Igneous intrusions in the cored Upper Jurassic succession of the Blokelv-1 borehole, Jameson Land Basin, East Greenland

Lotte Melchior Larsen

The fully cored Upper Jurassic succession in the Blokelv-1 borehole in the Jameson Land Basin, East Greenland, is intersected by igneous intrusions at four levels; the intrusions comprise a *c.* 15 cm thick dyke and three sills with thicknesses of 0.7, 1.2 and 1.9 m. The sills consist of fine-grained, sparsely plagioclase-olivine-phyric basalt with chilled contacts to the sediments. Analyses of two sills gave very similar results. The sills are tholeiitic basalts with compositions similar to the main group of dykes and sills in the Jameson Land Basin, and the Blokelv-1 sills are thus considered to belong to this group which has been dated at *c.* 53 Ma. The intrusions form part of a 55–51 Ma suite of tholeiitic basalt intrusions that was emplaced over an area extending for over 500 km north-to-south within the sedimentary basins of East and North-East Greenland.

Keywords: East Greenland, dykes, Cenozoic

L.M.L., *Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.*
E-mail: *lml@geus.dk*

The fully cored Blokelv-1 borehole was drilled in 2008 through Upper Jurassic sediments in the Jameson Land Basin, East Greenland (Bojesen-Koefoed *et al.* 2009), in order to study the sedimentary succession (Fig. 1A). The sediments in Jameson Land are intruded by many Cenozoic dykes and sills (e.g. Noe-Nygaard 1976; Hald & Tegner 2000), and one of the site selection criteria was to minimise the risk of encountering thick igneous intrusions during drilling. Although major intrusions were avoided, the 233.8 m succession in the Blokelv-1 core is cut by intrusive igneous rocks at four levels with a combined thickness of 4.1 m (Fig. 1B). The purpose of this paper is to present descriptions and analyses of these intrusions and compare them with other Cenozoic dyke and sill intrusions in northern East Greenland.

Intrusions in the Blokelv-1 core

The core is cut by igneous intrusions at four levels in the upper half of the section: 102.04–100.1 m (thickness 1.9 m), 56.4–55.2 m (thickness 1.2 m), 27.10–26.40 m (thickness 0.70 m) and 7.35–7.05 m (thickness 0.3 m). The uppermost intrusion has oblique boundary contacts, dipping at 60°, and is accordingly described as a dyke; its true thickness must be *c.* 15 cm. The three lower intrusions show boundary contacts that are broadly parallel to bedding in the host rock and thus appear to be sills. The two thickest sills have caused prominent alteration of the surrounding sediments (see Olivarius *et al.* 2018, this volume).

The thin dyke uppermost in the section (Fig. 1B) is thoroughly altered and was not studied further. The remaining three sills are lithologically similar and consist of fine-grained, sparsely plagioclase-olivine-phyric basalt. At the chilled contacts, they are very fine-grained to aphanitic, altered, and cut by carbonate veins. In the middle sill, a fracture is filled with biodegraded oil (Bojesen-Koefoed *et al.* 2018, this volume).

