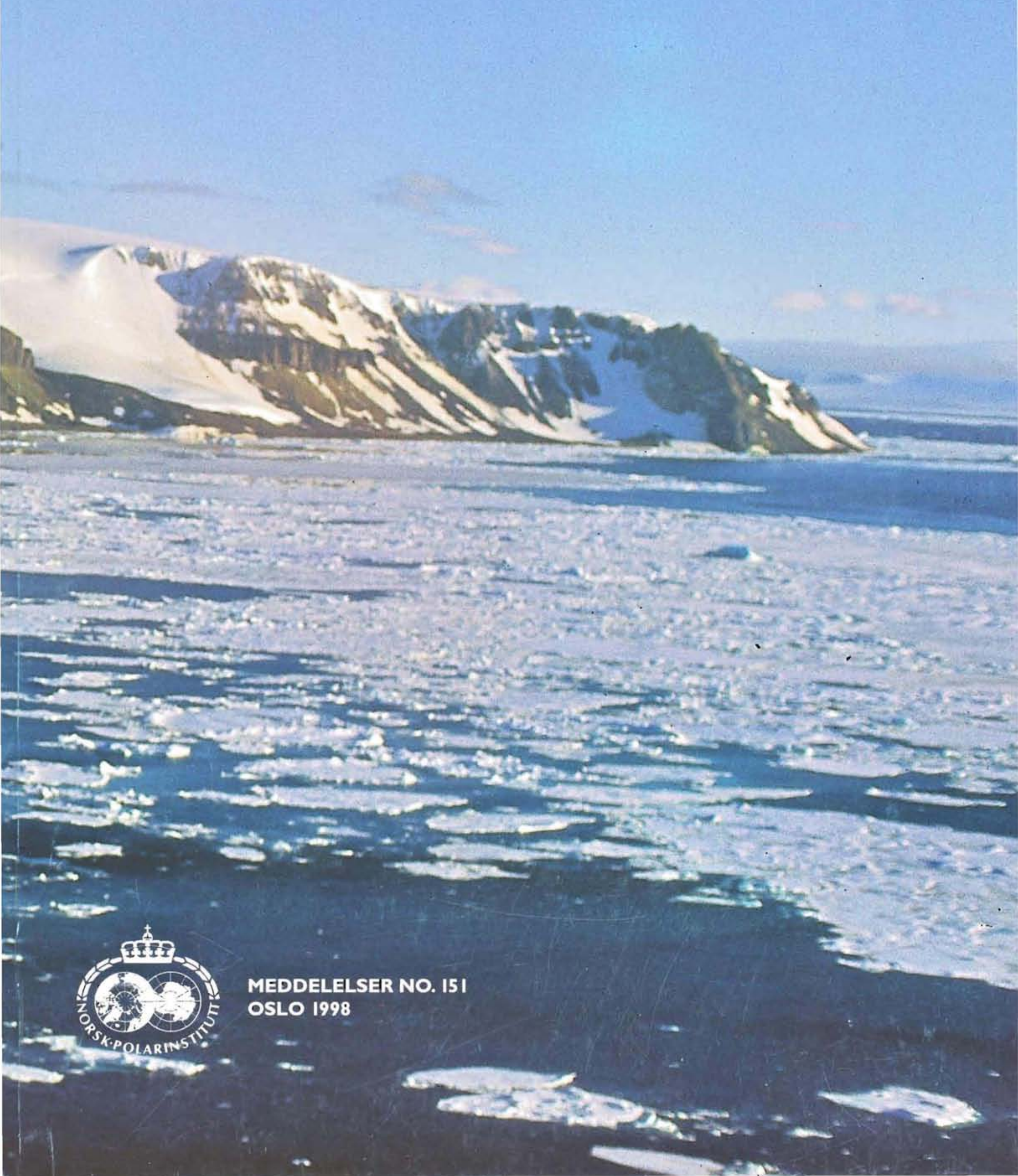
A. SOLHEIM, E. MUSATOV AND N. HEINTZ (EDITORS)

GEOLOGICAL ASPECTS OF FRANZ JOSEF LAND AND THE NORTHERNMOST BARENTS SEA

– The northern Barents Sea Geotraverse –



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Norsk Polarinstitutt

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Contents

1. GEOLOGICAL EVOLUTION AND CORRELATION BETWEEN FRANZ JOSEF LAND AND SVALBARD - THE NORTHERN BARENTS SEA GEOTRAVERSE; INTRODUCTION TO THE PROJECT

BY A. SOLHEIM[1], E. MUSATOV[2], N. HEINTZ[3] & A. ELVERHØI[4]

Planning and initial steps
Bilateral research programs between Norway and Russia on Arctic topics were agreed upon during a meeting in Oslo, Norway, in June 1989, between the Norwegian Research Council for Science and the Humanities (NAVF, now the Norwegian Research Council - NFR) and the Russian (at that time Soviet) State Committee for Science and Technology. The agreement covered four different research topics: 1. Upper atmosphere physics, 2. Oceanography, 3 Geology, and 4 Biology. Within the field of geology, a cooperative project in studying and comparing paleontological collections available in Norwegian and Russian museums was at that time already in progress. This project was finished in 1990 by publishing a catalogue on paleontological material mainly from Novaja Zemlja, housed in the Paleontological Museum, Oslo (Nakrem 1989). However, it was clearly a potential for an increase in the geological cooperation between the two countries. The political situation as well as the geological conditions made joint investigations of the northern Barents Sea region an interesting issue.

The northernmost part of the Barents Sea (Fig. 1) represents a key area for the understanding of the post Palaeozoic geological evolution of the European Arctic. The area has experienced a complicated tectonic evolution, influenced by the development of the Arctic Ocean and the Norwegian-Greenland Sea. The area between Svalbard and Franz Josef Land reflects the history of the various stages of fracturing and opening of the Arctic basin. Svalbard, on the other hand, has been mostly influenced by the post-Caledonian development with fracturing and opening of the Norwegian-Greenland Sea region. The tectonic development has resulted in large variations in sediment thickness as well as depositional regimes and faunal parameters. The differences are large both in east - west and north - south directions. The contrasting evolution of the two archipelagos is clearly illustrated by a Triassic sequence of at least 4200 m on Franz Josef Land, while it is less than 1000 m in Svalbard. Franz Josef Land is characterized by the presence of numerous sills of Mesozoic dolerites and thick Cretaceous basalts. Mesozoic dolerites and laterally extensive volcanics are also present in the Eastern Svalbard, but their thickness is much less. The northern Barents Sea consists of smaller sedimentary basins, while large scale structures are more typical for the southern parts. The present-day landscape and regional morphology of the area have been finally moulded by the repeated Late Cenozoic glaciations. Therefore, a better understanding of the younger geological deposits is also important as they may give valuable contributions to fully elucidate the geological evolution of the northern Barents Sea.

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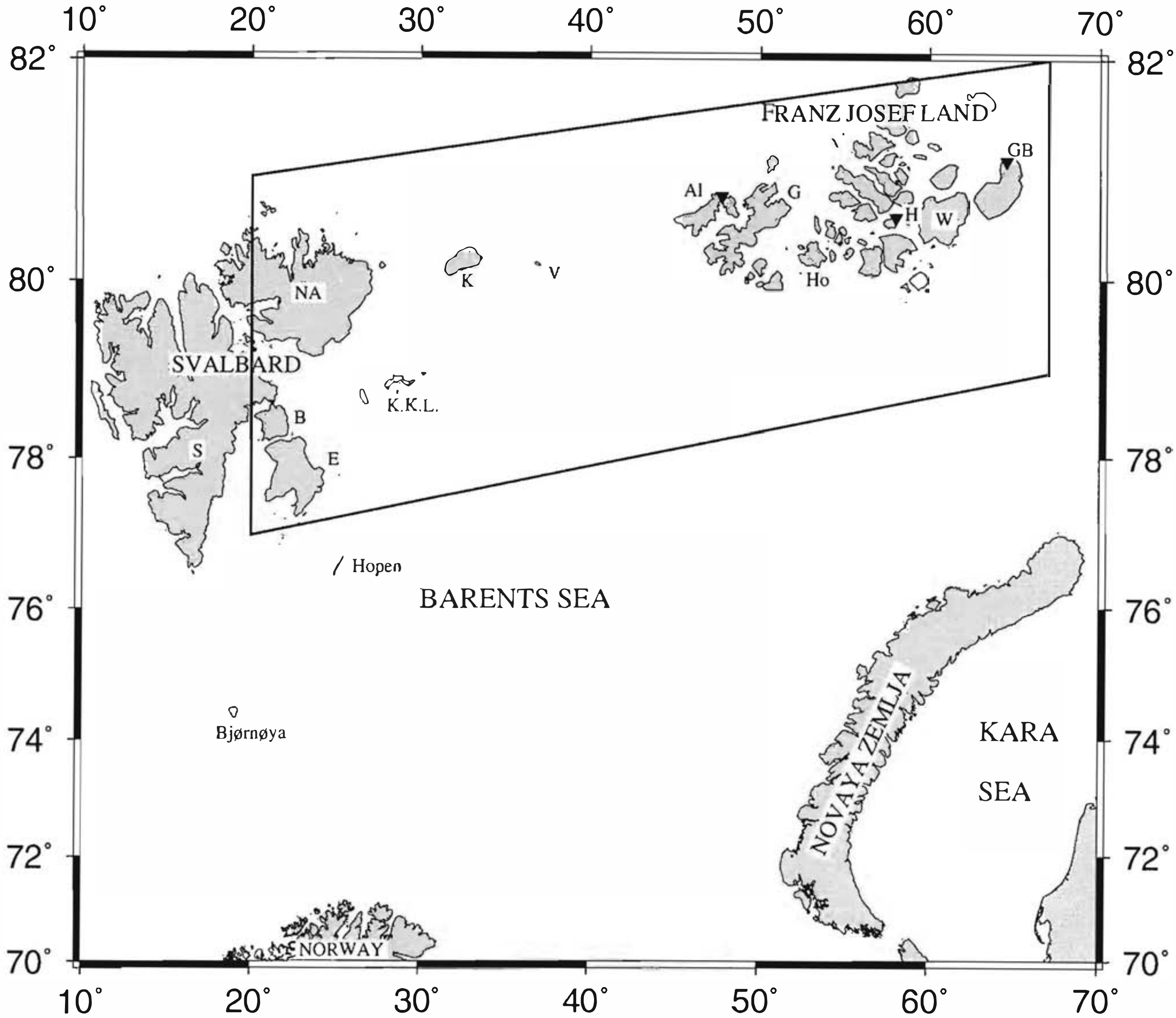

Fig. 1. Map of the Barents Sea, showing the area for the "Northern Barents Sea Geotraverse" program (framed). Allthough the area of interest covers both Franz Josef Land and Eastern Svalbard, new investigations have only been carried out on material from Franz Josef Land. The three deep wells on Franz Josef Land are shown by triangles. Islands in the Svalbard archipelago: S: Spitsbergen; NA: Nordaustlandet; K: Kvitøya; K.K.L.: Kong Karls Land; B: Barentsøya; E: Edgeøya. Islands in the Franz Josef Land archipelago: AI: Alexandra Land; G: George Land; GB: Graham Bell Island; H: Hayes Island; Ho: Hooker Island; W: Wilczek Land.

A joint Russian-Norwegian project to study the above described aspects of the geologcal evolution of the area was discussed and planned during a meeting in Oslo in February 1990. This meeting had participants from the Russian Scientific Research Institute for Geology and Mineral Resources of the World Ocean (VNIIOkeangeologia), the University of Oslo and the Norwegian Polar Institute. The present project *Geological Correlation and Evolution of the Eastern Svalbrd-Franz Josef Land Region: The Northern Barents Sea Geotraverse* (Fig. 1), was designed during this meeting. With reference to the geological problems, the availability of data and the possibilities for new data acquisition, the following important subjects were identified:

- The upper offshore bedrock geology (stratigraphy, sedimentology, shallow structures).
- Specified problems within stratigraphy, sedimentology, sediment petrography and depositional environments of the Upper Palaeozoic-Cenozoic succession.
- Volcanism and tectonic evolution.
- The marine Quaternary succession.

Four phases of investigations were planned:

Phase 1 (1990-1991)
- Compilation of all existing marine geological data in the northernmost Barents Sea.
- Exchange of information (maps, data, samples, references, etc.) between the Norwegian and Russian groups.

Phase 2 (1991-1992)
- More analyses on existing material, if necessary.
- Comparisons of data and results between the involved groups. Possible joint publications based on existing material.
- Outline problems and identify fields of future research.
- Identify geographical areas of inadequate data coverage- and quality, suitable for possible joint field activity.

