Petroleum geological activities onshore West Greenland in 1996, and drilling of a deep exploration well

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The 1996 summer season saw continued petroleum geological activities in the Disko–Nuussuaq area, onshore West Greenland. These took the form of a geological field project led by the Geological Survey of Denmark and Greenland (GEUS), and continued commercial exploration by grønArctic Energy Inc. (grønArctic). In the second year of their licence, grønArctic carried out an airborne geophysical programme early in 1996 and drilled a *c.* 3 km deep exploration well on Nuussuaq, GRO#3, in the late summer (Fig. 1).

Although the detailed results from grønArctic's exploration are confidential (apart from the information made available at conferences and in press releases), it is evident that knowledge of the Nuussuaq Basin has greatly increased in recent years and that the basin has considerable exploration potential of its own (see Christiansen *et al.*, 1995b, 1996a). The activities by GEUS and the exploration by grønArctic will significantly improve the understanding of the petroleum system of the basin; available data from the 1996 activities have shed light on the types and distribution of oils, source rocks and potential reservoir units.

Field work

The aim of the field work in 1996 was mainly to follow-up previous studies on Disko and Nuussuaq. In particular, this involved further search for, and sampling of, seepage and oil staining, specific sedimentological studies, structural studies of the western part of Nuussuaq and very detailed palaeomagnetic sampling of lavas of the Vaigat Formation over a critical interval within which a pole shift can be recognised.

Seep studies

Recognition of oil staining and seepage in the volcanic succession overlying the Nuussuaq Basin has been very important in the assessment of the exploration possibilities on Nuussuaq and was an important factor in attracting industry to the area in 1994. Evidence of migrated hydrocarbons (thermally altered) was reported by Pedersen (1986), but the first fresh oil samples that allowed reliable and encouraging organic geochemical studies were collected in August 1992 along the coast at Marraat on western Nuussuaq (Christiansen, 1993). The area with observed surface oil was substantially enlarged during field work in 1993 and 1994 when oil staining in the volcanics was also confirmed in a thick zone in the Marraat-1 drill hole (Christiansen *et al.*, 1994, 1995b, 1996b). During drilling of the first holes by grønArctic, GANW#1 in 1994, and GANE#1 and GANK#1 in 1995, more oil shows were discovered, both in cores of volcanic rocks and underlying sediments and at the surface in the vicinity of the drill sites, enlarging the area with oil impregnation significantly (Christiansen *et al.*, 1995a, 1996a). For the first time more than one oil type was recognised on Nuussuaq (Christiansen *et al.*, 1996c).

Based on previous experience, a more systematic approach was used for 'oil hunting' during the 1996 field season. Many localities were checked carefully on Disko and western Nuussuaq (see Fig. 3); some were close to previously known localities (infill sampling aiming at detailed analysis for various oil types and mixing), others were in new areas where seepage was considered likely based on general knowledge of the structure, stratigraphy and lithology. As a rule of thumb, oil seepage and staining is mainly observed at, but in no way limited to, localities that fulfil most of the following criteria:

1) a stratigraphic position in the lowermost part of the volcanic succession (lower part of the Vaigat Formation);
2) a structural position close to or within regional fracture zones or dyke swarms;