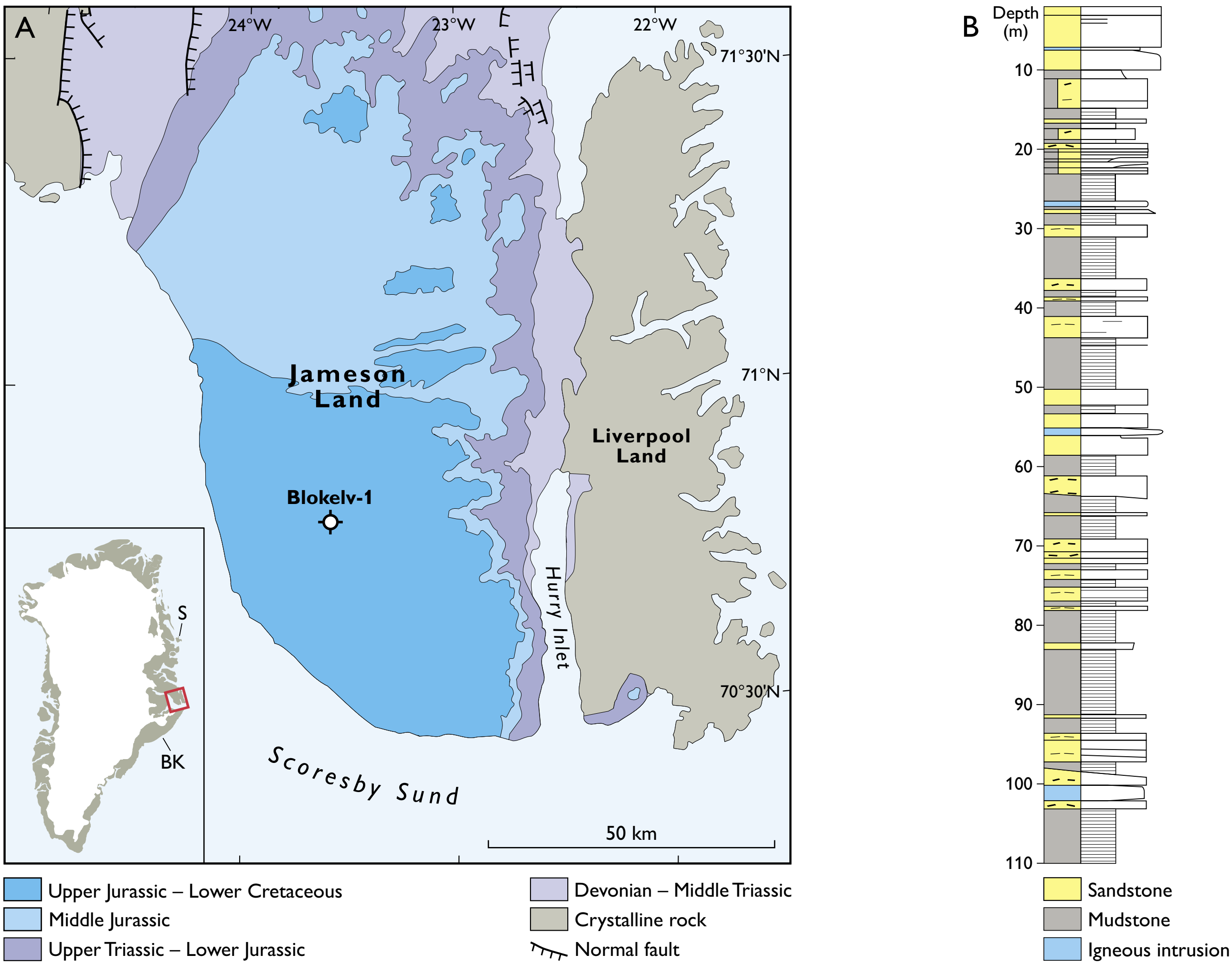

Fig. 1. **A**: Map of central and southern Jameson Land showing the location of the Blokelv-1 borehole (70°45.305′N, 23°40.430′W, WGS84 coordinates); inset shows the location of the study area in East Greenland. **BK**: Blosseville Kyst. **S**: Shannon. **B**: Simplified log of the upper part (0–110 m) of the Blokelv-1 core (GGU no. 511101).

Petrography

The 1.9 m thick lower sill (Fig. 1B, 102.04–100.1 m) has a lower chilled margin that is aphanitic with many plagioclase microlites, sparse 0.1–0.2 mm plagioclase microphenocrysts, and a few plagioclase-olivine glomerocrysts with up to 2 mm plagioclase laths and 0.8 mm olivine crystals. Plagioclase is fresh but the olivine is completely altered. The groundmass is extensively replaced by carbonate, but plagioclase phenocrysts are fresh. The rock is cut by 0.1–0.5 mm wide veins of ankerite with patches of pyrite which cut both sill and sandstone at the contact (Fig. 2; see Olivarius *et al.* 2018, this volume). The veins are thickest at the contact. The veins in the sandstone appear to fill tension cracks.

