Pre-basaltic sediments (Aptian–Paleocene) of the Kangerlussuaq Basin, southern East Greenland

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The recent licensing round in the deep-water areas south-east of the Faeroe Islands has emphasised the continued interest of the oil industry in the frontier areas of the North Atlantic volcanic margins. The search for hydrocarbons is at present focused on the Cretaceous–Paleocene succession with the Paleocene deep-water play as the most promising (Lamers & Carmichael 1999). The exploration and evaluation of possible plays are almost solely based on seismic interpretation and limited log and core data from wells in the area west of the Shetlands. The Kangerlussuaq Basin in southern East Greenland (Fig. 1) provides, however, important information on basin evolution prior to and during continental break-up that finally led to active sea-floor spreading in the northern North Atlantic. In addition, palaeogeographic reconstructions locate the southern East Greenland margin only 50–100 km north-west of the present-day Faeroe Islands (Skogseid *et al.* 2000), suggesting the possibility of sediment supply to the offshore basins before the onset of rifting and sea-floor spreading. In this region the Lower Cretaceous – Palaeogene sedimentary succession reaches almost 1 km in thickness and comprises sediments of the Kangerdlugssuaq Group and the siliciclastic lower part of the otherwise basaltic Blosseville Group (Fig. 2). Note that the Kangerdlugssuaq Group was defined when the fjord Kangerlussuaq was known as 'Kangerdlugssuaq'. Based on field work by the Geological Survey of Denmark and Greenland (GEUS) during summer 1995 (Larsen *et al.* 1996), the sedimentology, sequence stratigraphy and basin evolution of the Kangerlussuaq Basin were interpreted and compared with the deep-water offshore areas of the North Atlantic (Larsen *et al.* 1999a, b).

In August 2000, key stratigraphic sections were revisited by geologists from GEUS and Norsk Hydro and a number of additional localities described (Fig. 1). The aims of the field work included: (1) sedimentological description of Lower Cretaceous sandstones; (2) improved biostratigraphy in the Upper Cretaceous mudstone succession; and (3) detailed description of the transition between the uppermost sediments and the base of the volcanic succession. In addition, macrofossils (mostly ammonites, bivalves and belemnites) were sampled throughout the Cretaceous succession. Based on results from a preliminary diagenesis study (Larsen *et al.* 1999b), sandstones were collected across the contact metamorphic zone around Palaeogene intrusions in order to evaluate their thermal and diagenetic effects. The field work was financed with support from Norsk Hydro and formed part of a major field campaign in the Kangerlussuaq area (*EG 2000*) reported on by Nielsen *et al.* (2001, this volume).

Sedimentology

Lower Cretaceous (Christian IV Gletscher)

The oldest sediments in the Kangerlussuaq Basin are of Early Cretaceous (Aptian – Early Albian) age (Fig. 2). This succession is dominated by coarse-grained sandstones and was first described by Larsen *et al.* (1996, 1999a) from a locality north of Sødalen. At this locality a lower, alluvial succession is overlain by large-scale channelled and cross-bedded fluvio-estuarine sandstones (Larsen *et al.* 1999a). The general palaeocurrent direction was towards the east, but the lack of reference sections has hitherto hindered conclusions on distribution and palaeogeography. In summer 2000 a number of possible Lower Cretaceous reference sections were measured along the western side of Christian IV Gletscher (Fig. 1). These sections were briefly described during a helicopter reconnaissance visit in 1995, but more detailed measurements of sedimentological sections and sampling of ammonites was undertaken in 2000.

The sections are sandstone-dominated, and reach more than 170 m in thickness. The lowest parts are