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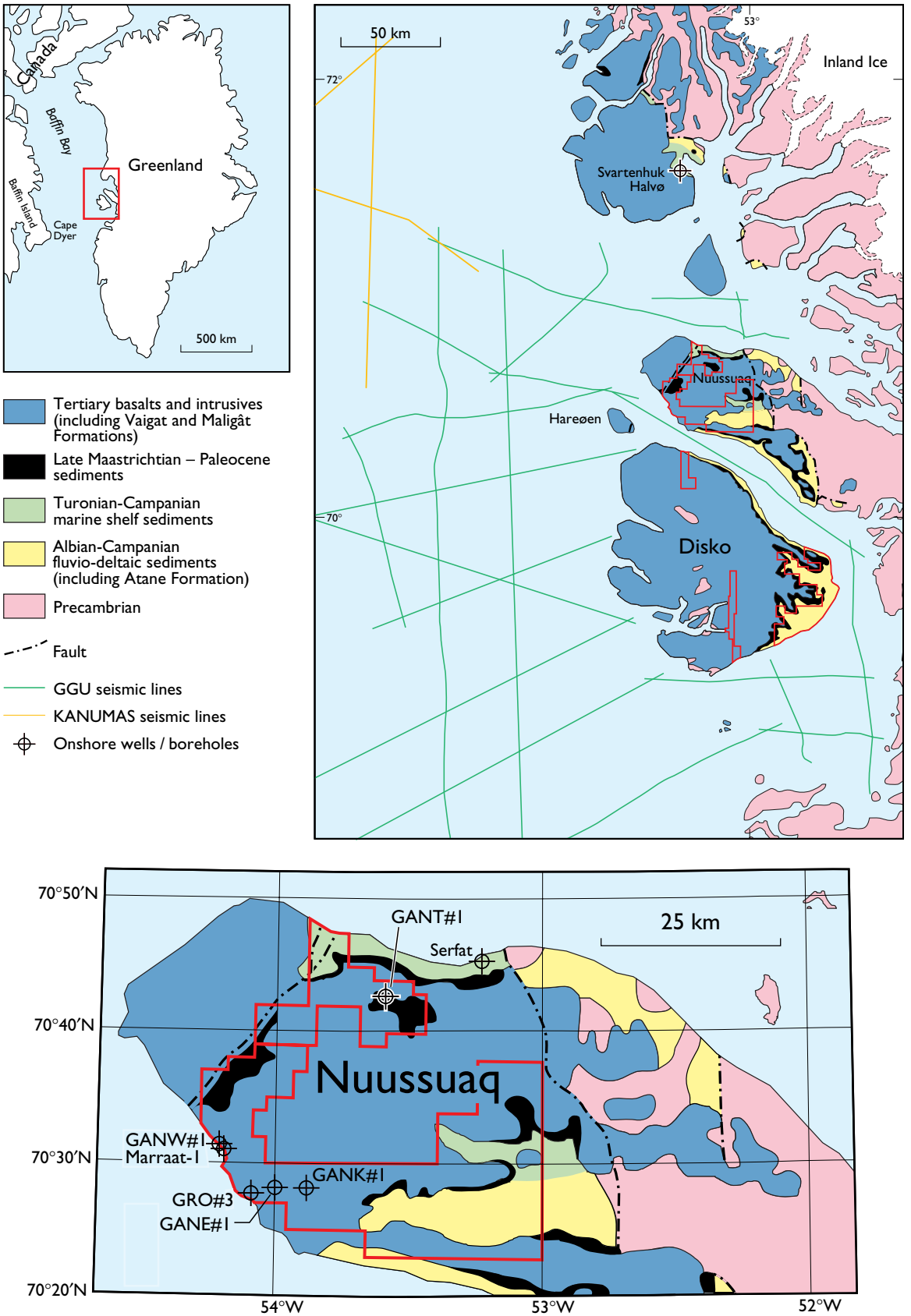

Fig. 1. Maps of the Disko – Nuussuaq – Svartenhuk Halvø area showing the position of wells and boreholes, grønArctic's licence area (enclosed by red lines), and the offshore seismic lines acquired in 1990 and 1995. Modified after Christiansen *et al.* (1996a).