Phase 3 (1992-1993)
- A marine geological / geophysical cruise in the area between Svalbard and Franz Josef Land, including shallow seismic profiling and low frequency echosounding (PDR), sediment coring and shallow bedrock coring.
- Land field work on Franz Josef Land and eastern Svalbard

Phase 4 (1993- 1995)
- Analyses of acquired data and material from the joint field activities.
- Publication of results.

The Northern Barents Sea Geotraverse Project
After a year of data exchange and mutual information, the next project meeting was arranged in St. Petersburg in March 1991. More detailed plans for the future progress of the project as well as practical aspects of joint field work were discussed. The latter included Norwegian participation in a Russian cruise planned for 1992. The main field activities, however, were planned for 1993 and 1994, with land work on Franz Josef Land in 1993 and a main marine cruise, including shallow rock core drilling, in 1994. Additionally, an agreement was made on joint studies of samples from three deep wells already drilled on Franz Josef Land in the 1970s (Fig. 1).

In the autumn of 1991 and spring of 1992, Norwegian geologists visited St. Petersburg. The cores from the three wells were sedimentologically studied and sampled. More than 100 samples from the cores were brought to Oslo for further analyses (Chapters 5 and 6). In addition, about 100 surface samples, mainly of volcanic rocks, were also brought to Oslo for various analyses (Chapter 7). The Russian marine geological cruise took place in the summer and early fall of 1992 (Chapters 3 and 4), and Norwegian geologists participated in the part of the cruise covering the area of the "Geotraverse".

From the Norwegian side, funding was provided by the participating institutions, from the Norwegian Research Council for Science and the Humanities (NAVF), now the Norwegian Research Council (NFR), and from the Norwegian state oil company, STATOIL. The proposed field operations, both the land field work and the cruise in 1994, would involve expenses far beyond those obtainable from the research council. The offshore industry was addressed for additional funding. Unfortunately, funds to carry out the planned extensive field operations were not obtained. These plans were therefore cancelled, and efforts have since been concentrated on the existing data and samples, in addition to samples and seismic data acquired during the joint Russian-Norwegian cruise in 1992.

Despite these limitations relative to the original plans, the project group considers the joint effort very successfull: 1. nine scientific papers (six in the present issue) and two reports have been published, 2. three graduate students at the University of Oslo, and one from the St. Petersburg Mining Institute have used material from this project for their Cand. scient./ Master theses, 3. two large Russian monographs, yet largely accomplished before the initiation of this project, have been printed as an integrated part of the project, and 4. last but not least, important contacts have been established, that may make future joint studies easier.

The present publication was planned during a project meeting in Hurdal, Norway, in February 1993. As the lack of external funding was clear at this point, the meeting agreed upon closing down the project with this publication.

PARTICIPATION

The following persons have been involved in the project:

Valentin I. Bondarev	VNIIOkean	Paleozoic and Mesozoic stratigraphy
Marianna V. Korchinskaya	VNIIOkean	Mesozoic stratigraphy and paleontology
Valery A. Basov	VNIIOkean	Mesozoic stratigraphy and paleontology
Alexey R. Sokolov	CSRGPM	Mesozoic stratigraphy and paleontology
Yuri J. Livshic (1)	VNIIOkean (1)	Mesozoic and Cenozoic geology
Vitaly D. Dibner	VNIIOkean	Geology of Franz Josef Land
Tatiana M. Pchelina	VNIIOkean	Sedimentary geology and stratigraphy
Evgeny G. Bro	VNIIOkean	Sedimentary geology and stratigraphy
Evgeny E. Musatov (2)	VNIIOkean	Quaternary geology, seismic stratigraphy,
Alexander N. Evdokimov	VNIIOkean	Magmatic petrology
Vladimir I. Gurevich	VNIIOkean	Modern marine sediments, geoecology
Leonid V. Polyak	VNIIOkean	Marine geology, paleontology
Olga R. Buzikova	VNIIOkean	Micropaleontology
Paul V. Rekant (student)	VNIIOkean	Marine Geology
Anders Solheim (3)	NPI	Marine geology, seismic stratigraphy
Anders Elverhøi (4)	IG, U.iO.	Marine Geology
Natascha Heintz	GM, U.iO.	Paleontology, translation
Henning Dypvik	IG, U.iO.	Sedimentary geology, stratigraphy
Jenø Nagy	IG, U.iO.	Biostratigraphy, paleontology
Arild Andresen	IG, U.iO.	Structural geology, igneous petrology
Hans Amundsen	Saga	Igneous petrology
Hans A. Nakrem	GM, U.iO.	Paleontology
Finn B. Gustavsen (student)	IG, U.iO.	Sesimic stratigraphy, sedimentology
Bård Fjellså (student)	IG, U.iO.	Sedimentary stratigraphyt, geochemistry
Sershar Ahmad (student)	IG, U.iO.	Geochemistry

1 Participation only first two years.
2 Russian coordinator.
3 Norwegian coordinator since 1991.
4 Norwegian coordinator before 1991.

VNIIOkean - VNIIOkeangeologia, St. Petersburg.
CSRGPM - Central Scientific Research Geological Prospecting Museum, St. Petersburg.
NPI - Norwegian Polar Institute, Oslo.
IG, U.iO.Department of geology, University of Oslo.
GM, U.iO - Geological Museum, University of Oslo.
Saga - Saga Petroleum Ltd., Oslo.

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Solheim, A., Musatov, E.E. & Heintz, N. (Eds.) 1998: Geological aspects of of Franz Josef Land and the northernmost Barents Sea. The northern Barents Sea Geotraverse. *Norsk Polarinstitutt Meddelelser 151* (this issue, with six scientific contributions).

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2. THE GEOLOGY OF FRANZ JOSEF LAND - AN INTRODUCTION

By V. D. DIBNER*

HISTORY OF EXPLORATION

Our knowledge of the geological evolution of the Franz Josef Land archipelago is based on numerous investigations ranging in time from its discovery in the late 19th century to the present day (Payer 1876; Koettlitz 1898; Nansen 1897, 1900; Samoilowich 1930, 1931; Horn 1932; Spizharsky 1937, 1947; Lupanova 1953; Dibner 1970, 1978; Dibner & Sedova 1959; Dibner et al. 1959; Livshits 1974; Tarakhovsky et al. 1980; Yefremova et al. 1983a, b; Shulgina & Mikhailov 1979). Geophysical investigations of the archipelago are, naturally, of somewhat younger date. The first aerial observations were made along the coasts of all the islands in 1953 (Dibner 1962), while aeromagnetic measurements across the archipelago were carried out by D.V. Levin and coworkers in 1962 (Volk 1964). During a three-year period from 1971 to 1973 the deeper structures of Franz Josef Land were seismically investigated for the first time (Avetisov & Bulin 1974).

A major stratigraphical effort was carried out in the period 1976-1981, when three deep stratigraphic wells were drilled on the islands of Alexandra, Graham Bell and Hayes (Gramberg et al. 1985a; Preobrazhenskaya et al. 1985a, b) (Fig. 1). Material from these wells also forms the basis for part of this contribution, as well as studies of Dypvik et al. (1998a, b). The most recent regional studies of the archipelago, including both geological and geophysical investigations, were carried out by the Polar Marine Geological and Prospecting Expedition of the Russian Federal Committee on Geology and Mineral Resources (Roscomnedra) in 1993.

TECTONIC EVOLUTION AND GEOMORPHOLOGY

The Franz Josef Land archipelago (Fig. 1) covers an area of approximately 25,000 km^2 and forms, together with northern Svalbard, the uplifted and dissected northern margin of the Barents Shelf. With respect to paleotectonics, Franz Josef Land and the adjacent offshore areas belong structurally to a northern closing of the East Barents Sea synclise (depression). The mosaic geomorphological pattern characteristic of Franz Josef Land, most likely reflects deep-seated tectonic features established already in the Precambrium. The cratonic Archaean-Proterozoic basement was during the late Proterozoic-Caledonian orogeny subdivided into numerous, separate tectonic blocks. Fragmentation of the crust into tectonic blocks was probably induced by deep-seated astenospheric plumes which, owing to radiogenically controlled thermal swelling, resulted in uplift of Moho. Such plumes may have separated the lithosphere into different blocks, today making up the central part of the archipelago. It is believed that this astenospherically controlled uplift resulted in fracturing, faulting and formation of radially oriented rifts at the surface. These structures intensified heat flow, mass transfer and compensatory subsidence, resulting in the formation of depocenters.

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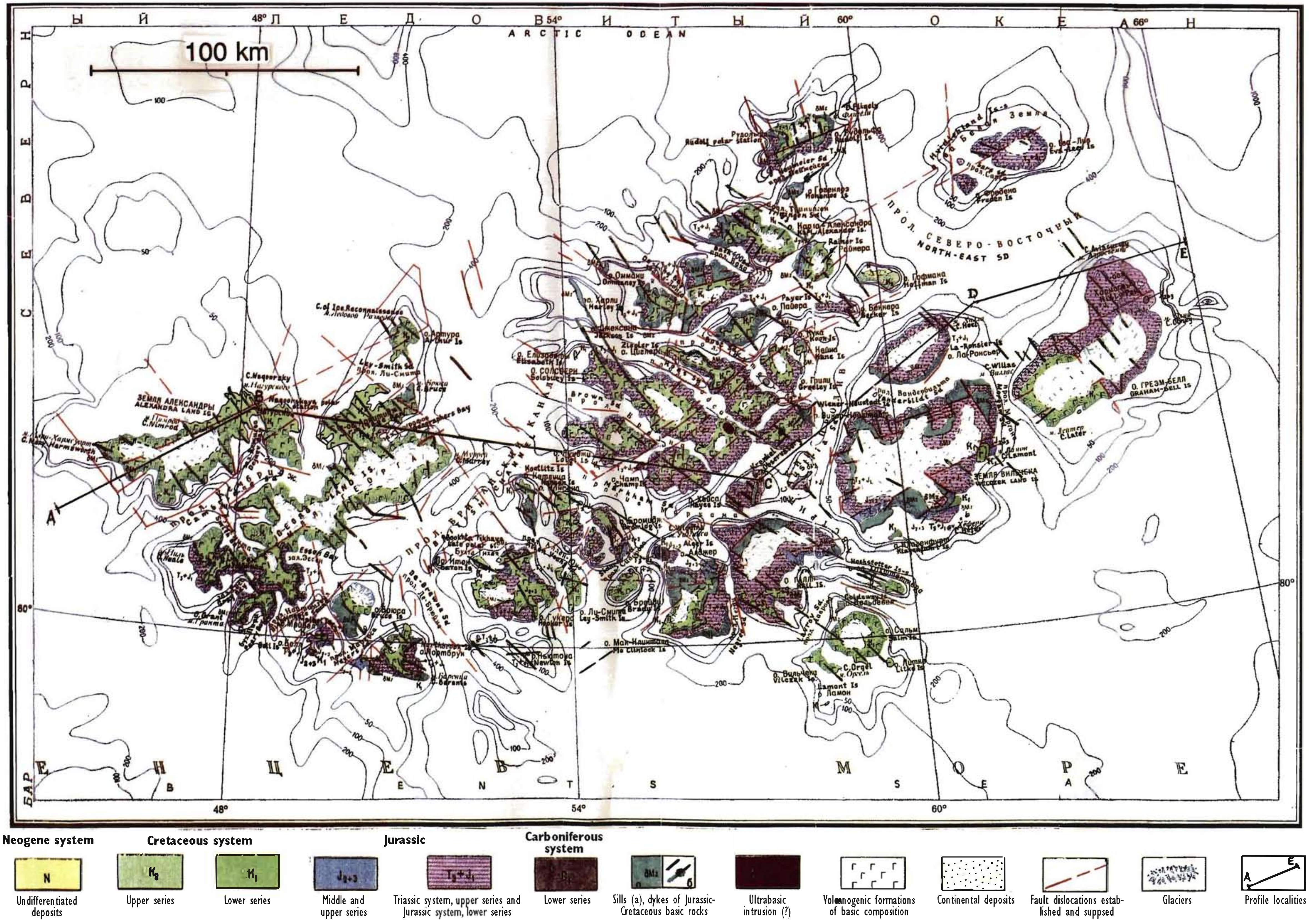
100 km
ARCTIC OCEAN
NORTH-EAST SD
ALEXANDRA LAND IS.
GRAHAM-BELL IS
Neogene system
Cretaceous system
Jurassic
Carboniferous system
N
Undifferentiated deposits
Upper series
Lower series
Middle and upper series
Triassic system, upper series and Jurassic system, lower series
Lower series
Sills (a), dykes of Jurassic-Cretaceous basic rocks
Ultrabasic intrusion (?)
Volcanogenic formations of basic composition
Continental deposits
Fault dislocations established and suppsed
Glaciers
Profile localities

Fig. 1. Geological map of Franz Josef Land, published by the Panrussian Scientific Research Institute of Geology and Mineral Resources of the Ocean (PNIIO). The map was primarily compiled in 1967 by V.D. Dibner, who also updated the map in 1992. Cartographers of this recent version are T.P. Vlasova and L.A. Skurkhina. The original version of the map was printed as a supplement to the XXVI volume of the *Geology of the USSR* (1970).