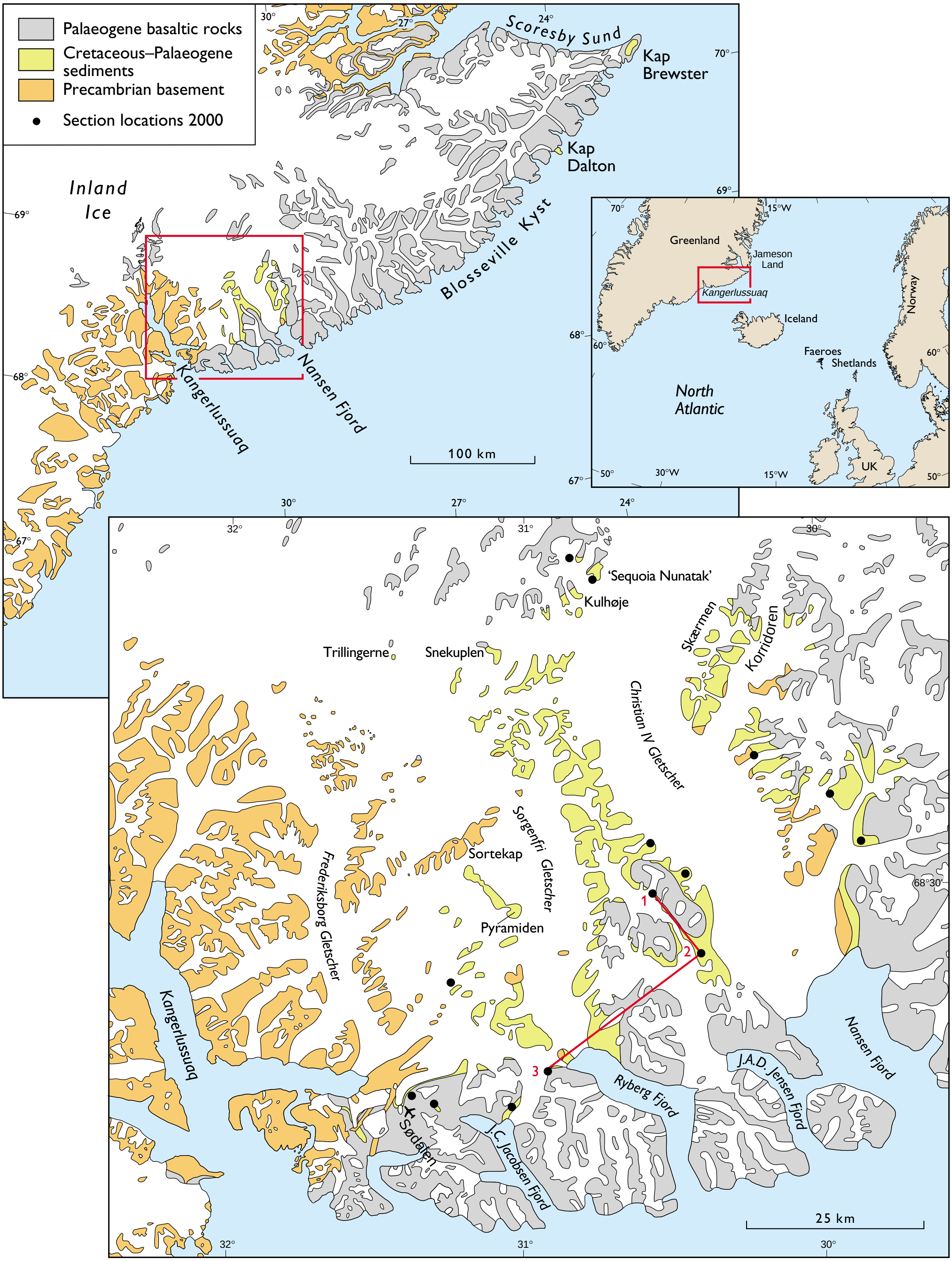

Fig. 1. Geological maps showing the distribution of Cretaceous–Palaeogene sediments and the Palaeogene flood basalts of the southern East Greenland volcanic province. The position of sections logged in 2000 (**black dots**) and localities mentioned in the text are indicated. **Red line** in lower map connects sections **1**, **2** and **3** shown in Fig. 5. Based on Larsen *et al.* (1996).

poorly exposed and consist of coarse-grained, locally pebbly, sandstones rich in coalified wood debris. These are overlain by medium- to coarse-grained, large-scale cross-bedded sandstones, which are bioturbated and show *Thalassinoides* isp. and *Planolites* isp. The upper boundary of the sandstone-dominated succession is a strongly carbonate-cemented horizon overlain by a thick succession of silty mudstones with numerous heteromorph ammonites. The Lower Cretaceous succession along the west side of Christian IV Gletscher is interpreted to consist of a lower alluvial part overlain by shallow marine deposits and finally offshore marine mudstones. The upwards change is thus the same as that seen in the Upper Aptian – Lower Albian succession at the locality north of Sødalen, and reflects an overall rise in sea level.