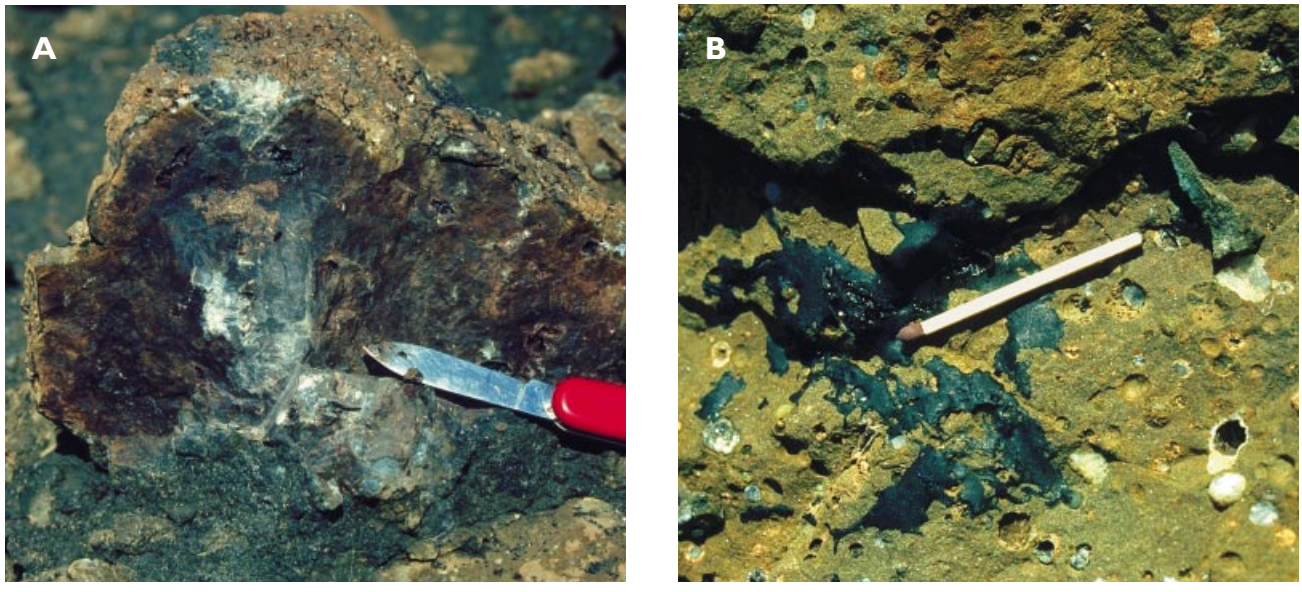

Fig. 2. Oil in volcanics. **A**: Pillow filled with oil (*c.* 3 km south-east of GRO#3). **B**: Vesicular lava with seeping oil (*c.* 7 km south-east of GRO#3).

3) a high concentration of fractures and mineralised veins (especially quartz and fine-grained calcite; less commonly coarse-grained calcite and zeolite minerals);
4) a high primary porosity such as within lava flow tops;
5) preferential lithology (especially flinty rocks such as silica-enriched basalts and hyaloclastites, less commonly olivine basalts, rarely picrites).

Examples of oil staining in lavas and pillow breccias on Nuussuaq are shown in Figure 2. All seeps and stains have been localised by systematic prospecting, combining visual characteristics such as the presence of liquid oil or discoloured carbonates with a rapid test for petroliferous odour carried out within seconds on a freshly exposed rock surface. In general, all samples which displayed a distinct petroliferous odour have given reliable geochemical results, even in cases where no visible liquid hydrocarbons could be observed. Samples which contained a dark soft substance with only an earthy smell, have not given reliable geochemical results; the samples extracted show evidence only of recent organic material.

The distribution of localities with oil seepage and staining observed in 1996 and previously are shown on the map in Figure 3. Many new and impressive examples have been found, especially along the south coast of Nuussuaq between GRO#3 and Niaqornaarsuk. Entirely new localities were located west of the Itilli valley on Nuussuaq (both on the south and north coasts). Staining was also found in a 25 km wide zone on northwestern Disko, from immediately east of Kuugannguaq to Serfarsuit. No seepage or staining has been recognised to date in central and southern Disko or on Hareøen.

Preliminary organic geochemical results from the oil seeps and oil-stained samples are very encouraging, and suggest the presence of at least five distinct oil types with quite different origins (Christiansen *et al.*, 1997; Bojesen-Koefoed *et al.*, in press). The pronounced regional variation is important for understanding the petroleum system of the sedimentary succession underlying the volcanics.

