

- nappe complex. Copenhagen: Geol. Surv. Greenland, 72 pp.
- Henderson, G., Rosenkrantz, A. & Schiener, E. J. 1976: Cretaceous-Tertiary sedimentary rocks of West Greenland. In Escher, A. & Watt, W. S. (edit.) *Geology of Greenland*, 340-362. Copenhagen: Geol. Surv. Greenland.
- Kalsbeek, F. 1989: GGU's expedition in the Disko Bugt area, 1988. *Rapp. Grønlands geol. Unders.* **145**, 14-16.
- Kalsbeek, F., Taylor, P. N. & Pidgeon, R. T. 1988: Unworked Archaean basement and Proterozoic supracrustal rocks from northeastern Disko Bugt, West Greenland: implications for the nature of Proterozoic mobile belts in Greenland. *Can. J. Earth Sci.* **25**, 773-782.
- Marker, M. & Knudsen, C. 1989: Middle Proterozoic ultramafic lamprophyre dykes in the Archaean of the Atâ area, central West Greenland. *Rapp. Grønlands geol. Unders.* **145**, 23-28.
- Pedersen, A. K. 1985: Reaction between picrite magma and continental crust: early Tertiary silicic basalts and magnesian andesites from Disko, West Greenland. *Bull. Grønlands geol. Unders.* **152**, 126 pp.
- Pulvertaft, T. C. R. & Chalmers, J. A. 1990: Are there Late Cretaceous unconformities in the onshore outcrops of the West Greenland basin? *Rapp. Grønlands geol. Unders.* **148** (this volume).
- Schiener, E. J. & Leythaeuser, D. 1978: Petroleum potential off W. Greenland. *Oil Gas J.* **76**(40), 223-234.
- Steenfelt, A. 1987: Gold in the fine fraction of stream sediments from supracrustal sequences in West Greenland. Unpubl. intern. GGU rep., 10 pp.
- Stemmerik, L., Pulvertaft, T. C. R. & Larsen, H. C. 1990: Current activities in the field of hydrocarbon geology. *Rapp. Grønlands geol. Unders.* **148** (this volume).

F. K., Geological Survey of Greenland, Copenhagen.



GGU has two principal functions in the field of hydrocarbon geology: (1) to identify and investigate sedimentary basins with hydrocarbon potential, in order to obtain information that can attract and guide industry in its choice of target areas for exploration, and (2) on the basis of the insight gained from (1), to advise the Mineral Resources Administration for Greenland in technical matters concerning the administration of licences and concessions.

Areas of interest for hydrocarbon exploration in Greenland can be grouped under four headings: onshore areas accessible to present or near future technology; onshore areas accessible only to distant future technology; offshore areas accessible to present technology; and offshore areas accessible only to distant future technology (fig. 1). In recent years GGU has concentrated its activities in onshore areas, but in 1987 a re-evaluation of the western Greenland continental shelf was initiated, and new seismic acquisition projects both to the west and east of Greenland are planned for the 1990s.

## Current activities in the field of hydrocarbon geology

*Lars Stemmerik, T. C. R. Pulvertaft and Hans Christian Larsen*

### Onshore East Greenland

#### *Jameson Land*

Jameson Land in central East Greenland is the only area in Greenland where hydrocarbon exploration is currently being carried out. The concessionaire is ARCO, in partnership with AGIP, Arktisk Minekompani A/S and the joint Greenland Home Rule/Danish State-owned company Nunaoil A/S. The first seismic programme in the area was completed in 1989, and a total of 1800 km of data has now been acquired and will form an important part of the basis for a decision as to whether and where drilling will be carried out.\* The main play is Upper Permian carbonate reefs sourced and capped by Upper Permian organic-rich shales.

GGU's responsibilities in Jameson Land include in-

\* Since this report went to press, ARCO announced its decision not to proceed to a drilling phase. In consequence, ARCO relinquishes its concession at the end of 1990.