The 1.2 m thick middle sill (Fig. 1B, 56.4–55.2 m) has a very fine-grained upper chilled margin with sparse 0.5 mm plagioclase microphenocrysts and tiny <0.5 mm euhedral olivine crystals; all olivine crystals are altered to clay. The groundmass is intersertal with numerous plagioclase microlites. The central part of the sill is fine-grained with sparse <1 mm plagioclase phenocrysts and sparse *c.* 0.5 mm fresh olivine microphenocrysts, often assembled in glomerocrysts. The groundmass is intergranular with plagioclase, clinopyroxene, Fe-Ti oxide, olivine, and abundant mesostasis.

The 0.7 m thick upper sill (Fig. 1B, 27.10–26.40 m) is a fine-grained, nearly aphyric rock with scattered vugs filled with colourless minerals. The lower contact is not preserved. The rock becomes slightly finer grained towards the upper contact and there is possibly a thin glass chill at the top. There is no visible influence on the overlying sediments.

Fig. 2. Lower contact towards sandstone of the 1.9 m thick lower sill at 102.04 m in the core. Two ankerite veins cross both sill and sandstone. Note plagioclase-olivine glomerocryst in the very fine-grained basalt matrix between the two veins. Thin section 511101.246; plane-polarised light.

Table 1. Chemical analyses of two sills in the Blokelv core, with comparisons from Jameson Land

	Middle sill	**Lower sill**	**Jameson Land**	
Depth (m)	55.2–56.4	100.1–102	ENE dyke	Thin sill
GGU no	511101.230	511101.229	407203	403021
Major elements, wt% (XRF analyses)				
SiO_2	47.84	48.43	48.34	48.30
TiO_2	2.30	2.11	2.35	2.33
Al_2O_3	13.71	12.87	13.79	13.80
Fe_2O_3	14.07	12.95	14.07	14.07
MnO	0.21	0.26	0.20	0.20
MgO	6.85	6.24	6.99	6.96
CaO	11.23	12.08	11.52	11.47
Na_2O	2.23	2.03	2.39	2.37
K_2O	0.22	0.40	0.29	0.30
P_2O_5	0.20	0.19	0.24	0.23
LOI	0.47	1.84	-0.27	0.14
Sum	99.33	99.40	99.91	100.17
Trace elements, ppm (ICP-MS analyses)				
Sc	38	36	40	38
V	374	345	371	362
Cr	190	179	259	249
Co	55	50	53	52
Ni	99	90	121	109
Cu	240	218	256	249
Zn	108	100	114	115
Ga	21.0	20.0		
Rb	3.4	8.7	5.3	6.3
Sr	217	230	237	228
Y	31.1	30.5	32.1	31.7
Zr	145	135	159	159
Nb	12.1	11.7	12.6	12.8
Cs	0.52	0.20	0.48	0.12
Ba	130	110	71.6	71.9
La	10.5	11.6	10.7	10.9
Ce	27.2	29.9	28.0	28.0
Pr	4.10	4.27	4.16	4.17
Nd	19.7	20.1	19.1	19.2
Sm	5.09	5.01	5.15	5.27
Eu	1.68	1.64	1.77	1.74
Gd	6.07	5.79	5.42	5.30
Tb	0.99	0.91	0.94	0.93
Dy	5.78	5.45	5.49	5.36
Ho	1.14	1.07	1.13	1.10
Er	3.09	2.95	2.91	2.87
Tm	0.47	0.44	0.43	0.43
Yb	2.77	2.69	2.65	2.61
Lu	0.41	0.39	0.36	0.38
Hf	3.77	3.47	3.60	3.57
Ta			0.84	0.84
Pb	0.91	5.61	1.29	1.71
Th	0.84	1.25	0.9	0.89
U	0.26	0.29	0.31	0.31

Total iron is reported as Fe_2O_3. LOI is loss on ignition.
Data for Jameson Land from Hald & Tegner (2000).

Chemical compositions

Two samples from the centres of the lower and middle sills have been analysed for major and trace elements. Major elements were analysed by N. Odling at University of Edinburgh by X-ray fluorescence spectrometry (XRF) and procedures as described by Fitton *et al.* (1998). Trace elements were analysed in GEUS' Rock Geochemical Laboratory using a PerkinElmer Elan 6100 DRC Quadrupole Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Sample dissolution followed a modified version of the procedure used by Turner *et al.* (1999) and Ottley *et al.* (2003). Calibration was done using two certified REE solutions and three international reference standards. Results for reference samples processed and run simultaneously with the unknowns are normally within 5% of the reference value for most elements with concentrations >0.1 ppm (results are shown in Table 1).