Younger and more important episodes of faulting in the late Neocomian, reactivated the Late Proterozoic lineaments. Accordingly, pre-Lower Neocomian sediments and magmatic rocks survived subsequent erosion in the down-faulted crustal blocks (grabens).

STRATIGRAPHY

To study the stratigraphy at depth on Franz Josef Land, three deep wells have been drilled on Alexandra Island, Graham Bell Island and Hayes Island. The well on Alexandra Island penetrates a section of downfaulted pre-Lower Neocomian rocks inferred to represent an onland continuation of rocks making up the subsurface of the Severnaya Bay Channel. The succession drilled on Alexandra Island is interpreted to be representative of faulted depressions that were rejuvenated in the Pliocene, resulting in the deep channels and sounds separating the islands that make up the archipelago.

The upper part of the Alexandra Island well penetrates about 300 m of Cretaceous (Barremian-Albian) sediments and volcanics intruded by dolerite sills and dikes. A major hiatus separates the Cretaceous sediments from the underlying Middle Triassic deposits. The Middle and Lower Triassic shales are about 1450 m thick, and overlie about 150 m of Carboniferous limestone and siltstone beds. At the 1900 metre level, however, the well hits Vendian greenschists and quartzites, carrying signs of Late Devonian/Early Carboniferous Svalbardian tectogenesis and related greenschist metamorphism.

More complete sections including both Triassic and Jurassic sequences are present in the wells from the Hayes and Graham Bell Islands. Both wells display rather continuous sand, clay and siltstone units ranging in age from Middle Triassic to earliest Jurassic, comprising 3400-3500 m (Fig. 2) (Dypvik et al. 1998a, b).

Younger Jurassic and Neocomian rocks are exposed in several outcrops at the islands of Bell, Northbrook, Hooker, McClintoc, Champ, Salisbury, Reiner, Berghaus, Wilczek Land, Graham Bell, Bekker and others (Fig. 2). The Lower Jurassic sandy deposits, 180-200 m thick, are lithostratigraphically almost indistinguishable from the underlying, terrigenous Norian-Rhaetian beds. As in Svalbard, these beds can only be separated on the basis of palynological analyses. All the characteristic Middle-Upper Jurassic stages are represented in the sandy and clayey marine deposits in the Graham Bell Island well. Together with the succeeding Berriasian-Valanginian beds, the total thickness is estimated to about 650 m (Fig. 2). The Aalenian-Lower Valanginian interval is characterized by several transgressive/regressive cycles, non-synchronously manifested at various islands. Younger Berriasian and Valanginian variegated beds are represented at Cape Lamont, while Valanginian-Hauterivian brackish water deposits are recognized at Cape Hofer (Wilczek Land Island) (Fig. 1). Above these deposits Barremian-Albian sediments and volcanic rocks are present. The plateau basalts capping many of the islands of Franz Josef Land, comprise both flows and pyroclastic deposits (tuff) (Amundsen et al. 1998). In other areas, this association also includes hypabyssal intrusives including dolerite and gabbro-dolerites, e.g. leucocratic and quartz gabbro-doleritic dikes. Some of the sills are up to 120 m thick. Contact metamorphism and hydrothermal alterations of enclosing rocks are common next to the intrusives, depending on the intrusion size.

Geological field observations on many of the islands of the Franz Josef Land archipelago indicate that hypabyssal intrusions were forced into the upper Triassic, Jurassic and

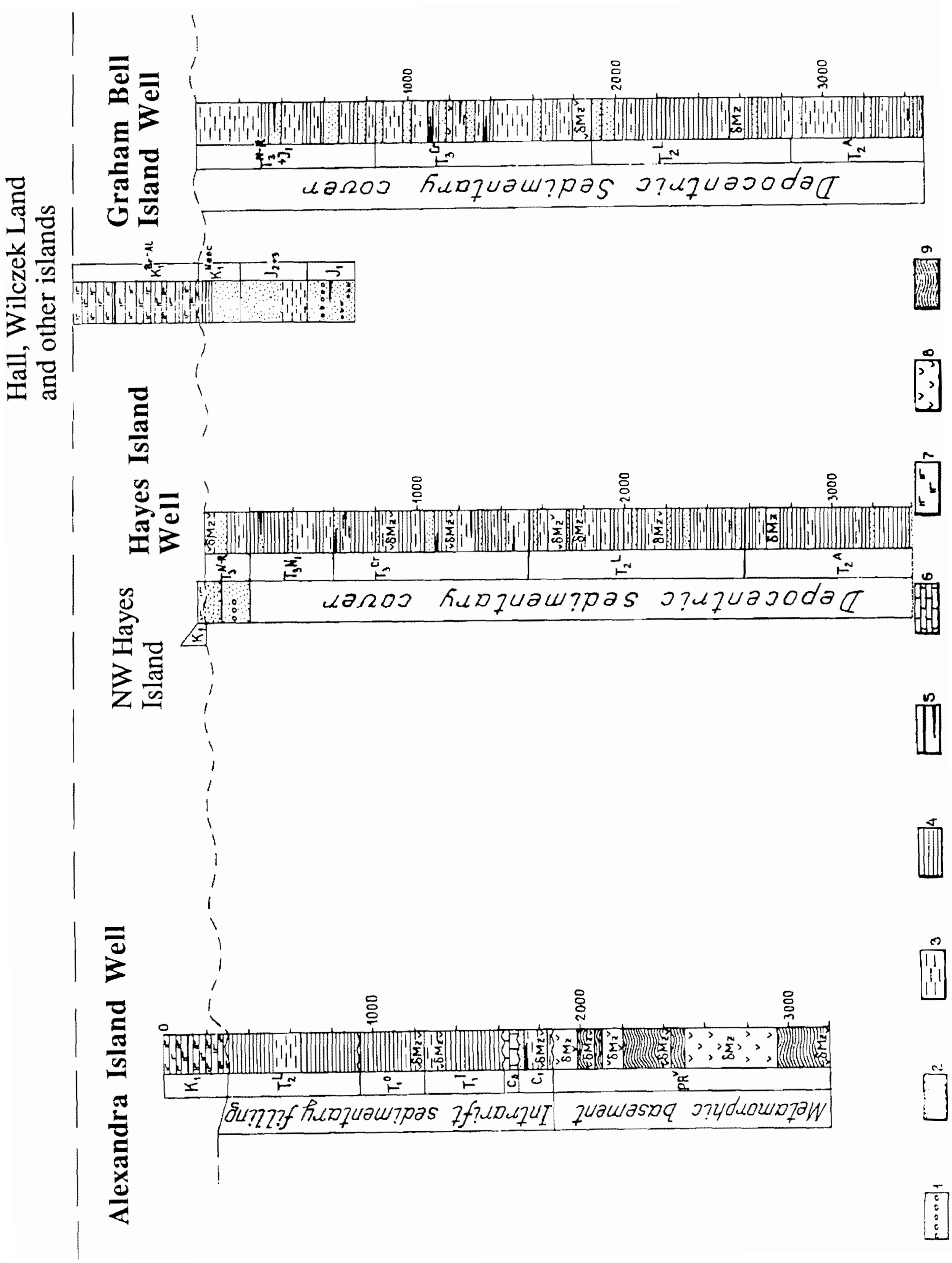

Fig. 2. Lithostratigraphic columns from the Alexandra Island, Hayes Island, and Graham Bell Island wells. The Hayes Island section also incorporates exposures of Cretaceous basalts from the northwestern part of the island. A composite section based on observations from Hall Island, Wilczek Land and other islands is also included. - 1. pebble and conglomerates; 2. sand/sandstone; 3. siltstone; 4. claystone; 5. coal beds; 6. limestone; 7. basalt flows; 8. dolerite and gabbro-dolerite; 9. greenschist rocks and quartzites.

Cretaceous beds, also including the Lower Cretaceous sedimentary- volcanic sequence. A post-Caledonian dike has been reported from Hoffman Island. Several K-Ar datings of dikes and sills, both from the deep wells and from outcrops, suggest emplacement ages ranging between 203 Ma and 34.5 Ma. The majority of the hypabyssal intrusions falls within 175-92 Ma (Aalenian - Turonian). The sedimentary-volcanic sequence shows a Barremian - Albian age, based on fossils occurrences in layers of terrigenous sediments interbedded with the basaltic flows. The age relations between the magmatic episodes are still unsolved.

Basaltic flows and sheets occur all over the archipelago, in many places with an erosional contact to the underlying beds. An extensive, well developed pre-Barremian hiatus is typical, representing an episode of uplifting and faulting, possibly also linked to volcanic activity. This phase of uplift was accompanied by deep erosion, reworking, and locally even by peneplanation (Dibner 1989, 1991). The Lower Cretaceous sedimentary-volcanic sequence is widespread on Franz Josef Land, and forms an important factor controlling the present day geomorphology of the archipelago. Abundant leaf imprints, calcitized and, more commonly, silicified wood, as well a miospores, are typically found in the terrigenous sediments interbedded with the lava flows. Locally, additional coal-bearing rocks allow the sequence to be subdivided into two stratigraphical units, namely the Tikhaya Bay and the Salisbury Formations, placed in the Barremian - Lower Aptian and the Upper Aptian - Albian, respectively (Fig. 2). The apparent thickness of the Lower Cretaceous sedimentary-volcanic sequence (including subordinate doleritic intrusions) reaches 600 m, but geophysical data indicate a much greater thickness in some areas.

The seafloor bathymetry, composition of seafloor samples and magnetic anomalies, suggest that basalts, as well as doleritic and gabbro-doleritic hypabyssal intrusions are common in the straits of the archipelago as well as in the adjacent Barents Sea. The latter is also supported by recent marine geophysical investigations (Gustavsen et al. 1997; Solheim et al. 1998). In the area north of Franz Josef Land, individual northwesterly trending dikes can be followed as far as the continental slope and even further into the Eurasian Basin. The sequence directly overlying the basaltic flows are only known in isolated outcrops as marine lower Cenomanian beds of up to 45 m thickness. In the same area deposits of 25 m thickness are exposed, with foraminiferal assemblages suggesting a Neogen age.

The measured thicknesses of the pre-Quaternary deposits in Franz Josef Land are 5980 m, of which 4770 m were drilled in the three deep wells, and 1210 m are known from outcrops only. Deep seismic soundings indicate, however, the presence of more than 10-12 km sedimentary cover in the depocenters. Gravity data indicate thicknesses of 8-9 km. These large thicknesses most likely include pre-Anisian Triassic, Paleozoic and possibly also the Upper Proterozoic platform successions.

Pre-Quaternary sedimentary rocks have been recovered during several marine geological investigations adjacent to Franz Josef Land. Of particular interest are fragments of organic-rich Paleozoic limestones, locally dolomitic or recrystallized. Such rocks were trawled by M.M. Yermoalev aboard the icebreaker *Sadko* in 1935-1936, southeast of Wilczek Land Island, and by N.A. Belov and N.A. Lapina aboard the icebreaker *Feodor Litke* in 1956, offshore the islands of Rudolf and Arthur, as well as north of the islands, at 82°N. The composition of these rocks are similar to the limestones and dolomites of Victoria Island. The latter contains a foraminiferal assemblage suggesting a Moscovian age (Middle Upper Carboniferous). Even younger, Upper Carboniferous limestones were penetrated by the Alexandra Island well. Briquette-like clay clasts, resembling the Upper Jurassic siltstone at Cape Medvezhy and yielding Lower Callovian foraminiferal forms, were found in samples from the bays of Hooker and Rudolf Islands, as well as in the Cambridge Strait. Recent investigations have revealed both Upper Jurassic and Lower Cretaceous beds subcropping on the seafloor adjacent to Franz Josef Land (Gustavsen et al. 1997; Solheim et al. 1998).