Upper Cretaceous – Paleocene ('Sequoia Nunatak')

Monotonous silty mudstones and fine-grained sandstones reaching several hundred metres in thickness (Fig. 3) dominate the Upper Cretaceous succession. The mudstones are best exposed in the area around Pyramiden and between Sorgenfri Gletscher and Christian IV Gletscher where they reach their maximum thickness. Nørgaard-Pedersen (1992) reported a probable Cretaceous succession at 'Sequoia Nunatak' (an unofficial name) north-east of Kulhøje, greatly expanding the then known extension of the Cretaceous basin (Fig. 1). The sediments were described as a few metres of fine-grained sandstones containing internal casts of echinoderms and ammonites. Field work in 2000, however, revealed in addition a several hundred metres thick succession of fine-grained micaceous sandstones just east of the locality described by Nørgaard-Pedersen. These sandstones contain a rich fauna of ammonites, echinoderms and bivalves of Late Cretaceous age. The fine-grained sandstones are truncated at the top of the succession by a 7 m thick conglomerate bed interpreted as a fluvial channel-fill, which is overlain by volcaniclastic deposits. The stratigraphic position of the conglomeratic unit immediately underlying the first volcanic deposits, together with the abrupt change from marine to continental deposits and the coarse-grained lithology, suggest that it may be correlated with the Schjelderup Member of the coastal areas (Soper *et al.* 1976). Biostratigraphic samples collected in 2000 may provide the evidence for the correlation between the nunatak area around 'Sequoia Nunatak' and the coastal region.