Upper Permian carbonate mounds (30–40 m thick) overlying folded and eroded Devonian rocks are draped by Upper Permian black shales which have a high content of organic material. These shales may be the most important source rock for hydrocarbons in the Jameson Land basin of East Greenland, Photo: L. Stemmerik.

spection of the seismic operations in the field, interpretation of the acquired seismic data in order to be able to advise the Mineral Resources Administration for Greenland on matters concerning the fulfilment of the concession requirements, and the carrying out of field and laboratory investigations of specific hydrocarbon-related and more general character in order to gain a better understanding of the development and hydrocarbon potential of the basin.

Interpretation of seismic data has focused on the mapping of the most prospective units in the basin, a task that cannot be completed until the 300 km of data acquired in 1989 have been received (these data are being processed at present – November 1989). A grant from the Ministry of Energy has allowed processing of the deep seismic data from ARCO (12 sec., c. 35 km) in order to gain an understanding of the early evolution of the Jameson Land basin; interpretation of these data has led to a new concept for the early evolution of the basin (H. C. Larsen *et al.*, 1989). According to this the main rifting event in Jameson Land took place in the Devonian, a conclusion that is important in evaluation

of hydrocarbon generation and preservation as it implies a lower thermal gradient during latest Palaeozoic and Mesozoic time than had previously been assumed.

Field work in 1989 was carried out in the Upper Permian and Upper Triassic – Lower Jurassic units. The work in the Upper Triassic – Lower Jurassic was a continuation of a BP supported sedimentological investigation that was started in 1987 (Dam, 1988, 1989). This project was designed to provide detailed and regional facies models that might help in the understanding of reservoirs of similar age in the North Sea, and has led in addition to the recognition of a prolific lacustrine source rock unit in the Jurassic of Jameson Land.

The Upper Permian study is part of a joint GGU–ARCO group project to evaluate the reservoir potential of the various carbonate facies (Stemmerik *et al.*, 1989, 1990). Additional work carried out by GGU on the Upper Permian sediments comprises palynostratigraphy, source rock evaluation, and studies of the thermal history, including a study of the maturity variation in the Wegener Halvø area along the eastern margin of the basin (Christiansen *et al.*, 1990).