The Quaternary deposits of Franz Josef Land include 1. Upper Pleistocene glacial drift deposits, related to continental glaciation of the whole archipelago, and deposited mainly below sea level; 2. Holocene deposits associated with raised beaches; 3. glacial and glaciofluvial drift formed by recent glaciers and coeval recent lacustrine, fluvial, alluvial and eolian deposits. The extreme climatic conditions of Franz Josef Land have resulted in only modest bedrock weathering. The basalts and dolerites are represented in all the Quaternary sediments as clasts and rock debris, and the Upper Triassic sandstones are also present, with unaltered, original composition.

Platform tectonics of the pre-Barremian cover is represented by plicative (folds) and disjunctive dislocations (faults), evident in faults and fractures of the hypabyssal sills. A series of N-S oriented listric faults occur in the southwestern part of Northbrook Island as well as on the northern coast of Wilczek Land Island. The Barremian - Albian sedimentary-volcanic sequence mainly lies subhorizontally.

Diapiric structures involving Triassic carbonates and terrigenous rocks are found piercing younger rocks (as young as Volgian) on Graham Bell Island, as cap rocks on Wilczek Land Island, and at Cape Tegetthoff on Hall Island. Dislocations of a diapiric nature are also known to occur within the Neogene rocks of Hoffman Island.

The present geomorphology of Franz Josef Land has mainly been formed as result of Pliocene tectonic activity. Fracturing and faulting divided the area into structural highs separating graben-shaped depressions represented by the deep channels of the straits and sounds. These lineaments are usually also traceable on the adjacent islands, and as troughs on the shelf surrounding Franz Josef Land.

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3. MODERN SEAFLOOR SEDIMENTS

By V.I. GUREVICH[1], A. V. YAKOVLEV[1] & E.E. MUSATOV[1]:

SEDIMENT THICKNESS

The distribution of post-glacial, Holocene sediments in the northernmost Barents Sea has been mapped from 5.6 kHz echo sounder data and gravity cores. The thickness of Holocene sediments varies from 0-0.5 m to 5-10 m, and locally more (Fig.1). The largest thicknesses are found in the fjords of Svalbard and in the straits of Franz Josef Land, while the minimum thickness prevail on the shallow shelf banks and their slopes, where Holocene sediments may be locally absent.

LITHOLOGY

The grain size distribution of the Holocene deposits varies with the hydrographic regime. In areas of only a thin Holocene veneer, such as the shallow banks, coarse grained sediments prevail as a result of current reworking. In the remaining areas pelites and silty pelites are the predominant sediment types. In the area between southern Franz Josef Land and Svalbard, roughly in the area covered by the present Russian - Norwegian project, "the geotraverse area", very fine-grained muds occur, with a variable but high content of subcolloidal fractions (< 0.001 mm) (Fig.2).

SELECTED CHEMICAL COMPONENTS

The Holocene deposits of the geotraverse area are enriched by some authigenic components, with the highest concentrations in the fine grained clayey muds. The content of manganese may locally exceed 0.1 - 0.3 % in these deposits (Fig.3), while the content of arsenic reaches more than 100 mg/kg sediment (Fig. 4).

BIOGENIC CARBONATES

Significant contents of carbonates are found only locally. In particular these are found on Spitsbergenbanken, near Bjørnøya and Hopen, northeast of Spitsbergen and southeast of Franz Josef Land. In these areas the carbonate content varies between 0.3 % and more than 5% (Fig. 5).

ORGANIC MATTER

Fine-grained pelitic muds have the highest content of organic carbon in the region. Organic carbon contents in these sediments are usually more than 1-1.5%, and sometimes exceeding 2.5% (Fig. 6). Raised concentrations are commonly related to high concentrations of polycyclic aromatic hydrocarbons (PAH), which may reach 0.1-0.3 mg/kg (Fig. 7). The most significant concentrations of heavy hydrocarbon gases adsorbed by the modern sediments are also found in the same areas (Fig. 8).

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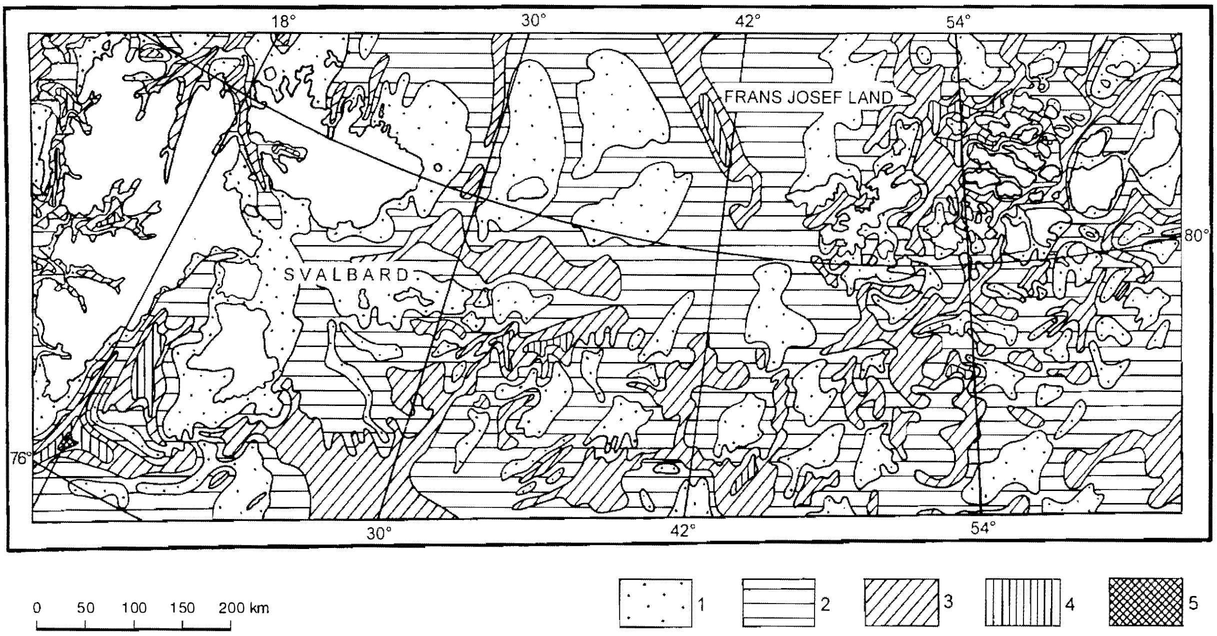

Fig. 1. Thickness of the Holocene deposits. 1: 0-0.5 m; 2: 0.5-2 m; 3: 2-5 m; 4: 5-10 m; 5: >10 m.

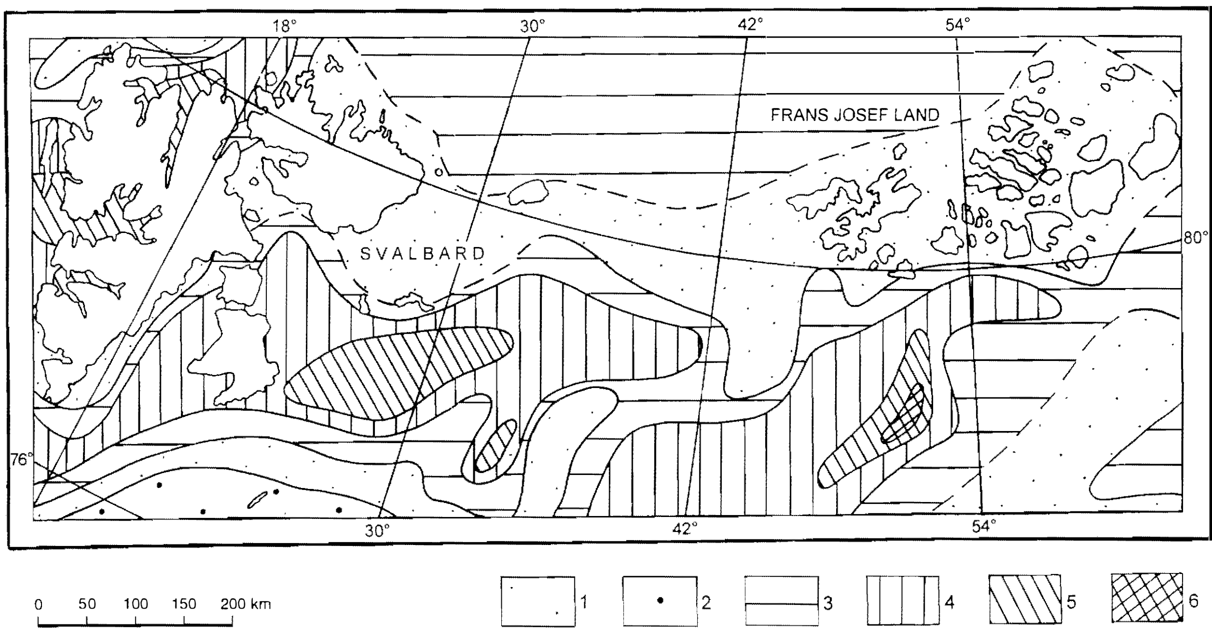

Fig. 2. Content of subcolloidal (fractions less than 0.001 mm) pelite in the modern deposits, in % of total mass. 1: <5%; 2: 5-10%; 3: 10-20%; 4: 20-30%; 5: 30-40%; 6: >40%.

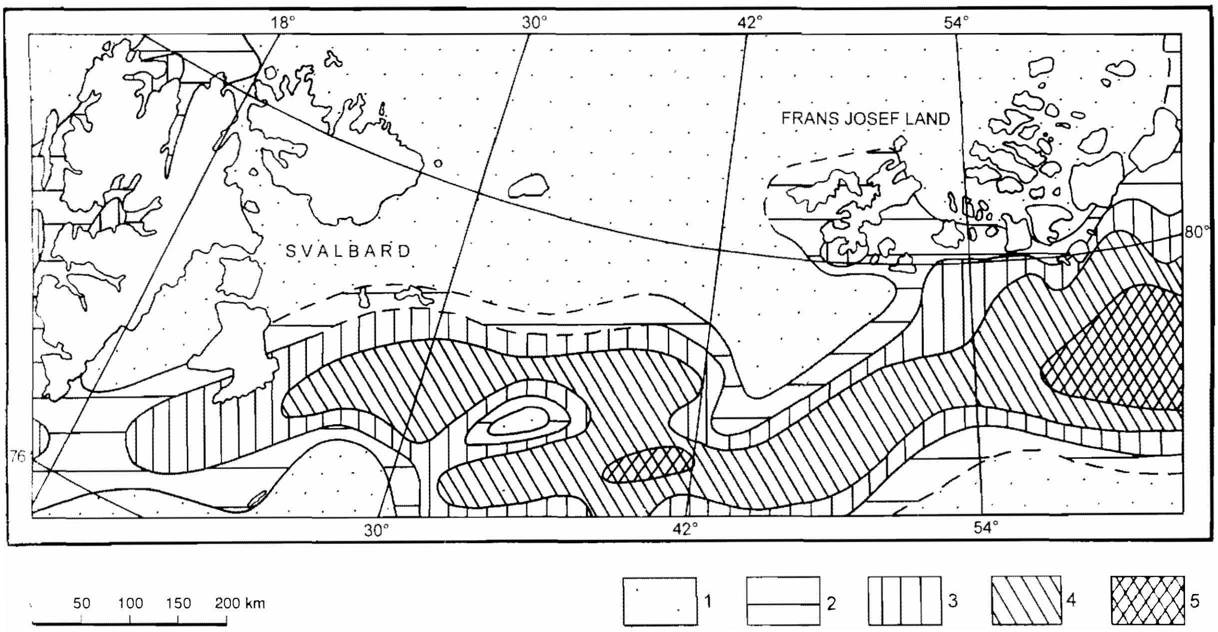

Fig. 3.Content of manganese in the modern deposits. 1: <0.03%; 2: 0.03-0.05%; 3: 0.05-0.1%; 4: 0.1-0.3%; 5: >0.3%.