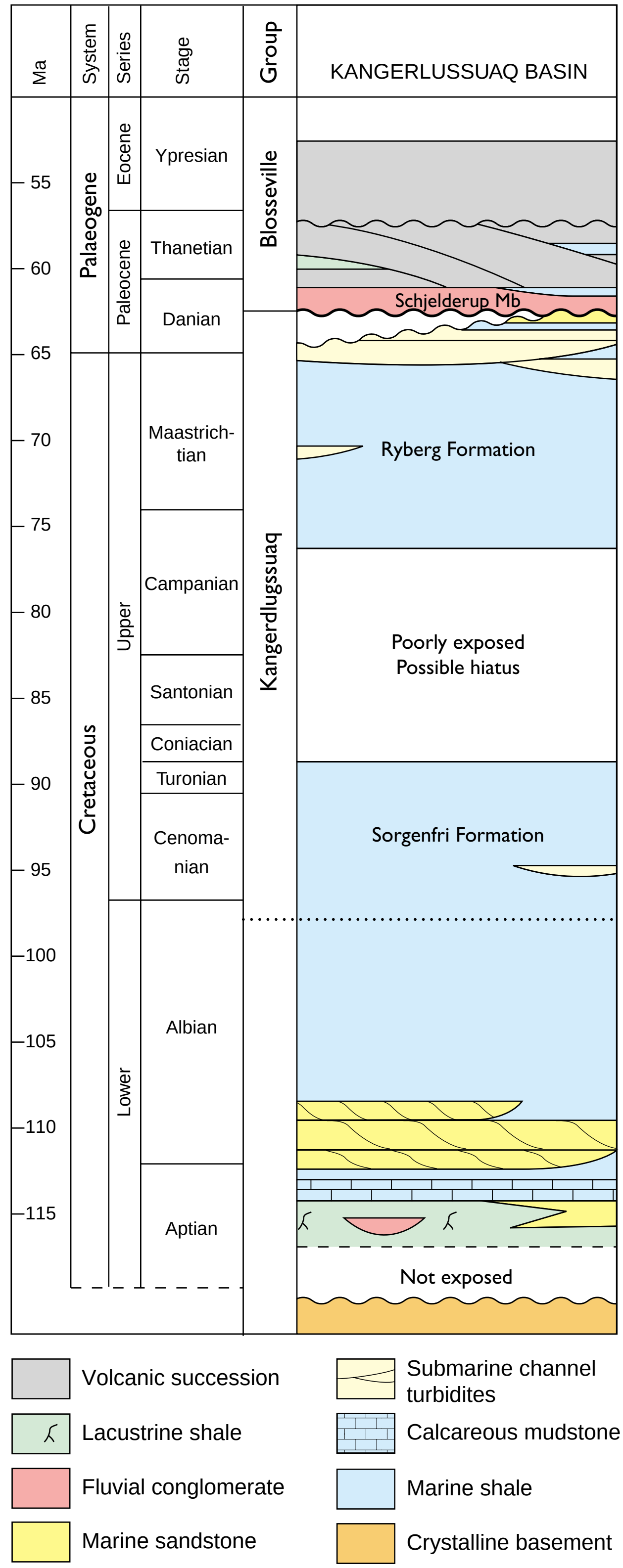

Fig. 2. Lithostratigraphy of the Kangerlussuaq Basin. The succession below the Sorgenfri Formation (Aptian – Early Albian) was not described until 1995 and therefore was not included in the lithostratigraphic scheme by Soper *et al.* (1976). A revision of this succession (below the dotted line) is in preparation by the senior author (M.L.). Based on Soper *et al.* (1976), Nielsen *et al.* (1981) and Larsen *et al.* (1999a).

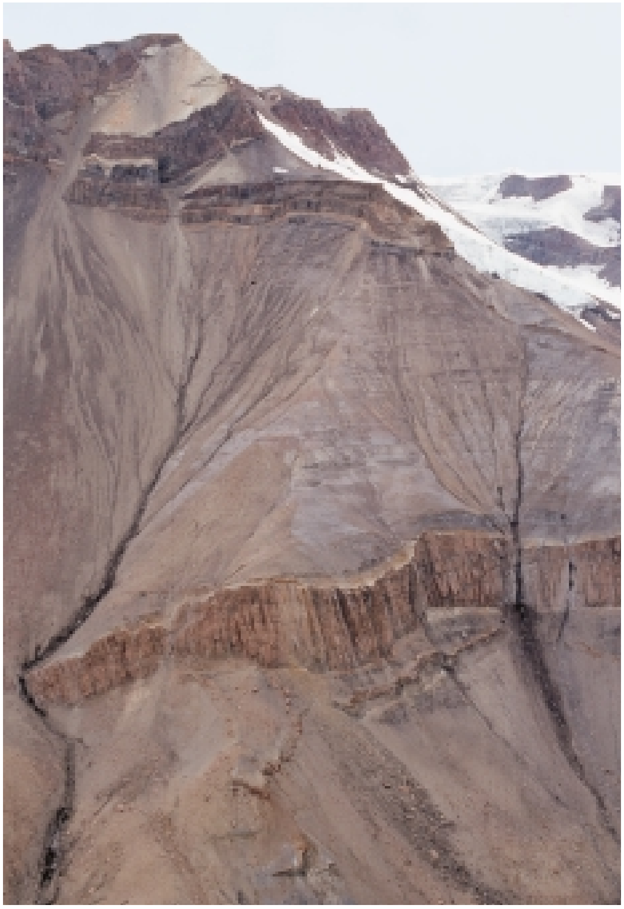

Fig. 3. Upper Cretaceous marine mudstone succession exposed along the western side of Christian IV Gletscher. The section shown is approximately 450 m thick and consists of silty, mica-rich mudstones with thin interbeds of fine-grained sandstones. Ammonites and echinoderms are present in several horizons and may form the basis for an improved Upper Cretaceous stratigraphy.

Paleocene (Ryberg Fjord)

