated nature of Klokken tends to suggest that it may not be related. The isotopic data shows, however, that Klokken is indeed one of the last intrusions of the Gardar, following the chronological progression of the Igaliko centres, and its age may well represent the termination of Gardar magmatism in South Greenland.

The initial ratio of 0.7031 ± 0.0003 indicates that Klokken may be derived from a relatively primitive magma from a source region in the mantle or lower crust, showing evidence of little or no higher crustal contamination. In this respect also, it resembles most of the Igaliko centres (North Qôroq stands alone in having a relatively high initial ratio of 0.705).

Acknowledgements. The authors wish to thank J. Hutchinson and J. Jocelyn for assistance with laboratory work and O. van Breemen and B. G. J. Upton for critically reviewing the manuscript. The encouragement and support of Professor H. W. Wilson is appreciated. Fieldwork was carried out on behalf of Grønlands Geologiske Undersøgelse and this paper appears by permission of the Director, K. Ellitsgaard-Rasmussen, to whom thanks are also due for the opportunity to work on this complex of which he made the earliest study. J. G. Anderson gave invaluable field assistance. One of the authors (A. B. B.) is the recipient of a Natural Environment Research Council (Great Britain) grant.

Dansk sammendrag

Klokken gabbro-syenit-intrusionen synes geologisk at repræsentere en fortsættelse af den række af intrusive faser, som førte til dannelsen af det store, undermættede Igaliko nefelin-syenit komplex; dette på trods af Klokkens generelt overmættede natur. En Rb/Sr bjergartsisokron på 1159±11 m. år indebærer, at Klokken intrusionen er en af de yngste i Gardar magma provinsen. Et initialt $^{87}Sr/^{86}Sr$ forhold på 0.7031±0.0003, som ligger nær forholdene for de andre intrusive centre i Igaliko komplexet, tyder på en genetisk sammenhæng med materiale fra jordens kappe, medens skorpemateriale ikke har spillet nogen rolle.

References

Blaxland, A. B., van Breemen, O., Emeleus, C. H. & Anderson, J. G. in preparation: Age and origin of major syenite centres in the Gardar Province of South Greenland: Rb–Sr studies.

Blaxland, A. B., van Breemen, O. & Steenfelt, A. in press: Age and origin of peralkaline magmatism at Ilímaussaq, South Greenland: Rb-Sr study. *Lithos.*

Bridgwater, D. 1965: Isotopic age determinations from South Greenland and their geological setting. *Bull. Grønlands geol. Unders.* 53 (also *Meddr Grønland* 131[8]), 56 pp.

Brooks, C., Hart, S. R. & Wendt, I. 1972: Realistic use of two-error regression treatments as applied to rubidium-strontium data. *Rev. Geophys. Space Phys.* 10, 551–577.

Emeleus, C. H., & Harry, W. T. 1970: The Igaliko nepheline syenite complex. General description. *Bull. Grønlands geol. Unders.* 85 (also *Meddr Grønland* 186[3]), 115 pp.

Emeleus, C. H. & Upton, B. G. J. in press: The Gardar period in Southern Greenland. *In Geology of Greenland.* Publ. Geol. Survey of Greenland.

Harry, W. T. & Pulvertaft, T. C. R. 1963: The Nunarssuit intrusive complex, South Greenland, Part 1. *Bull. Grønlands geol. Unders.* 42 (also *Meddr Grønland* 169[1]).

Parsons, I. 1972: A preliminary description of the Klokken intrusion, South Greenland. *Grønlands geol. Unders. Rapp.* nr. 45, 29–32.

Upton, B. G. J. 1960: The alkaline igneous complex of Kûngnât Fjeld, South Greenland. *Bull. Grønlands geol. Unders.* 27 (also *Meddr Grønland* 123[4]), 145 pp.

Upton, B. G. J. 1962: The geology of Tugtutôq and neighbouring islands, South Greenland, Part 1. *Bull. Grønlands geol. Unders.* 34 (also *Meddr Grønland* 169[8]), 59 pp.

Upton, B. G. J. 1974: The alkaline province of Southwest Greenland. In Sørensen, H.: *The Alkaline Rocks,* 221–238. New York: Academic Press.

van Breemen, O., Aftalion, M. and Allaart, J. H. 1974: Isotopic and geochronologic studies on granites from the Ketilidian mobile belt of South Greenland. *Bull. geol. Soc. Amer.* 85, 403–412.

van Breemen, O. and Upton, B. G. J. 1972: Age of some Gardar intrusive complexes, South Greenland. *Bull. geol. Soc. Amer.* 83, 3381–3390.

York, D. 1969: Least squares fitting of a straight line with correlated errors. *Earth Planet. Sci. Lett.* 5, 320–324.