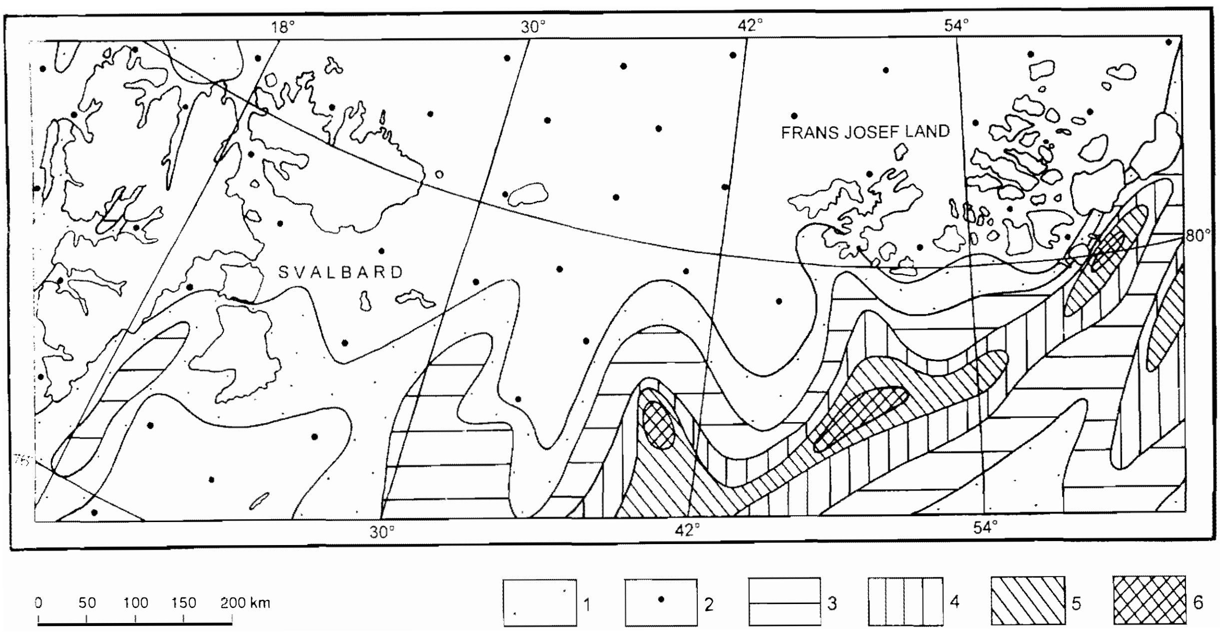

Fig. 4. Content of arsenic in the modern deposits. 1: <20mg/kg; 2: 20-30 mg/kg; 3: 30-50 mg/kg; 4: 50-75 mg/kg; 5: 75-100 mg/kg; 6: >100 mg/kg.

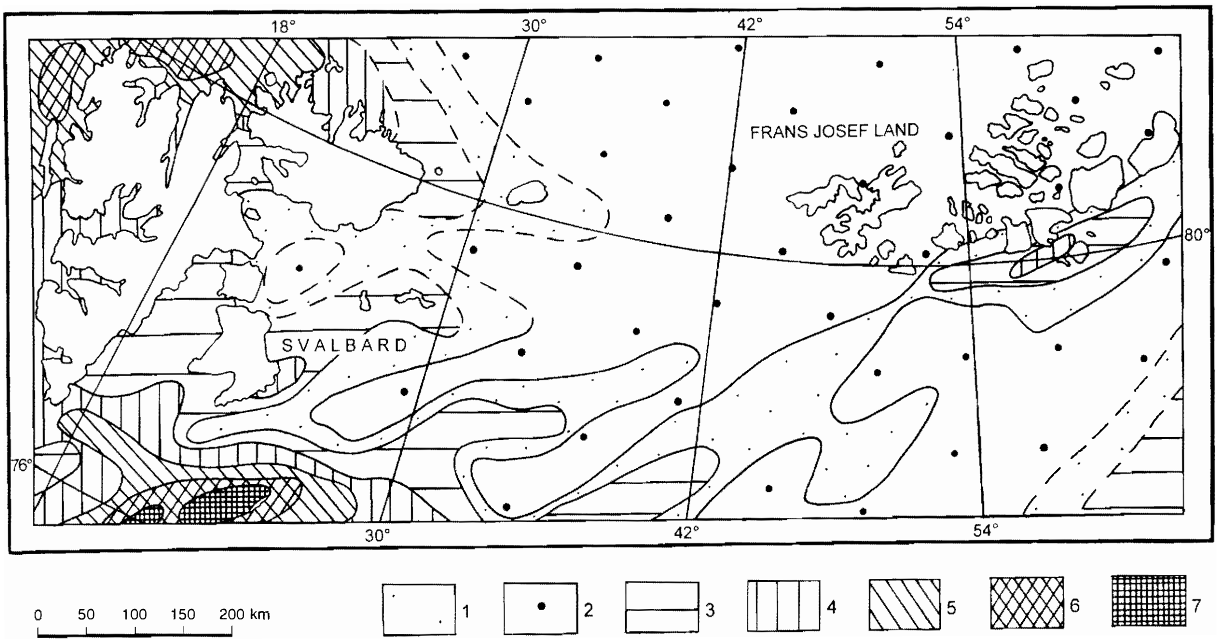

Fig. 5. Carbonate content in the modern deposits. 1: <0.03%; 2: 0.03-0.1%; 3: 0.1-0.3%; 4: 0.3-1.0%; 5: 1-3%; 6: 3-5%; 7: >5%.

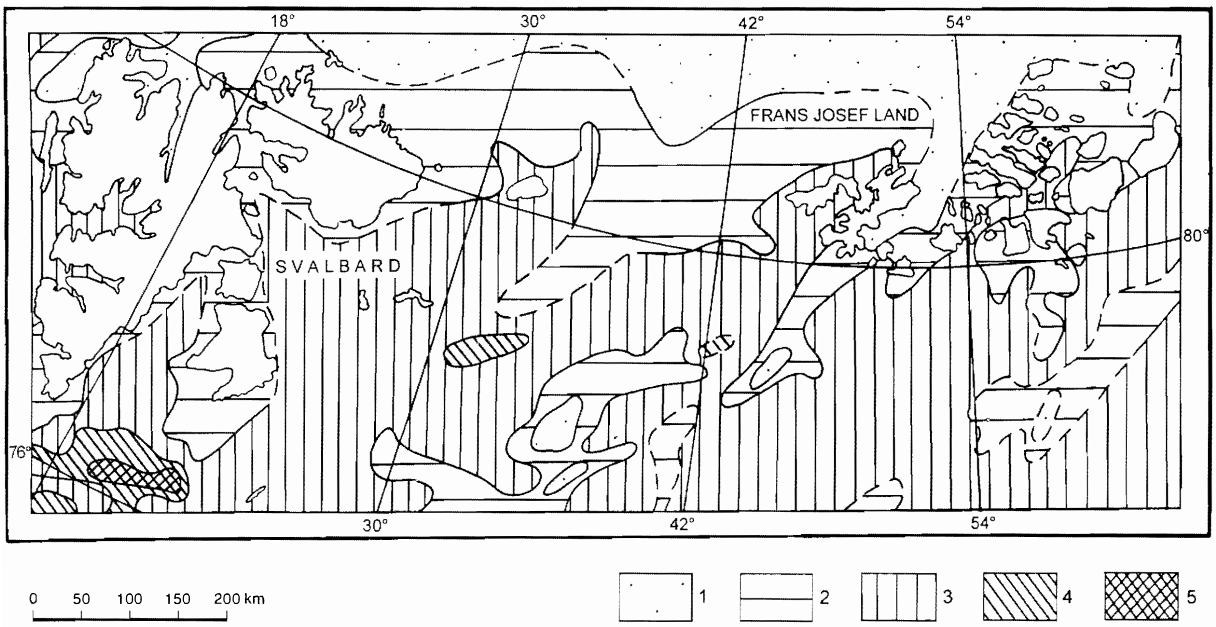

Fig. 6. Organic carbon content in the modern deposits, in % of total mass. 1: <0.5%; 2: 0.5-1%; 3: 1-2%; 4: 2-2.5%; 5: >2.5%.

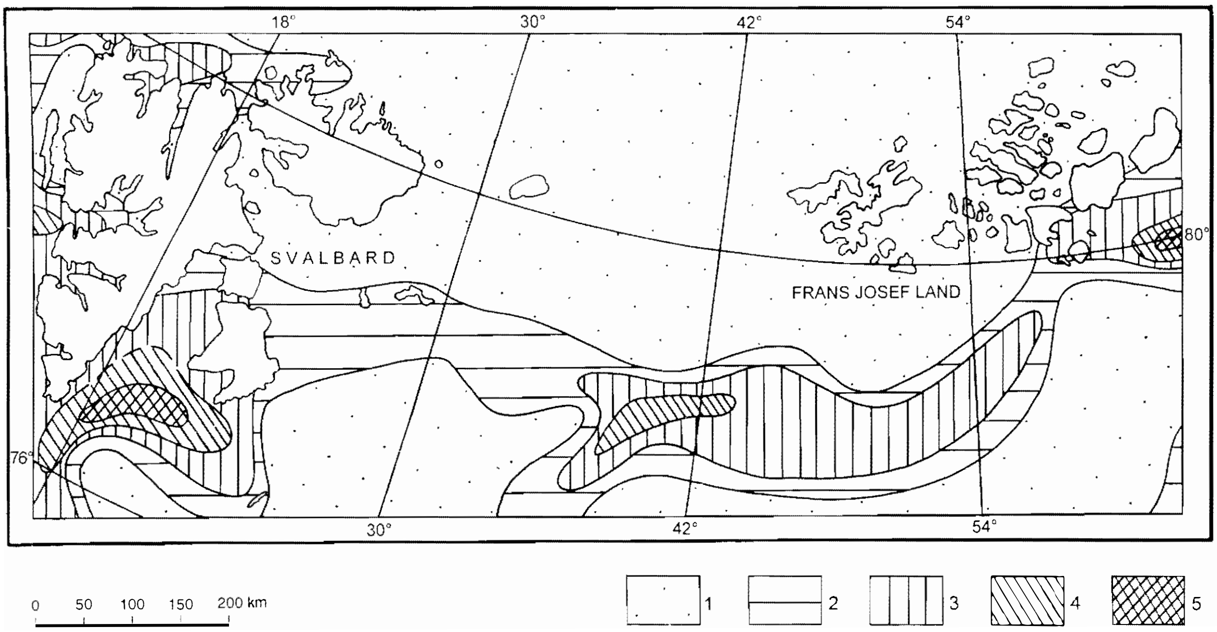

Fig. 7. Content of polycyclic aromatic hydrocarbons (PAH) in the modern deposits. 1: <0.05 mg/kg; 2: 0.05-0.1 mg/kg; 3: 0.1-0.2 mg/kg; 4: 0.2-0.3 mg/kg; 5: >0.3 mg/kg.

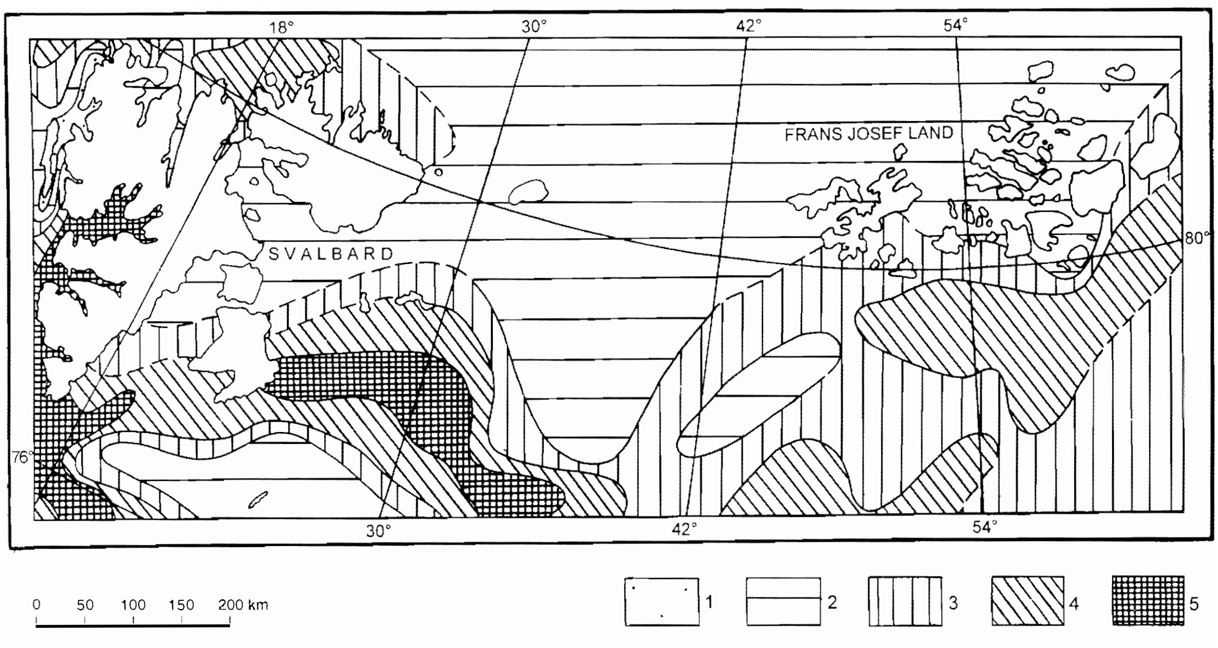

Fig. 8. Content of hydrocarbon gases adsorbed in the modern deposits ($\Sigma\ C_2H_6+C_3H_8+C_4H_{10}+C_5H_{12}$). 1: <0.003 cm^3/kg; 2: 0.003-0.01 cm^3/kg; 3: 0.01-0.03 cm^3/kg; 4: 0.03-0.1 cm^3/kg; 5: 0.1-0.3 cm^3/kg.