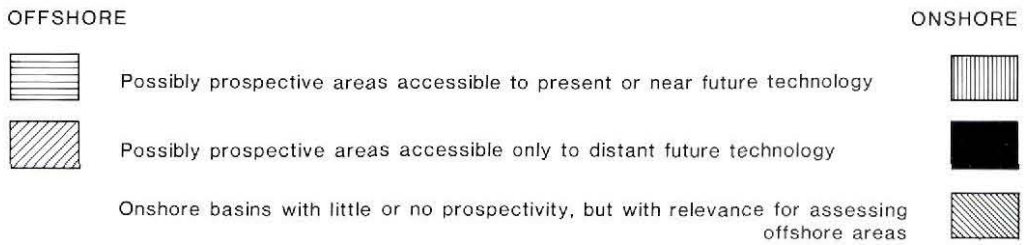
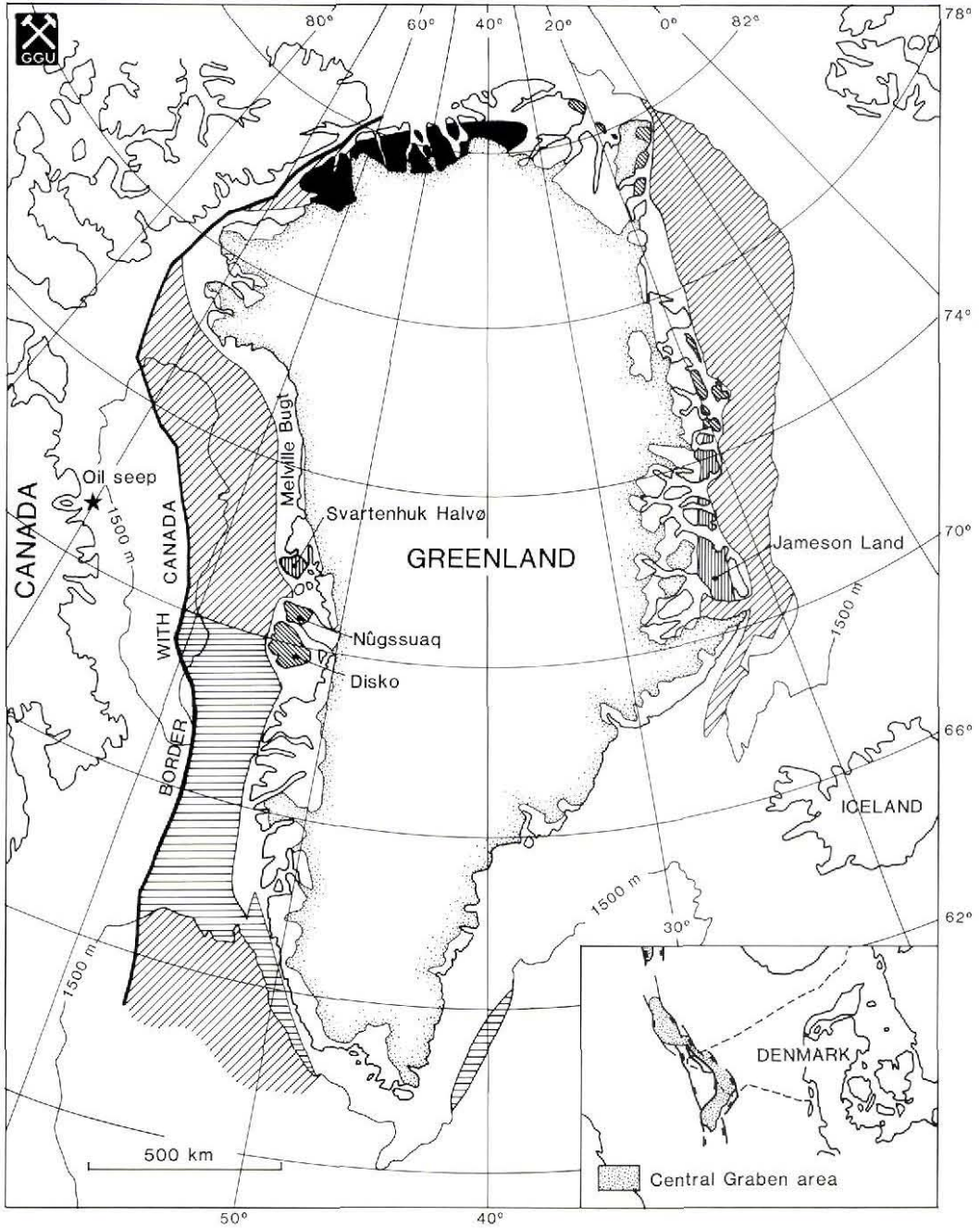


Fig. 1. Main areas of interest for hydrocarbon exploration in Greenland. Ice-congested regions and regions with more than 1500 m water depth are not considered accessible with present-day technology. Central Graben area (North Sea) shown for scale.

### *North-East Greenland*

In 1986 a research programme was initiated to evaluate the petroleum potential of the onshore part of the Upper Palaeozoic – Mesozoic sedimentary basin between 72° and 78°N, and to collect information relevant to the evaluation of basins offshore North-East Greenland (Marcussen *et al.*, 1987, 1988; P.-H. Larsen *et al.*, 1989). During the 1989 field season the few remaining areas to be investigated within this region were visited (Stemmerik & Piasecki, 1990) and the field work is now finished.

The basin comprises a more than 12 km thick sedimentary section spanning the interval Middle Devonian to Upper Cretaceous. The depositional units have different importance with regard to petroleum potential and therefore they have been studied in different ways and in varying degrees of detail.

The Devonian has been studied with regard to regional sedimentology, stratigraphy, structural style, and history. The petroleum potential of the Devonian sequence is negligible, although a few thin organic-rich lacustrine shales of source rock quality were discovered. The relevance of the structural studies lies in the necessity of having a first-hand knowledge of the structural style and sedimentary history of the exposed part of the Devonian basin if the deeper structure and early history of the Jameson Land basin are to be understood. A new geological map of the western part of the Devonian basin is almost complete and a new lithostratigraphy and a model for the tectonic-sedimentary evolution of the more than 7 km thick non-marine basin fill are being developed. Some of these results have been presented internationally and submitted for publication. The sedimentological studies have been made possible by a post-doctoral fellowship from the Carlsberg Foundation, Copenhagen.