The boundary between the Kangerdlugssuaq Group and Blosseville Group is represented by a major unconformity which separates Upper Cretaceous or Lower Paleocene marine mudstones below from coarse-grained fluvial deposits above (Soper *et al.* 1976; Dam *et al.* 1998; Larsen *et al.* 1999a). However, towards the coast (localities 2 and 3, Ryberg Fjord; Fig. 1) the unconformity correlates with a number of less distinct bounding surfaces separating shallow marine, deltaic and fluvial units. At Ryberg Fjord, a thick sandstone-dominated succession is exposed (Fig. 4). It consists of marine, fossiliferous fine-grained sandstone unconformably overlain by an up to 7 m thick pebbly sandstone bed, in turn overlain by black carbonaceous mudstones and fine-grained sandstones showing rootlets (Fig. 5). The erosionally based pebbly sandstone is interpreted as a fluvial channel-fill that marks a change from marine to dominantly continental deposition. Higher in the succession a return to shallow marine conditions is marked by strongly bioturbated sandstones interpreted as upper shoreface and beach deposits. The siliciclastic succession is overlain by a thick succession of volcaniclastic deposits and hyaloclastites. The Paleocene succession at Ryberg Fjord comprising shallow marine and deltaic deposits is thicker and more complete than that described from the inland areas. This indicates that increasing accommodation room was present in the more basinal areas to the south-east and that multiple episodes of shoreface and delta progradation took place during the uplift phase preceding the onset of volcanism in East Greenland.

Fig. 4. Paleocene sandstones exposed at Ryberg Fjord. The sandstone unit in the foreground is 7 m thick and is interpreted as a fluvial channel-fill. These coarse-grained channel sandstones were deposited following regional uplift in the mid-Paleocene, just before the onset of volcanism. In the background volcaniclastic deposits and hyaloclastites can be seen.