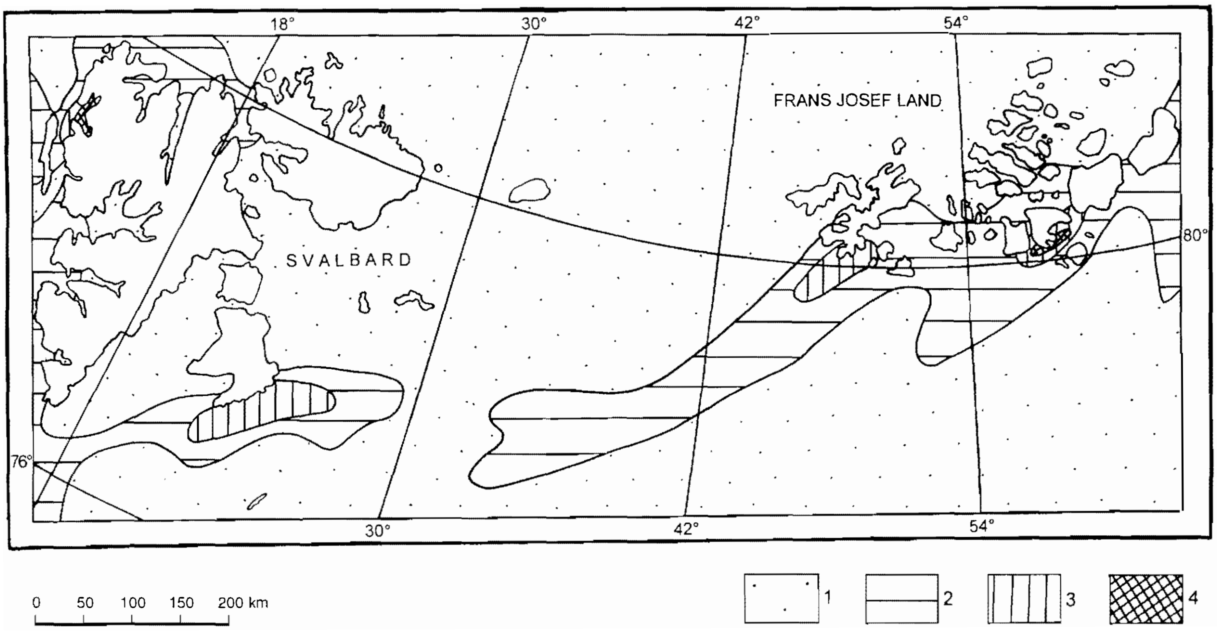

Fig. 9. Content of polychlorinated biphenyls (PCB) in the modern deposits. 1: absent; 2: 0.5-1 ng/g; 3: 1-2 ng/g; 4: >2 ng/g.

These are most likely thermogenic gases released from underlying Mesozoic rocks. On the other hand, a similar distribution is seen with regards to polychlorinated biphenyls (PCB) (Fig. 9).

In summary, the modern sediments of the northernmost Barents Sea shelf are composed of terrigenous clastic, clayey deposits containing chemogenic, biogenic and also anthropogenic components. The contents of the various components vary greatly, possibly in response to physical oceanographic conditions.

4. THE SHALLOW SUBSURFACE GEOLOGY OF THE NORTHEASTERN BARENTS SEA.

By SOLHEIM[1], F.B. GUSTAVSEN[1], E. E.MUSATOV[2], H.DYPVIK[3] & T. BJÆRKE[4]

ABSTRACT
Shallow single channel seismic investigations combined with gravity coring have been used to map the lithology and age of the shallow bedrock in the northeastern Barents Sea. The data reveal post-Jurassic sediment thicknesses exceeding 1700 m. Seismic character varying from chaotic to stratified can be roughly correlated to the Mesozoic subcropping bedrock. Chaotic and intermediate seismic characters correspond to tectonized Triassic - Middle Jurassic and Late Jurassic - Early Cretaceous sedimentary rocks, respectively. A palynologically investigated sample from *in situ* bedrock, giving Aptian - Early Albian age, is crucial in determining an Early Cretaceous age for the seismically stratified, fine grained clastic sediments found over most of the area. These sediments were deposited in a shallow marine setting and contain palynological assemblages comparable to those described from the Carolinefjellet Formation of Svalbard. Igneous activity is represented by the eroded remnants of basaltic lavas which form positive topographic features with high amplitude magnetic anomalies. The Cretaceous - Tertiary tectonic regime, as well as the interpreted sediment transport direction, reflect tectonic events related to rifting in the adjacent ocean basins. Organic geochemical analyses of the Lower Cretaceous rocks indicate maximum 2000 m of post-Early Cretaceous erosion in the study area.

INTRODUCTION
The northern Barents Sea (north of approximately 74 °N) (Fig. 1A) is in general characterised by thin Quaternary sediments which cover dipping Mesozoic and older strata. The Quaternary cover is rarely more than 10 m thick and the underlying bedrock is exposed locally (Solheim & Kristoffersen 1984). The reason for this is Late Cretaceous - Tertiary uplift and repeated erosion by Quaternary grounded ice sheets, of which the Late Weichselian was the last (Elverhøi & Solheim 1983; Solheim & Kristoffersen 1984; Elverhøi et al. 1990; Solheim et al. 1990). Hence, the Quaternary cover generally consists of a layer of basal till, covered by deglacial ice-proximal muds and postglacial ice-distal muds, respectively (Elverhøi et al. 1988). This geological configuration makes the northern Barents Sea well suited for bedrock investigations using shallow sampling tools and high resolution seismic surveys.

Several studies in other areas have shown that clast material in basal tills often has a dominantly local provenance (Gross & Moran 1971; Linden 1975; Lundqvist 1977; Vorren 1979; Haldorsen 1983; Elverhøi et al. 1988). Clast investigations in sediment cores from glacial tills can therefore give valuable information on the subcropping bedrock geology. Combined with high resolution seismic investigations, with ties to deeper multichannel seismic (MCS) lines, this may form a powerful tool for reconnais-sance bedrock investigations, as shown in the western Barents Sea (west of 35 °E) (Elverhøi et al. 1988; Antonsen et al. 1991).

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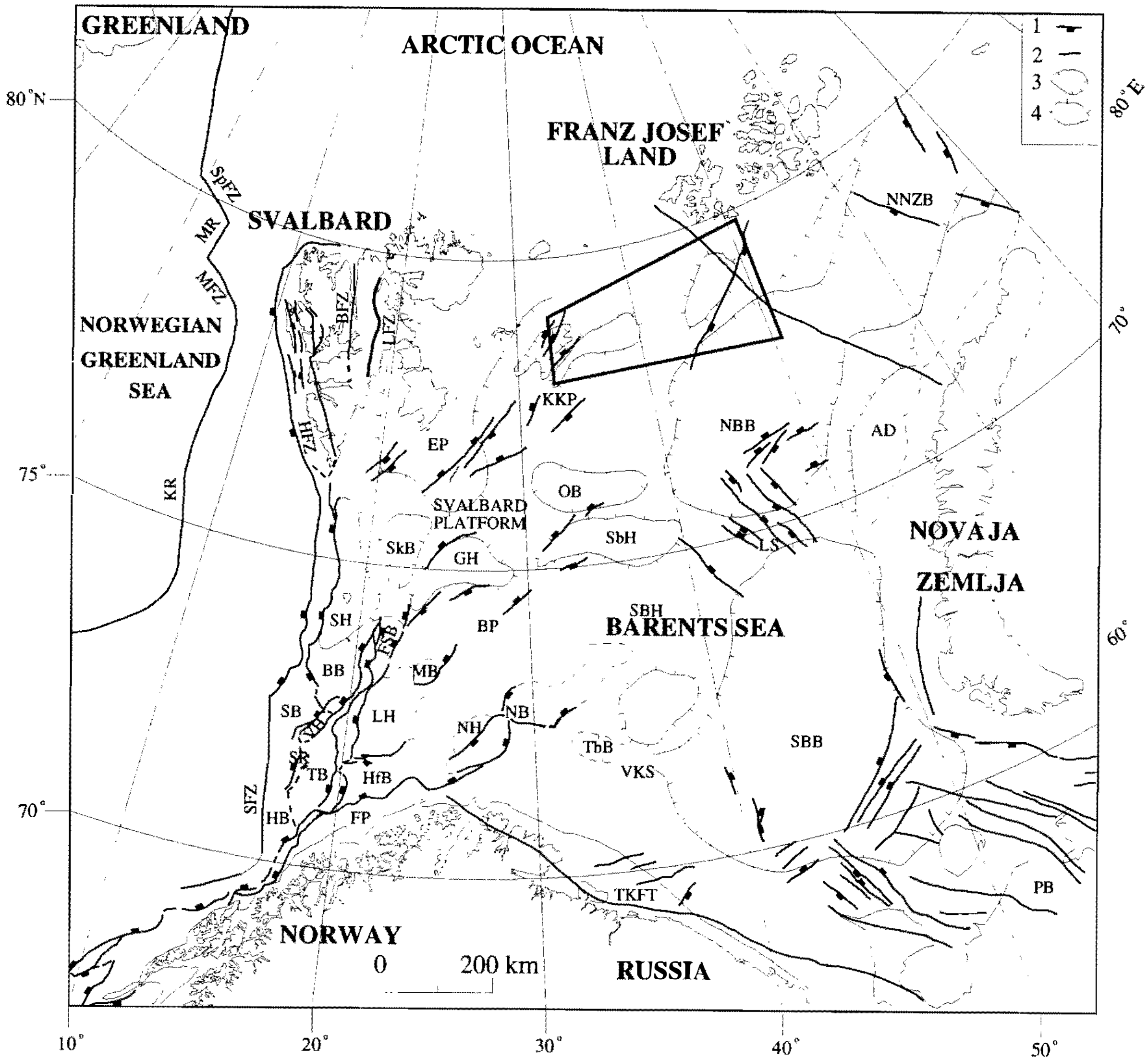

Fig. 1A. Structural elements of the Barents Sea (based on Gabrielsen et al., 1990; Faleide et al., 1993; Johansen et al., 1993). 1 = fault, 2 = lineament, 3 = basin, 4 = high, AD = Admiralty High, BB = Bjørnøya Basin, BFZ = Billefjorden Fault Zone, BP = Bjarmeland Platform, EP = Edgeøya Platform, FSB = Fingerdjupet Subbasin, FP = Finnmark Platform, GH = Gardarbanken High, HB = Harstad Basin, HfB = Hammerfest Basin, HFZ = Hornsund Fault Zone, KKP = Kong Karl Platform, KR = Knipovich Ridge, LFZ = Lomfjorden Fault Zone, LH = Loppa High, LS = Ludlov Saddle, MB = Maud Basin, MFZ = Molloy Fault Zone, MR = Molloy Ridge, NB = Nordkapp Basin, NBB = North Barents Basin, NH = Norsel High, NNZB = North Novaja Zemlja Basin, OB = Olga Basin, PB = Pechora Basin, SB = Sørvestsnaget Basin, SBB = South Barents Basin, SBH = Sentral Barents High, SbH = Sentralbanken High, SFZ = Senja Fault Zone, SH = Stappen High, SkB = Sørkapp Basin, SpFZ = Spitsbergen Fault Zone, SR = Senja Ridge, TB = Tromsø Basin, TbB = Tiddlybanken Basin, TKFT = Trollfjord-Komagelv-Fault Trend, VH = Veslemøy High, VKS = West Kola Saddle. The study area is marked with a frame.