The 1–3 km thick Carboniferous – Lower Permian sequence is also non-marine. Efforts have been concentrated on establishing a palynostratigraphy for the succession and evaluation of the source potential of the lacustrine shales. The biostratigraphic work is not yet complete; the results of the source rock studies have been presented in a series of papers submitted for publication. In these it is concluded that the non-marine shales have a hitherto overlooked source potential not only onshore North-East Greenland but possibly also in offshore basins around the North Atlantic.

Much of the work has been focused on the Upper Permian sediments because the Upper Permian is the main target for exploration in Jameson Land. GGU work in the Upper Permian north of 72°N includes palynostratigraphy, conodont stratigraphy (Rasmussen

*et al.*, 1990) and evaluation of source rock potential of the shales, as well as studies of the sedimentology and diagenesis of the carbonates. The sequence resembles that seen in Jameson Land, and it is therefore suggested that this stratigraphic level may well be prospective in the northern areas.

The Mesozoic succession has been investigated mainly from the point-of-view of stratigraphy and source rock potential of the Lower Triassic, Upper Jurassic and Lower Cretaceous shales. The source rock analytical work has been completed and the biostratigraphical studies are well advanced. Potential source rocks in the Mesozoic section are restricted to Upper Jurassic shales which form a northern continuation of the Kimmeridgian source rock known especially in the North Sea. Palynological studies in the Lower Cretaceous are being supported by a research scholarship from the Carlsberg Foundation.

### **North Greenland**

A study of the petroleum potential of the Lower Palaeozoic Franklinian basin in North Greenland was completed by the end of 1987. This project was supported by a grant from the Ministry of Energy, and involved surface studies and shallow core drilling, followed up by source rock and bitumen geochemistry, and maturity and palynological studies. In 1989 work was limited to final editing of a bulletin in which most of the results from the project are reported (Christiansen, 1989). The implications of the study are that there are three potential plays in North Greenland: (1) sheet sandstones within the Cambrian Henson Gletscher Formation, with organic-rich mudstones of this formation as both source and seal; (2) Upper Proterozoic and particularly Lower Cambrian shelf sandstones, again with the Henson Gletscher Formation as source; this play requires long-distance migration; (3) Silurian marginal limestones and reefs, with adjacent organic-rich mudstones as source and overlying non-source mudstones and siltstones as seal. Because of the regional thermal maturity pattern, with increasing maturities to the north, only the sandstones along the southern part of the belt (play 2) are really prospective. Interested readers are referred to the bulletin for details.

### **Onshore West Greenland**

Cretaceous–Tertiary sediments outcropping in Disko, Nûgssuaq and Svartenhuk Halvø in central West Greenland can provide information that is very valuable for the interpretation of seismic data offshore West Greenland and for the evaluation of the petroleum potential

of the West Greenland shelf and farther north into Melville Bugt. The occurrence of potential source rocks in the onshore outcrops has already been suggested by Schiener & Leythaeuser (1978). GGU is planning to start a new programme in this area in 1991 in which sedimentology, palynostratigraphy, and source rock studies with modern analytical methods will be integrated with a view to establishing a model for basin development that can be used to predict source rock intervals and seismic sequence boundaries in the Upper Cretaceous and lowermost Tertiary offshore. As a preliminary step towards these new investigations a two-man party spent a short field season in 1989 on Nûgs-suaq and Disko examining localities where mid-Upper Cretaceous unconformities had been reported by an ARCO-Chevron group in 1976 (see Kalsbeek, 1990). Unconformities were found, but it is believed that they are between Upper Cretaceous and Lower Tertiary sediments (Pulvertaft & Chalmers, 1990).