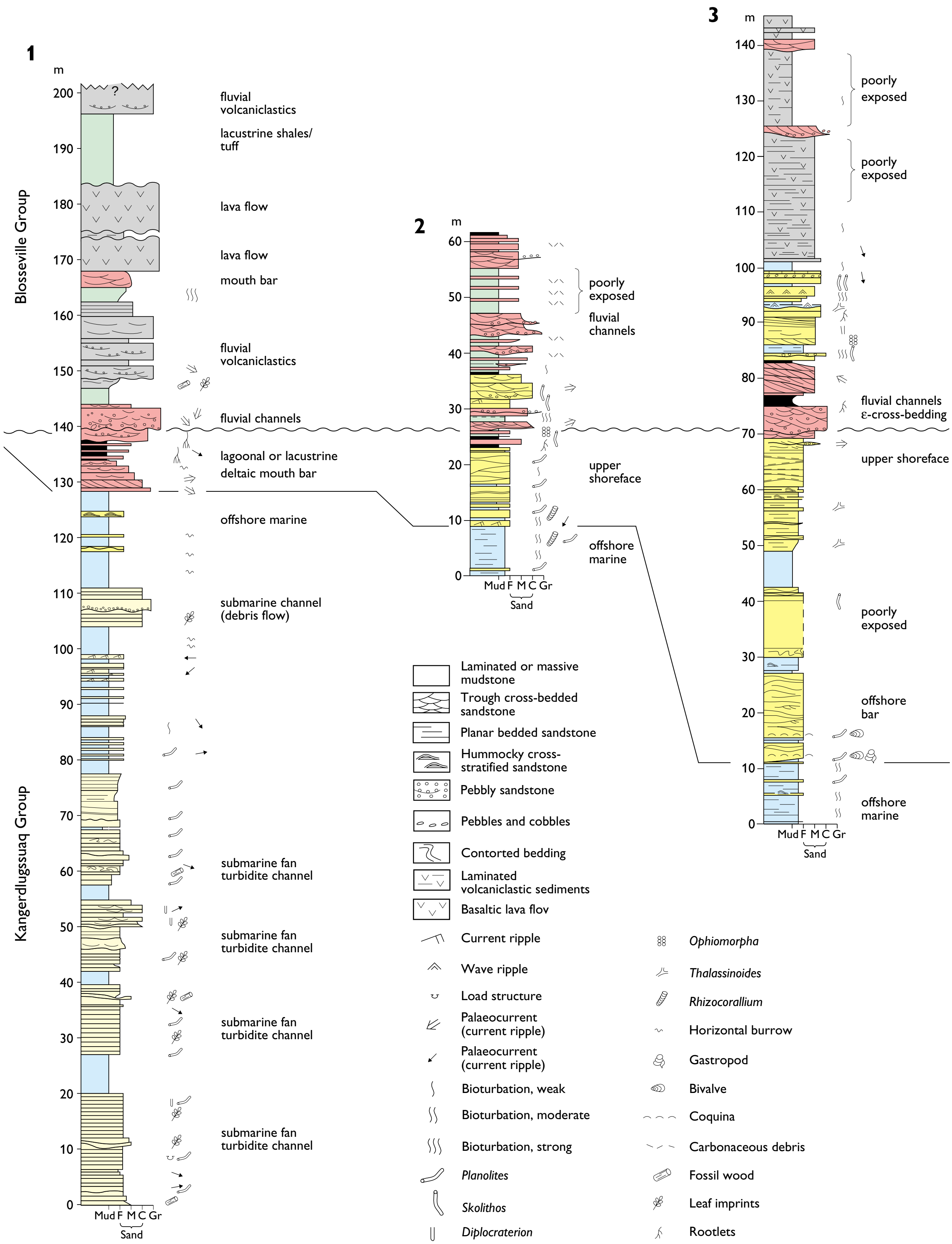

Fig. 5. Geological logs showing correlation of the Paleocene successions in the central part of the Kangerlussuaq Basin. Locations of sections (**1**, **2**, **3**) are shown on Fig. 1. Note the thick shallow marine and deltaic succession present below the unconformity in the southernmost section (**3**) compared to the strong truncation that occurs inland. The succession indicates that repeated progradation of shallow marine and deltaic successions occurred during the mid-Paleocene pre-volcanic uplift. **Colour coding** refers to depositional environments. For legend, see Fig. 2.

Stratigraphy

Biostratigraphy

Detailed understanding of the Kangerlussuaq Basin has hitherto been hampered by the low resolution of the biostratigraphic data. This is partly a consequence of failure to collect macrofossils, and partly due to very low yields of microfossils from the existing sample material. In order to overcome these problems special attention was paid to the collection of macrofossils, and several mudstone sections situated away from major intrusions were sampled for palynological work (Fig. 3). The efforts put into the macrofossil collecting were rewarded, such that close to 50 ammonites representing both Lower and Upper Cretaceous species were brought back from the field.

Lithostratigraphy

The discovery of an Aptian–Albian, sandstone-dominated succession below the Sorgenfri Formation in 1995 (Fig. 2) and the finds of new ammonite-bearing intervals made it clear that a revision of the existing lithostratigraphy was necessary (Larsen *et al.* 1999a). However, the lack of biostratigraphic control in the Upper Cretaceous mudstone-dominated succession, and the poor understanding of the lower volcanic succession which appeared to interfinger with the sedimentary rocks, impeded interpretation. The results of the field work in 2000 combined with biostratigraphical and sedimentological data compiled by Cambridge Arctic Shelf Programme (CASP) will enable a common lithostratigraphic scheme for the Kangerlussuaq Basin to be published in the near future. This new lithostratigraphy is a collaborative project between GEUS and CASP.

Diagenesis

The sandstones of the Kangerlussuaq Basin have been strongly diagenetically altered, due to their position close to major Palaeogene intrusive centres and a burial history that included rapid pre-volcanic uplift followed by deep burial beneath continental flood basalts. The complex diagenetic history comprises chlorite and illite precipitation, mechanical crushing, detrital feldspar dissolution and albitisation followed by albite precipitation and quartz overgrowth. The last common phase is calcite, while later kaolinite is only observed in the coarse-grained fluvial sandstones of the Schjelderup Member (Larsen *et al.* 1999b). The original excellent porosity of the sandstones is only preserved in a few places due to early chlorite coating of grains preventing quartz overgrowth. Otherwise, the original porosity has been completely destroyed, and the present porosity (5–10%) mainly reflects secondary porosity originating from dissolution of detrital feldspar. The dissolution process seems to be significantly enhanced in the coarse-grained sandstones in areas with many intrusions. The secondary pore space may be reduced by authigene albite growth on detrital grain remnants together with later syntaxial quartz overgrowths engulfing the albite (Fig. 6). In places, clay coatings or ductile clay clasts can be seen to inhibit quartz ingrowths, thus preserving the secondary porosity. The coarse-