While recent investigations have given a relatively good understanding of the subcropping bedrock geology (approximately upper 500 m) in the western Barents Sea, little has been published from the eastern and northeastern Barents Sea since the work of Klenova (1960) and Dibner (1978). The geology of Svalbard (Steel & Worsley 1984; Worsley et al. 1986;

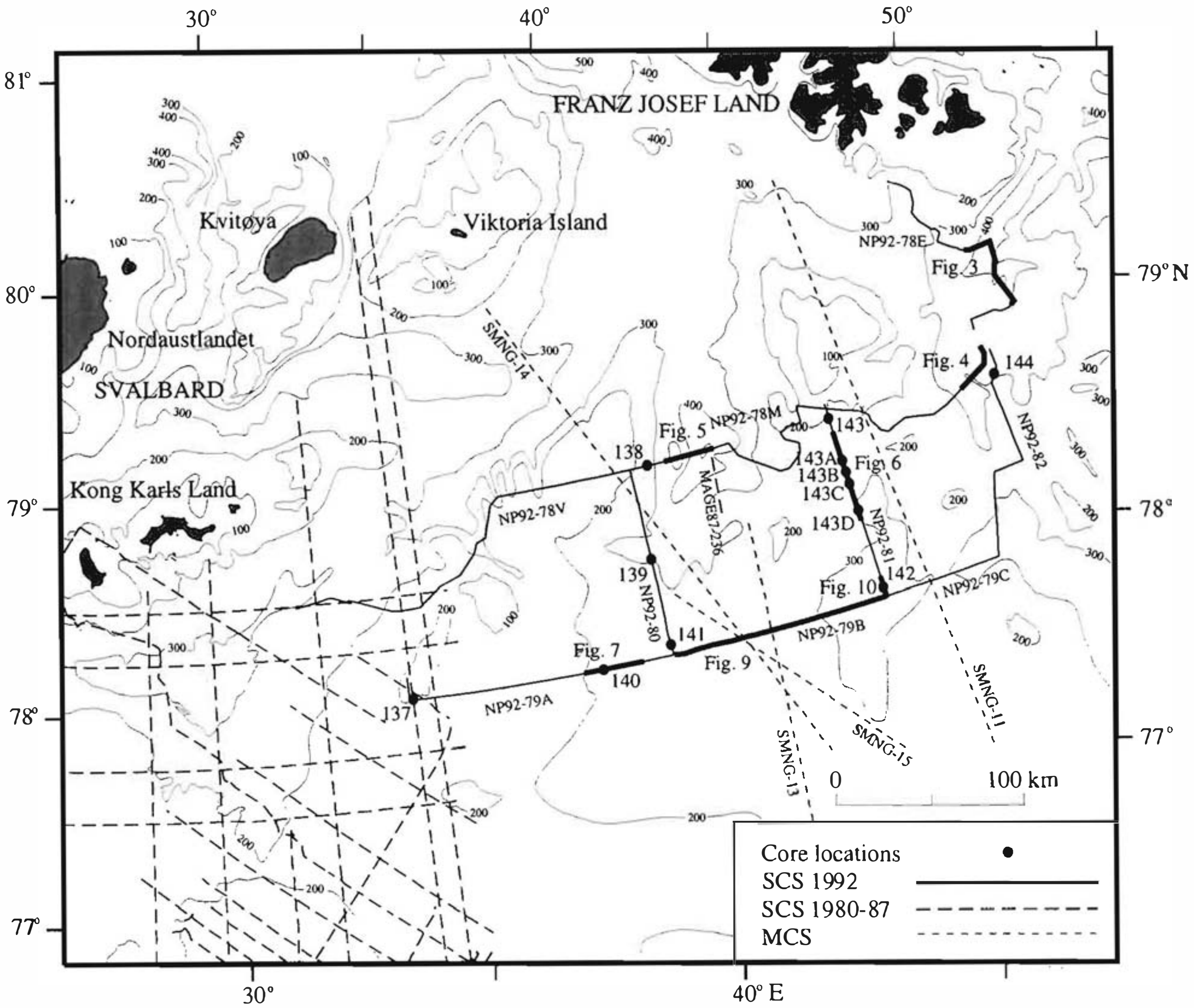

Fig. 1B. Map showing seismic lines available for this study. Locations of sediment coring stations and figures 3, 4, 5, 6, 7, 9 and 10 are also indicated. MCS = multichannel seismic, SCS = single channel seismic. Bathymetry is shown by 100 m contour intervals.

Gramberg 1988) and Franz Josef Land (Dibner 1957, 1998; Gramberg & Pogrebitskyi 1984) (Fig. 1A) is relatively well known, but difficulties in stratigraphical correlation between the two archipelagos have left many questions to be answered with regards to geological correlation and evolution of the entire northern Barents Sea region (Solheim et al. 1998). These questions can only be answered through a better knowledge of the geology in the area between Svalbard and Franz Josef Land. Therefore, the objectives of this study are:

- To map the shallow (upper 500 m, or above first sea-floor multiple) structure and seismic stratigraphy of the bedrock between Svalbard and Franz Josef Land, and to tie the obtained results to available deep seismic data and adjacent land areas.
- To obtain new information on the type and age of the subcropping bedrock through gravity coring of basal till or possibly sampling of *in situ* bedrock.
- To improve the correlation and the understanding of the geological evolution between the two archipelagos during post-Paleozoic times.

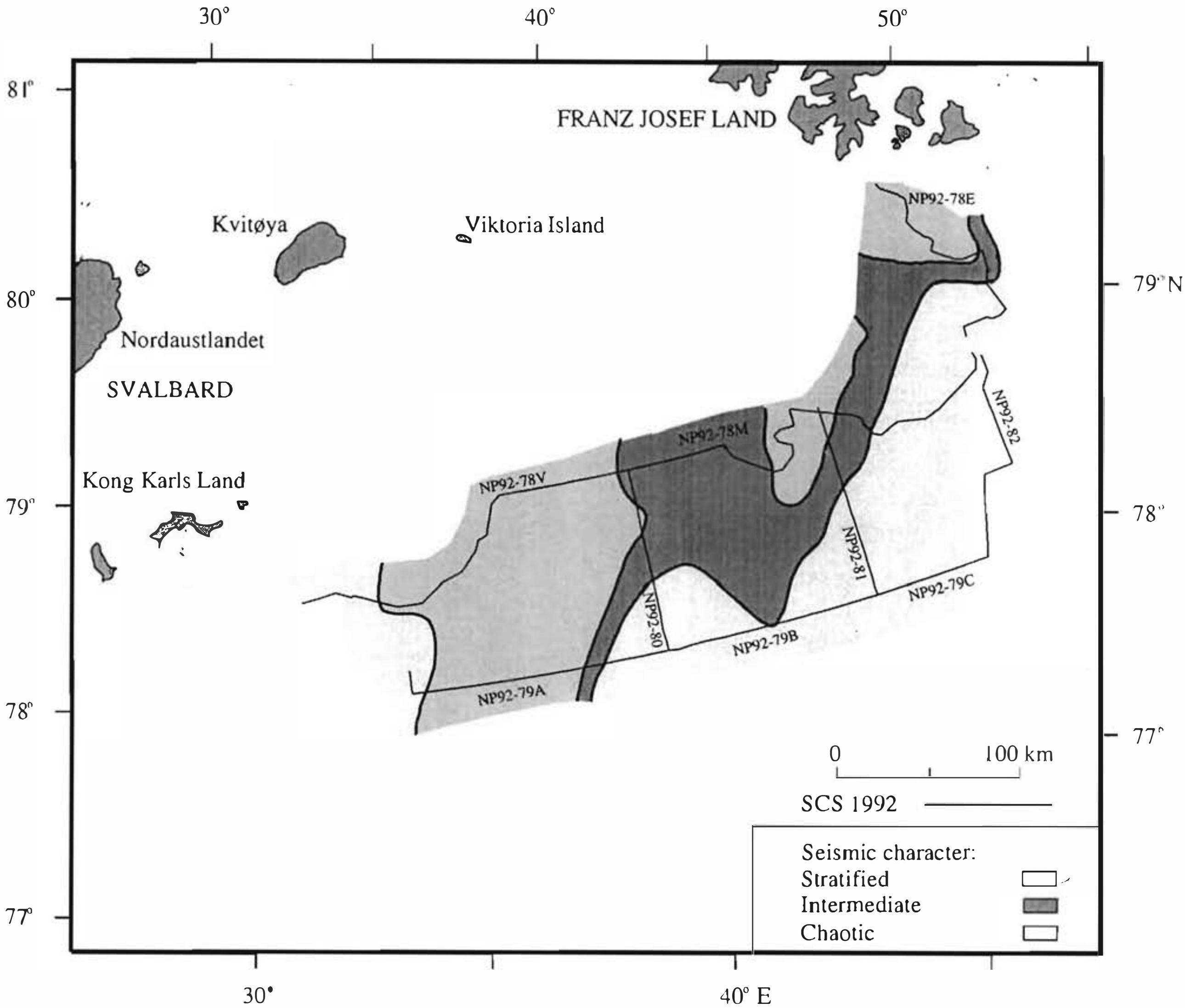

Fig. 2. Map showing seismic character in the study area. Examples of different seismic characters are shown in figures 3 and 4.

GEOLOGICAL BACKGROUND

The geology of the northern Barents Sea is only sparsely documented. Most published data and interpretations come from the southern Barents Sea, and in particular from petroleum exploration in the southwestern Barents Sea where the seismic stratigraphical interpretations have been tied to well data. In the northern Barents Sea correlations have to be made to adjacent land areas, occasional shallow cores and to analyses of clast material in the Quaternary deposits.

Regional seismic stratigraphic interpretations for the western Barents Sea (west of 35 °E and between Norway and Svalbard) were published by Rønnevik et al. (1982) and Faleide et al. (1984) and more recently in a collection of papers edited by Vorren et al. (1993). For the areas east of 35°E, relatively few seismic lines have been published, and geological interpretations have largely been based on extension of the onshore geology, combined with sparse MCS reflection and refraction results (Dibner 1978; Gramberg & Pogrebitskyi 1984; Murzin et al. 1984; Verba 1984; Ulmishek 1985; Baturin 1987, 1988; Tarachovskij et al. 1987; Gramberg 1988; Senin et al. 1989; Verba et al. 1990; Musatov & Musatov 1992). Most publications from this area are in Russian, and have therefore been less accessible internationally.

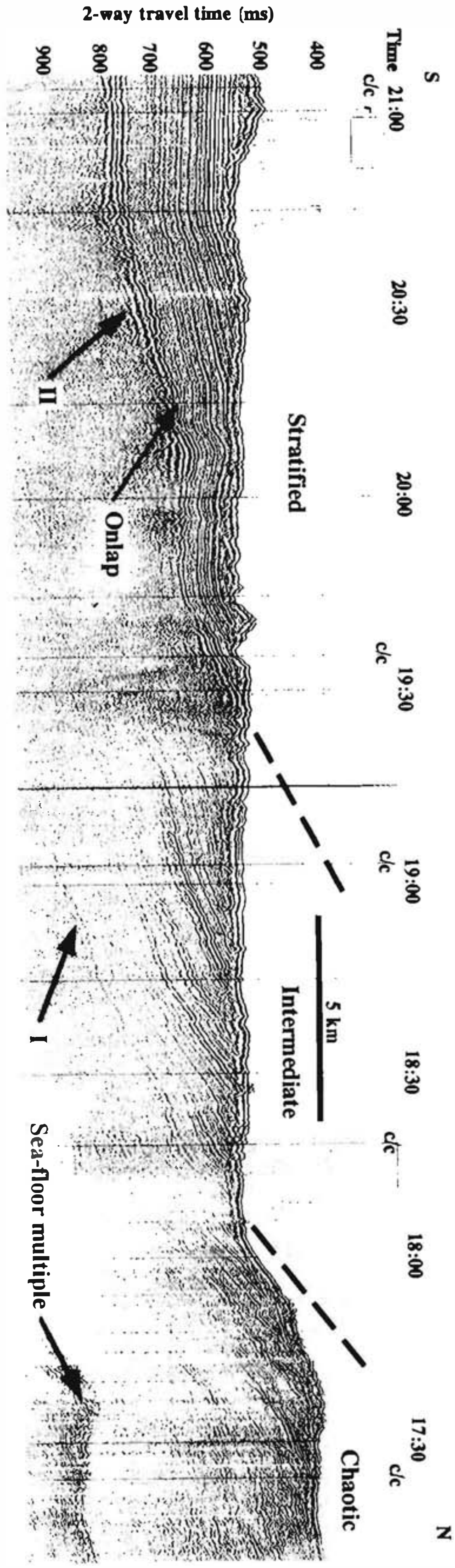

Fig. 3. Seismic record from line NP92-78E, illustrating the stratigraphic relations between stratified (stratigraphically shallowest), intermediate and chaotic (stratigraphically deepest) seismic characters. Boundaries between seismic characters are indicated with heavy dashed lines, drawn as imaginary continuations of reflectors I and II above the sea-floor. Reflector I subcrops below a sea-floor slope, and reflector II forms a band of reflectors. Course changes during the profiling are marked with c/c. See figure 1B for location.