Sedimentological investigations

Sedimentological field work focused on three topics:

1) acquisition of a new data set: the natural gamma radiation of the sedimentary rocks;
2) documentation of lateral facies variations within the Atane Formation;
3) sampling of late to post-volcanic lacustrine sediments on Hareøen.

A Geometrics GR-410 gamma ray spectrometer borrowed from Risø National Laboratory was used for measurements. The equipment is portable, but heavy, and data acquisition fully occupied one person. In order to test whether a correlation existed between gamma radiation counts and sedimentary facies, two sections some

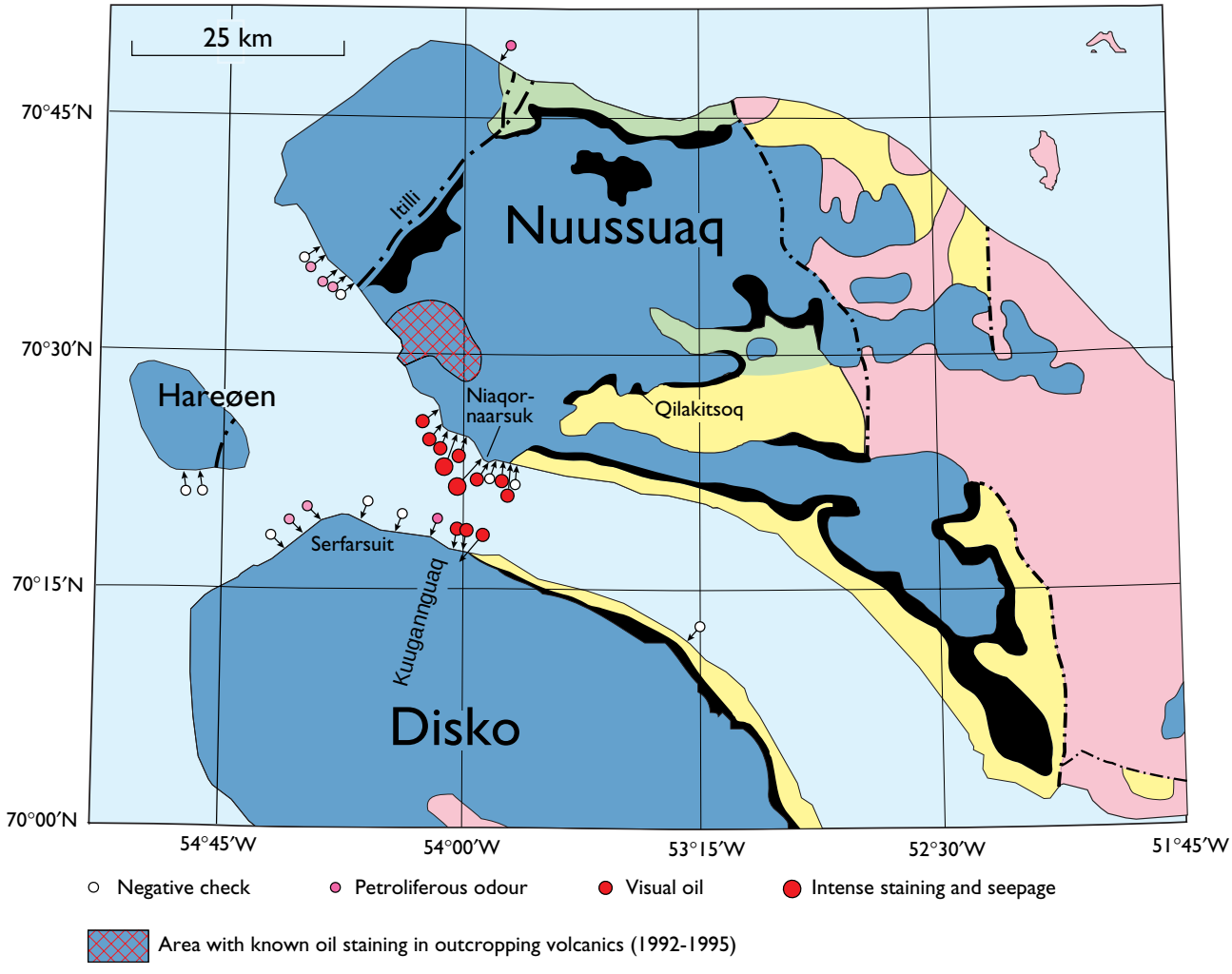

Fig. 3. Map of Nuussuaq and the northern part of Disko showing the distribution of localities with seepage and staining of oil, localities where a petroliferous odour was recognised, and localities that were carefully checked without finding evidence of oil. See figure 1 for explanation of geological units.Modified after Christiansen *et al.* (1996a).

distance apart, but with comparable sedimentary facies were selected. As expected, the sandstones were characterised by low values, but, surprisingly the shales also had low radiation counts. The latter probably reflects a high silt content in the shales and the predominance of brown or black lignite in the organic matter. Comparison of the gamma radiation curves with the sedimentological logs indicates that the depositional cycles of the Atane Formation may be difficult to recognise from a gamma-log without supporting evidence from additional petrophysical logs, side-wall cores or conventional cores.

The cyclic nature of the Atane Formation is evident in most outcrops, but the degree of lateral facies variation within each cycle is less well-known. The area around Qilakitsoq (central Nuussuaq) was selected for the study of this variation, since numerous gullies provide closely spaced sections (0.5 – 1 km apart). The stratigraphic section includes two thick shale sections which are easily correlated, as are a number of intensely bioturbated sandstones. Numerous short, upward coarsening successions are present; a number of these are interpreted to represent local phases of progradation, as they cannot be traced with confidence from one section to the next.