The two sills consist of tholeiitic basalt with 6–7 wt% MgO and 2.1–2.3 wt% TiO_2. Losses on ignition are low and the samples appear to be fresh. Measured values of tantalum (Ta) are high (1.1–1.4 ppm) where only *c.* 0.8 ppm Ta is expected; this may be contamination from the tungsten carbide crushing vessel and the data are not included in Table 1. The lower sill has 5.6 ppm Pb which is very high, indicating contamination with Pb either during emplacement or from the drilling process; there is no evidence of additional contamination.

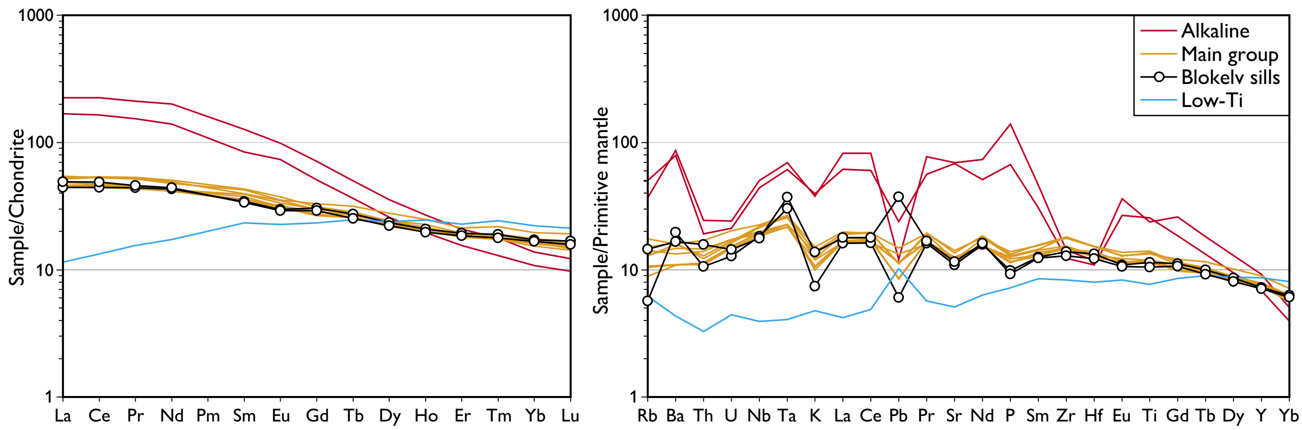

Fig. 3. Multi-element patterns for the Blokelv sills compared with sills and dykes in the Jameson Land Basin (data from Hald & Tegner 2000). Alkaline and Low-Ti basalt are two other basalt groups defined by Hald & Tegner (2000). Note the close similarity between the main group of intrusions and the Blokelv sills. The high Pb in one of the Blokelv samples must be due to contamination.

Discussion

The two analysed sills have very similar compositions and are considered to have been intruded during the same magmatic event. The tholeiitic basalt represents a magma type that is known from widespread sills and dykes in the Jameson Land Basin (Larsen *et al.* 1989; Hald & Tegner 2000). Hald & Tegner (2000) recognised five different magma types represented by sills and dykes, and by far the most common group is the one found in the Blokelv sills. This group was called the 'High-Ti group' by Hald & Tegner (2000), but as the Ti contents are not high, it is referred to here as the 'main group'. Figure 3 shows geochemical patterns for the Blokelv sills compared with similar patterns for the Jameson Land sills and dykes. The close similarity of the Blokelv sills with the main group of tholeiitic sills and dykes in Jameson Land is clear.