### **The southern West Greenland shelf**

The West Greenland shelf south of 70°N is the only offshore area in Greenland where hydrocarbon exploitation is possible with existing technology. In spite of this, the area was dropped from the industry-financed KANUMAS project when this had to be reduced (see later article). GGU has always been of the opinion that this area was abandoned prematurely by the oil industry in 1979. Five dry wells should not have been so discouraging to an industry accustomed to having to drill more than 30 wells in frontier areas before the first strike is made. However, in response to a political decision that priority should be given to onshore areas, GGU transferred most of its capacity in 1982 to the study of onshore areas in North-East, East and North Greenland, and did not resume systematic studies in West Greenland until 1987, when a reinterpretation of industry seismic data from the 1970s was initiated (Chalmers, 1989). Progress in this project is the topic of the next article.

As an additional initiative, GGU has arranged for test reprocessing of 275 km of the seismic data acquired in the Labrador Sea by Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) in 1977. If this test is successful, it is planned to reprocess a further *c.* 2100 km of data which should greatly improve our knowledge of the deep-water basin off the southern West Greenland shelf and help to provide a better insight into how the Labrador Sea developed. The latter is important for the general assessment of the prospectivity of the shelf. The reprocessing is being financed by a grant from the Ministry of Energy.

Acquisition of regional seismic data is also planned for 1990 (see the following two articles).

### **The eastern Greenland shelf**

Ice conditions off eastern Greenland make this area very difficult to investigate by ship-borne geophysical methods. For this reason the first survey of the area was by airborne magnetometer; the survey – known as project EASTMAR – was financed by the Ministry for Trade, and the results are summarised in Thorning *et al.* (1982). In 1980–82 EASTMAR was supplemented by project NAD (North Atlantic D), a reflection seismic project financed by the EEC. Due to ice conditions this project was limited to the area south of 72°N, and even in this area coverage is uneven as some areas were never ice-free at a time when the seismic vessel could visit them. A review of the geology of the whole of the shelf based on the combined results of the EASTMAR and NAD projects is in press and is expected to be published in the near future (Larsen, in press). In 1989 more detailed interpretation of some of the NAD lines was undertaken.

### **Regional marine seismic reconnaissance project KANUMAS**

The KANUMAS project is a marine seismic reconnaissance programme to be carried out in the little known areas of the shelf north of 72°N in eastern Greenland and north of 71°N in western Greenland. (KANUMAS is an acronym for Kalaallit Nunaat Marine Seismic; Kalaallit Nunaat is the Greenlandic name for Greenland). The project will be financed by industry, the operator is Nunaoil A/S, and GGU is chief technical advisor. It is planned to acquire 13 500 km reflection seismic data in four ship-seasons in the course of the coming six years, starting in 1990. Negotiations and planning of the KANUMAS project have been one of GGU's preoccupations in 1989. Further details about the history and philosophy behind the KANUMAS project are given in a later article.

### **Seismic database**

During the last year seismic navigation data from offshore western and eastern Greenland have been filed in databases with a new geophysical software system purchased with funds from the Mineral Resources Administration. In addition to navigation data the system can handle interpreted seismic sections, for example depth-convert time sections, and create various types of maps from the sections. The system will be an essential tool in carrying out the seismic projects outlined in the foregoing paragraphs.