Syn-volcanic lacustrine sediments are known from eastern Nuussuaq and Disko, and these have been interpreted as the deposits of volcanic dammed lakes (A. K. Pedersen *et al.*, 1996; G. K. Pedersen *et al.*, in press). The volcanics exposed at Hareøen include the youngest lava flows known in the region and the 1996 field work suggests that the associated lacustrine sed-

Fig. 4. GRO#3 well. **A**: Mobilisation by ship. **B**: Well site from the north-west.

iments are distinctly different from those known from Disko and Nuussuaq. Two outcrops were studied, representing two lakes at different stratigraphical levels, and samples were collected for analysis of palynofacies, spores and pollen, organic geochemistry and for clay mineral analysis.

Structural studies

The aim of the structural studies is to establish a model for the development of the western part of the Nuussuaq Basin by integration of structural field data with the available photogrammetric and geophysical data. Field work in 1996 concentrated on the south coast of western Nuussuaq between Niaqornaarsuk and Itilli (Fig. 3), where a structural analysis was carried out on the exposed Maastrichtian – Lower Paleocene Itilli succession (Dam & Sønderholm, 1994) and the lower part of the volcanic Paleocene Vaigat Formation. The structural orientation of lava flows and hyaloclastites, faults, dykes, joints and mineralised veins was measured. Several complex systems of faults, dykes and joints have been identified. The structural analysis suggests distinct changes in the stress system during and after the period of volcanism. Oil seepage and staining are mainly related to late or post-tectonic calcite-filled veins with a N–S trend.

Palaeomagnetic studies

As a continuation of the palaeomagnetic investigations of volcanic rocks from the Vaigat Formation (Riisager & Abrahamsen, 1996), a very detailed sampling programme was carried out at two locations (western Nuussuaq and northern Disko) of lava flows within the lower part of the Vaigat Formation, erupted around the polarity change N27-R26. In addition, lava flows were sampled from two intervals within the Maligât Formation on south-western Disko and on western Nuussuaq.

Drilling of a commercial well (GRO#3) by grønArctic Energy Inc.

Exploration of the Nuussuaq Basin by grønArctic was continued in 1996, the second year of their licence, by completing a major airborne geophysical survey over parts of Disko and Nuussuaq and by drilling a deep exploration well, GRO#3, on Nuussuaq (Fig. 4).