The Blokelv intrusions are poorly suited for $^{39}Ar/^{40}Ar$ dating because of the low K_2O content and few and small plagioclase phenocrysts. However, Hald & Tegner (2000) dated a sill and a dyke from the main group by the $^{39}Ar/^{40}Ar$ method. The sill yielded a 5-point isochron age of 52.7 ± 1.2 Ma, and the dyke yielded a four-point isochron age of 53.3 ± 1.4 Ma; the two ages are within the uncertainty of each other (the ages are here recalculated to an age of 28.201 Ma for the Fish Canyon Tuff standard). It is therefore most probable that the two Blokelv sills were emplaced at *c.* 53 Ma.

The intrusions in the Jameson Land Basin were emplaced after the plateau lavas of the Blosseville Kyst at 56.4–55.3 Ma (Storey *et al.* 2007) and after or just concomitantly with the plateau lavas in north-eastern Greenland at 56–53 Ma (Larsen *et al.* 2014). They are within the age range of 55–51 Ma obtained for tholeiitic sills and dykes intruded into the sediments from Jameson Land in the south to the island of Shannon in the north (Hald & Tegner 2000; Larsen *et al.* 2014). Most intrusion ages are in the interval 54–52 Ma and magma production at that time must have been very extensive. These intrusions cover a stretch of least 500 km which is close to the entire onshore extent of the Mesozoic basins.

The intrusions are older than the Igtertivâ Formation at Kap Dalton on the Blosseville Kyst which comprises two parts dated at 49.1 ± 0.5 Ma and 43.8 ± 1.1 Ma (Larsen *et al.* 2013). Larsen *et al.* (2013) found significant geochemical differences between the Igtertivâ Formation basalts and the underlying 55 Ma lavas of the Skrænterne Formation, in particular in the rare-earth element (REE) ratios. As seen in Fig. 4, the intrusions at 55–51 Ma retained the geochemical characteristics of the older plateau lavas, indicating that the conditions of magma generation were unchanged, probably mainly governed by the relatively thick lithosphere beneath the continent away from the developing oceanic rift (Hald & Tegner 2000).

Conclusions

The two analysed sills in the Blokelv-1 core are compositionally similar to the main group (high-Ti group) of tholeiitic basalt sills and dykes that occur frequently in the Jameson Land Basin, of which two have been dated at *c.* 53 Ma. The Blokelv sills are considered to belong to this group. The group shares trace element characteristics

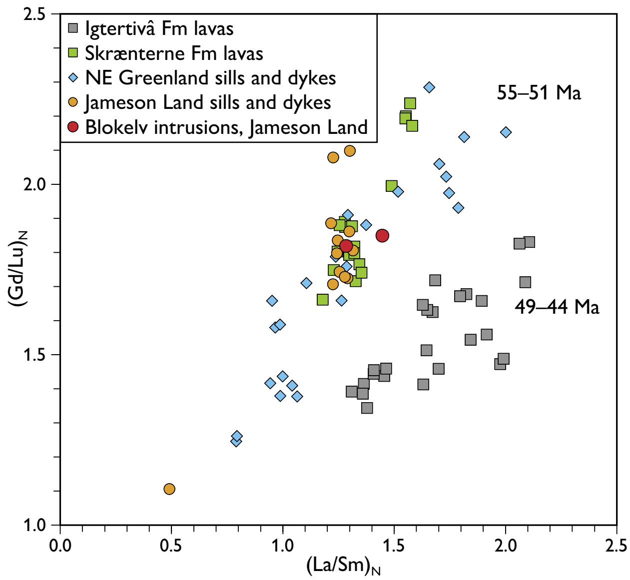

Fig. 4. Rare-earth element (REE) ratios for older (55–51 Ma) lavas and intrusions (Blosseville Kyst to Shannon) and younger (49–44 Ma) Igtertivâ Formation lavas on Blosseville Kyst, East Greenland. Data from Hald & Tegner (2000), Larsen *et al.* (2013), Larsen *et al.* (2014) and unpublished GEUS data (2008–2010). A few crustally contaminated samples are not plotted. La/Sm is the light REE ratio and Gd/Lu is the heavy REE ratio; N designates chondrite-normalised concentrations.

with the older Blosseville Kyst lavas and the 55–51 Ma tholeiitic sills and dykes in East Greenland, but not with the younger 49–54 Ma Igtertivâ Formation lavas. The older magmas were probably generated under similar conditions beneath relatively thick lithosphere.

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