## References

- Christiansen, F. G. (edit.) 1989: Petroleum geology of North Greenland. *Bull. Grønlands geol. Unders.* **158**, 92 pp.
- Christiansen, F. G., Piasecki, S. & Stemmerik, L. 1990: Thermal maturity history of the Upper Permian succession in the Wegener Halvø area, East Greenland. *Rapp. Grønlands geol. Unders.* **148** (this volume).
- Chalmers, J. A. 1989: A pilot seismo-stratigraphic study on the West Greenland continental shelf. *Rapp. Grønlands geol. Unders.* **142**, 16 pp.
- Dam, G. 1988: Sedimentological studies of the fluvial-marine Upper Triassic to Lower Jurassic succession in the Jameson Land, East Greenland. *Rapp. Grønlands geol. Unders.* **140**, 76–79.
- Dam, G. 1989: Sedimentological studies of the Upper Triassic to Lower Jurassic succession in the Jameson Land basin, central East Greenland. *Rapp. Grønlands geol. Unders.* **145**, 75–79.
- Kalsbeek, F. 1990: Disko Bugt Project, central West Greenland. *Rapp. Grønlands geol. Unders.* **148** (this volume).
- Larsen, H. C. in press: The East Greenland shelf. In Grantz, A., Johnson, [G.] L. & Sweeney, J. F. (edit.) *The Arctic Ocean region. The geology of North America* L. Boulder, Colorado: Geol. Soc. America.
- Larsen, H. C., Armstrong, G., Marcussen, C., Moore, S. & Stemmerik, L. 1989: Deep seismic data from the Jameson Land basin, East Greenland. *Terra Abstracts* **1**, 10–11 (IFP/ILP/IUGS Exploration Research Conference: The potential of deep seismic profiling for hydrocarbon research, Arles, France, June 1989).
- Larsen, P.-H., Olsen, H., Rasmussen, F. O. & Wilken, U. G. 1989: Sedimentological and structural investigations of the Devonian basin, East Greenland. *Rapp. Grønlands geol. Unders.* **145**, 108–113.
- Marcussen, C., Christiansen, F. G., Larsen, P.-H., Olsen, H., Piasecki, S., Stemmerik, L., Bojesen-Koefoed, J., Jepsen, H. F. & Nøhr-Hansen, H. 1987: Studies of the onshore hydrocarbon potential in East Greenland 1986–87: field work from 72° to 74°N. *Rapp. Grønlands geol. Unders.* **135**, 72–81.
- Marcussen, C., Larsen, P.-H., Nøhr-Hansen, H., Olsen, H., Piasecki, S. & Stemmerik, L. 1988: Studies of the onshore hydrocarbon potential in East Greenland 1986–87: field work from 73° to 76°N. *Rapp. Grønlands geol. Unders.* **140**, 89–95.
- Pulvertaft, T. C. R. & Chalmers, J. A. 1990: Are there Late Cretaceous unconformities in the onshore outcrops of the West Greenland basin? *Rapp. Grønlands geol. Unders.* **148** (this volume).
- Rasmussen, J. A., Piasecki, S., Stemmerik, L. & Stouge, S. 1990: Late Permian conodonts from central East Greenland. *Neues Jb. Geol. Paläont. Abh.* **178**, 309–324.
- Schiener, E. J. & Leythaeuser, D. 1978: Petroleum potential off W. Greenland. *Oil Gas J.* **76**(40), 223–234.
- Stemmerik, L. & Piasecki, S. 1990: Post-Caledonian sediments in North-East Greenland between 76° and 78° 30'N. *Rapp. Grønlands geol. Unders.* **148** (this volume).
- Stemmerik, L., Scholle, P. A., Thomas, E., Amendolia, M., Henk, F. H. & Uncini, G. 1989: Facies mapping and reservoir evaluation of the Upper Permian Wegener Halvø Formation in Wegener Halvø, East Greenland. *Rapp. Grønlands geol. Unders.* **145**, 84–87.
- Stemmerik, L., Scholle, P. A., Henk, F. H., Di Liegro, G., Mantovani, M. & Ulmer, D. S. 1990: Facies mapping and reservoir evaluation of the Upper Permian Wegener Halvø Formation along the western margin of the Jameson Land basin, East Greenland. *Rapp. Grønlands geol. Unders.* **148** (this volume).
- Thorning, L., Larsen, H. C. & Jacobsen, N. L. 1982: *Project EASTMAR – final report*. 82 pp. Copenhagen: Geol. Surv. Greenland.
- L. S., T. C. R. P. & H. C. L., *Geological Survey of Greenland, Copenhagen.*



## Re-evaluation of the geology of the southern West Greenland shelf – Project VEST SOKKEL

James A. Chalmers

From 1970 to 1977 approximately 40 000 km of multichannel seismic data were acquired between latitudes 63°N and 68°N on the continental shelf of southern West Greenland. In 1976 and 1977 five wells were drilled to explore for hydrocarbons, but all of them were dry. All exploration licences were relinquished by 1979.

In order to start re-evaluation of the shelf, GGU initiated a Pilot Study in 1987 using a limited amount of seismic data from a selected area of the shelf (fig. 1). The study used seismo-stratigraphic interpretation techniques to try to learn more from the seismic data than had been found using 'conventional' interpretation