Table 1. Technical data from the grønArctic well GRO#3

Well name:	Nuussuaq Kugssuaq GRO#3
Classification:	Exploration
Operator:	grønArctic Energy Inc., Calgary, Alberta, Canada
Drilling contractor:	Terroco Drilling Ltd.
Drilling rig:	Terroco Rig 1
Logging contractor:	Schlumberger
Mud logging contractor:	Sperry-Sun Drilling Services of Canada
Drill stem test contractor:	Alpine Testers
Locality:	South-west coast of Nuussuaq, West Greenland
Co-ordinates:	70°27.765′N, 54°05.227′W
Ground elevation:	17.6 m a.s.l.
Kelly bushing:	22.5 m a.s.l.
Well spud:	3 August 1996
Termination:	17 September 1996
Rig released:	5 October 1996
Total depth (TD):	Driller 2996.7 m
Total depth (TD):	Schlumberger 2995.5
Hole diameter	660 mm (0–33 m) 455 mm (33–247 m) 311 mm (247–801 m) 216 mm (801–2996.7 m)
Core:	No core taken
Sidewall core:	No sidewall cores taken
Logs:	A full suite of petrophysical wireline logs and a VSP (vertical seismic profile) were acquired
Formation drilled:	The drilling and wireline logs recorded 312 m of basalt at top and sand and shale successions from 312 m to TD
Hydrocarbons:	A number of sand intervals contained hydrocarbons
Test:	Eight of the most prospective zones were drill stem tested
Status:	Plugged and abandoned

In May 1995, grønArctic Energy Inc. and Platinova A/S were granted an exclusive exploration licence for a 1692 km² area covering western Nuussuaq; this area was increased to 2355 km² in the spring of 1996. Parts of the area were relinquished at the end of 1996, and the remaining licence area is now 988 km² (Fig. 1). The exploration programme started in 1995 with the drilling of three slim-core holes (GANE#1, GANK#1 and GANT#1) to depths between 400 and 900 m (see Christiansen *et al.*, 1996a). In addition, grønArctic holds a licence from 1996 covering a minor part (1011 km²) of Disko (Fig. 1). In the period from February to April 1996, grønArctic carried out airborne gravity and magnetic reconnaissance surveys covering areas of western Nuussuaq and northern Disko; a total of 6040 line km of gravity data and 6222 line km of magnetic data were acquired with a 2 × 12 km flight grid.

The GRO#3 well was drilled in the period from August 3 to September 17 on a site less than 1 km from the mobilisation point at the beach (Figs 1, 4). Drilling equipment arrived with the ship *Cecilia Desgagnes* at the south coast of Nuussuaq on July 10 and was moved ashore by barges. The original plan was to drill two exploration wells GRO#1 and GRO#2, both at locations more than 10 km inland from the landing site. However, transfer of the equipment inland was suspended due to soft ground conditions and permafrost problems. Consequently, a new well location, GRO#3, was selected in order "to evaluate the stratigraphic section along this structural trend which is associated with oil seeps at Marraat to the north-west and the oil seeps to the south-east of this drilling location" (grønArctic press release dated August 1, 1996).

GRO#3 was spudded on August 3 and reached a total depth (TD) of 2996 m on September 17 (see technical details in Table 1). The well penetrated 312 m of volcanics and a number of sandy and shaly successions from 312 m to TD. A full suite of petrophysical wireline logs and a vertical seismic programme were run in the hole. The company reported a number of sand intervals containing hydrocarbons and eight zones were tested. The drill stem tests showed that the intervals were tight and not able to flow (grønArctic press release dated September 30, 1996).

Future work

Encouraged by the many interesting results obtained in recent years, petroleum-related studies and commercial exploration are expected to continue at a high activity level in the coming years. GEUS activities will include field work in 1997. Work in the near future will concentrate on sedimentological and structural studies, as well as further searches for oil seepage and staining in other areas on Disko, Nuussuaq and Svartenhuk Halvø. Exploration programmes will be continued by grønArctic on Disko and Nuussuaq; these will include geophysical studies as well as drilling.

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