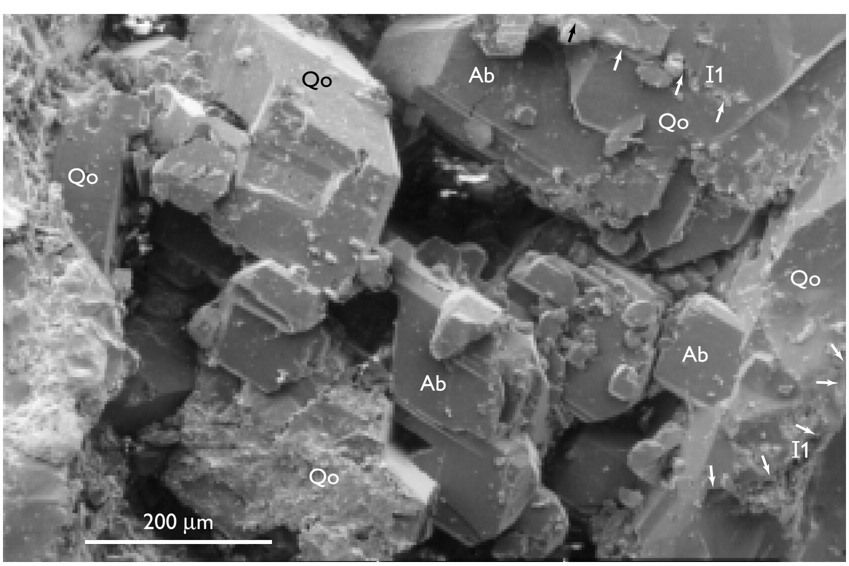

Fig. 6. Scanning electron photomicrograph of a coarse-grained Paleocene sandstone, showing secondary pore space formed by feldspar dissolution. The pore space is partly filled by growth of euhedral albite crystals (**Ab**) nucleated on the detrital feldspar remnants. Illitic clay lining (**Il**) marks the boundaries of the former detrital grains (**arrows**). Later, euhedral quartz (**Qo**) overgrows the clay linings and engulfs the authigene albite.

grained sandstones in the north-eastern part of the basin show the most complete feldspar dissolution, but also experienced the most intensive phase of late quartz overgrowth, which nearly infilled all of the secondary formed porosity.

In order to better understand the diagenetic history and evaluate models for sandstone diagenesis in sub-basaltic settings, sandstone samples from the measured sections were studied. However, local effects from cross-cutting basic dykes and sills have strongly influenced diagenesis, and thus sandstones were collected across the contact metamorphic zone from adjacent to the intrusion to a distance as far away as two to three times the thickness of the intrusion. The results of these investigations will be compared with the samples unaffected by intrusions in order to separate local and regional effects.

Conclusions

Field work in the Kangerlussuaq Basin in 2000 has added much information to the understanding of the basin evolution. Most important, perhaps, is the improved biostratigraphic resolution that allows identification and correlation of unconformities between measured sections. Unconformities mark major changes in basin configuration and are often associated with uplift and erosion. The unconformity present at the base of the Schjelderup Member, and now recognised throughout the basin, thus suggests that coarse-grained sediments bypassed the Kangerlussuaq area at this time and were transported across the East Greenland margin to offshore basins to the south-east. With a pre-drift position only 50–100 km north-west of prospective areas around the Faeroe Islands the understanding of the pre-basaltic basin evolution in southern East Greenland may be used to identify possible reservoir intervals and play types in the undrilled deep-water areas of the northern North Atlantic volcanic margins.

Future work

The Palaeogene flood basalts along the Blosseville Kyst are part of an extensive basalt province extending from Kangerlussuaq in the south to Scoresby Sund in the north. Sediments are exposed only at two isolated localities along the coastal stretch, at Kap Dalton and Kap Brewster (Fig. 1). These two localities form important datapoints for reconstruction of the North Atlantic region during continental break-up and for biostratigraphic control of the onset and duration of the volcanism in southern East Greenland. Both localities were visited by geologists in the 1970s (Birkenmajer 1972; Soper *et al.* 1976), but no recent sedimentological descriptions have been published. In the summer of 2001 field work will be carried out in the sedimentary successions at Kap Brewster and Kap Dalton using sedimentological, biostratigraphical and sequence stratigraphical methods. The results will be integrated with basin models and stratigraphy in the areas to the south-west around Kangerlussuaq and to the north in North-East Greenland.

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