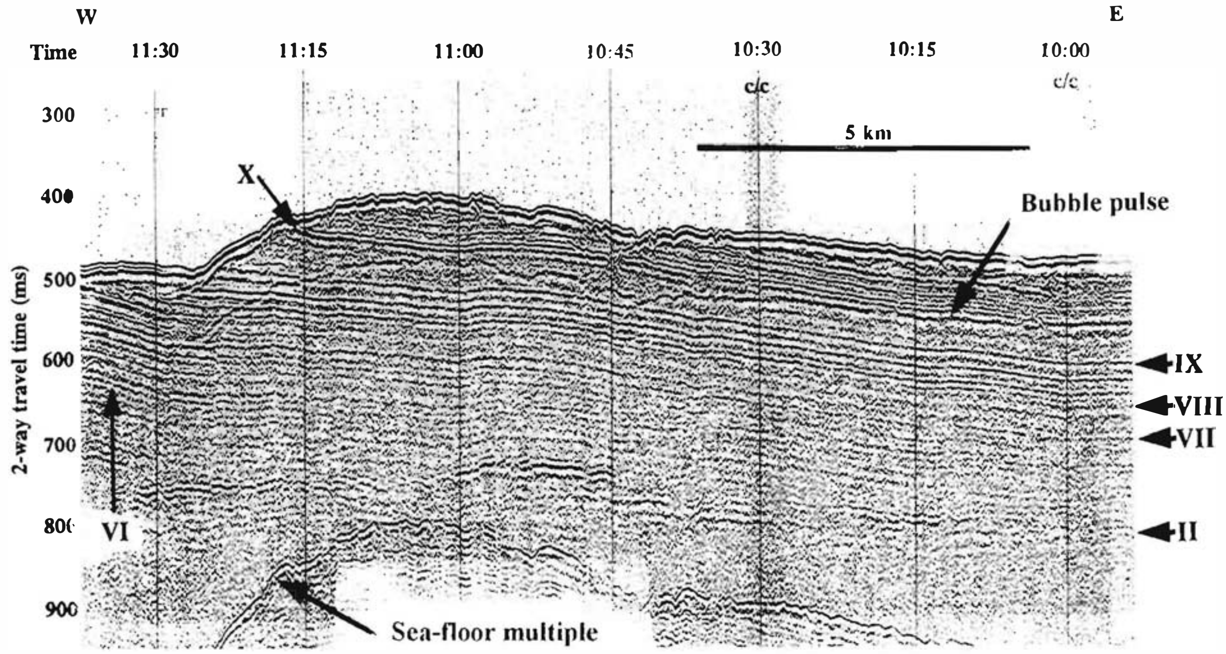

Fig. 4. Seismic record from line NP92-78M showing reflectors **II** and **VI-X**. Course changes during the profiling are marked with c/c. See figure 1B for location.

Faleide et al. (1984) defined nine regional sequence boundaries, ranging in age from the Upper Devonian to Mid-Oligocene, based on both well correlation and correlation to Svalbard. The Barents Sea sequences consist mainly of clastic sedimentary rocks, with the exception of a thick sequence of Middle Carboniferous to Lower Permian carbonates and evaporites. The northern area, the Svalbard Platform (Fig. 1A), typically has a relatively thick, flat-lying sequence consisting of mainly clastic rocks, with doleritic intrusions in the northernmost part (Faleide et al. 1984).

Lower Paleozoic seismic sequences have been identified in the southeasternmost part of the eastern Barents Sea. Most of the regional reflectors defined by Faleide et al. (1984) for the western Barents Sea can be correlated to the east (Johansen et al. 1993), but with possible diachronous relationships between major Mesozoic units in the two areas.

The subcrop geology and shallow structure of the northern Barents Sea has been investigated through analyses of shallow seismic records, clast material in Quaternary samples and a few *in situ* bedrock samples (Klenova 1960; Edwards 1975; Bjørlykke et al. 1978; Dibner, 1978; Bjærke 1979; Elverhøi & Lauritzen 1984; Kristoffersen et al. 1984; Verba 1984; Antonsen & Flood 1987; Elverhøi et al. 1988; Okulitch et al. 1989; Senin et al. 1989; Zarkhidze & Musatov 1989; Antonsen et al. 1991; Musatov 1992; Sigmond 1992; Gustavsen 1995). Whereas conventional MCS data mostly indicate Upper Triassic to Jurassic subcrop in the northwestern Barents Sea, the shallow investigations have revealed a more varied subcrop pattern. In particular Elverhøi et al. (1988) mapped the distribution of Upper Triassic - Lower Jurassic and Upper Jurassic - Lower Cretaceous subcropping rocks, respectively, in relatively great detail, and compared these rocks to their assumed equivalents in Svalbard. Later, Antonsen et al. (1991) mapped out the structure and

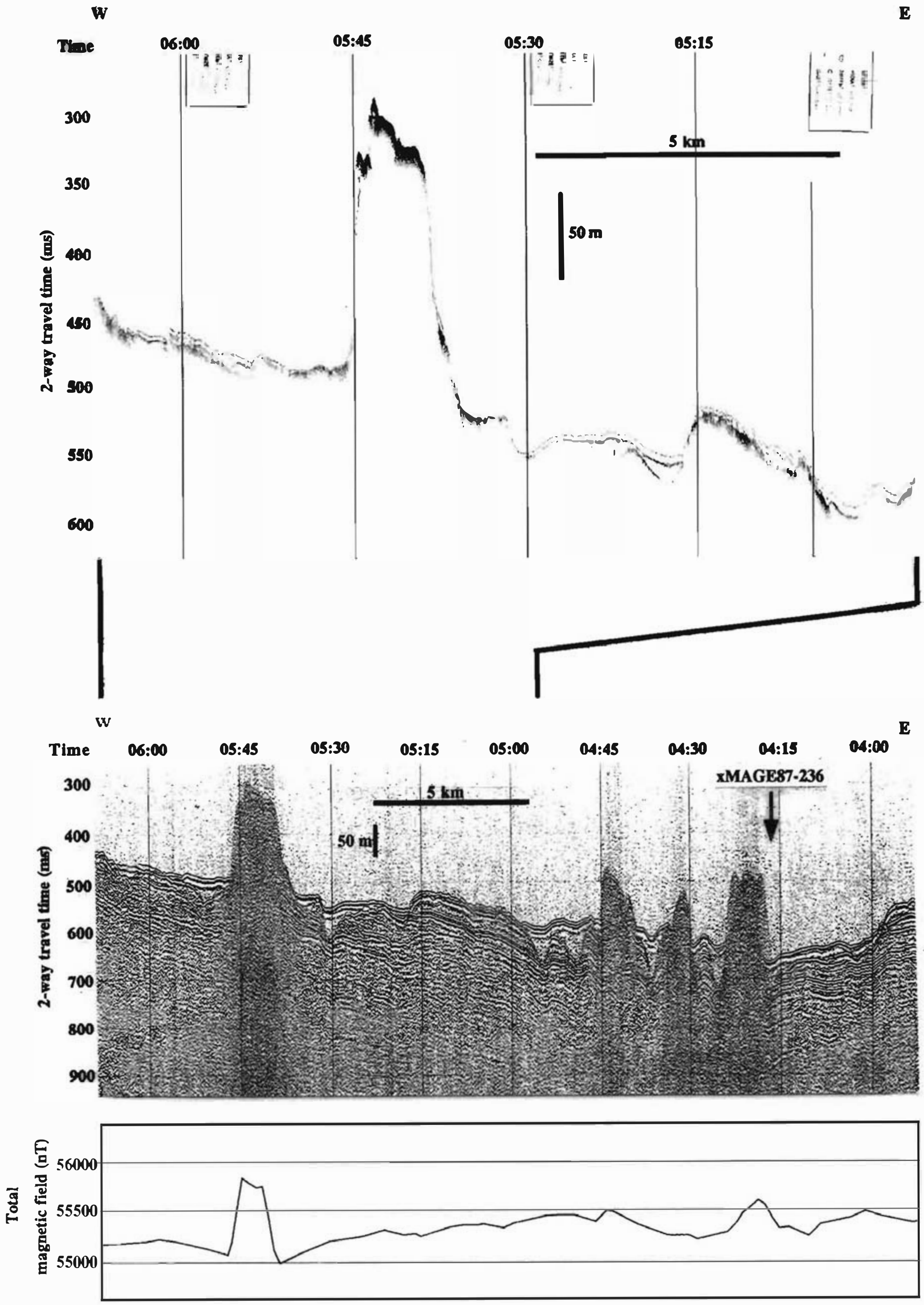

Fig. 5. PDR (upper), seismic (middle) and total magnetic field (lower) records over four ridges along line NP92-78M. Note the magnetic anomalies over the ridges. In the PDR record, terraces can be observed on top of the 180 m high and almost 2 km wide ridge. These ridges are most likely remnants of eroded basaltic lavas. Intersection with Russian SCS line MAGE87-236 is indicated. See figure 1B for location.

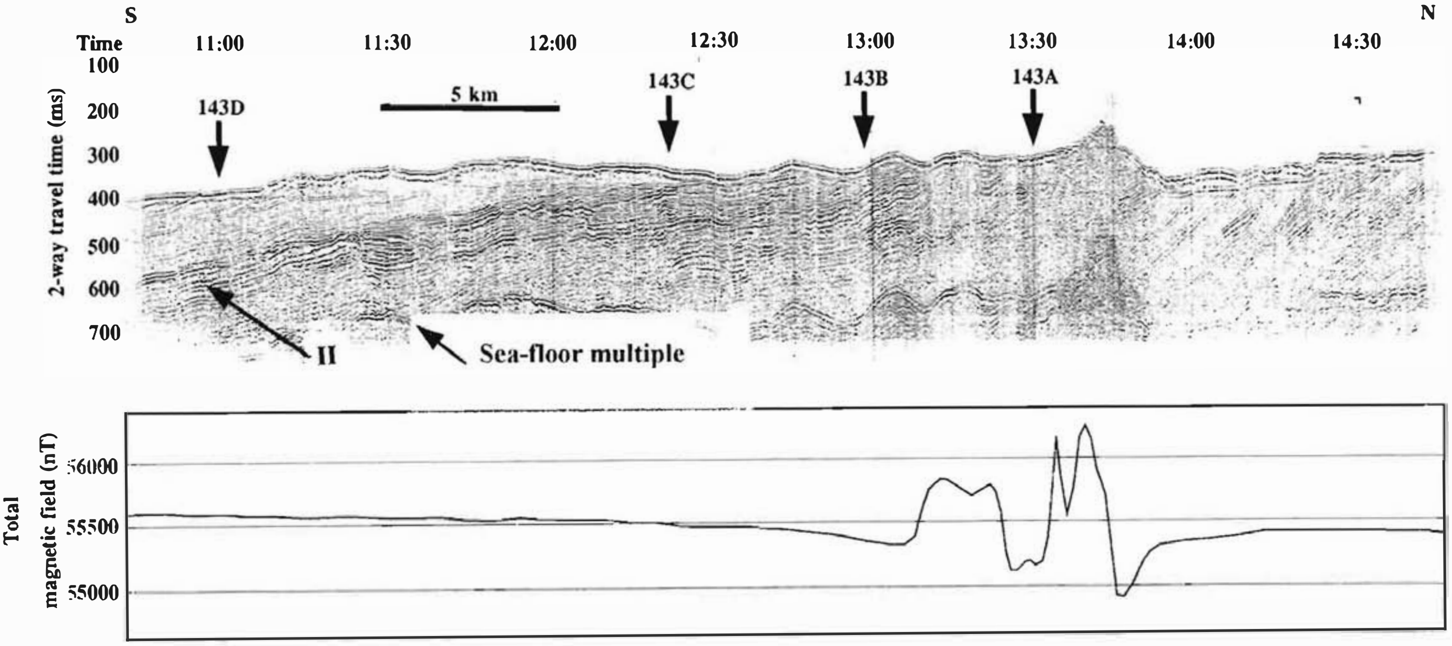

Fig. 6. Seismic (upper) and total magnetic field (lower) records from line NP92-81. Reflector **II** is indicated. Note the large magnetic anomalies, which are located over partly buried, ridge-like structures, most likely of igneous origin. Coring at station NP92-143A recovered eroded basaltic material, supporting a lava origin for these structures. See figure 1B for location.

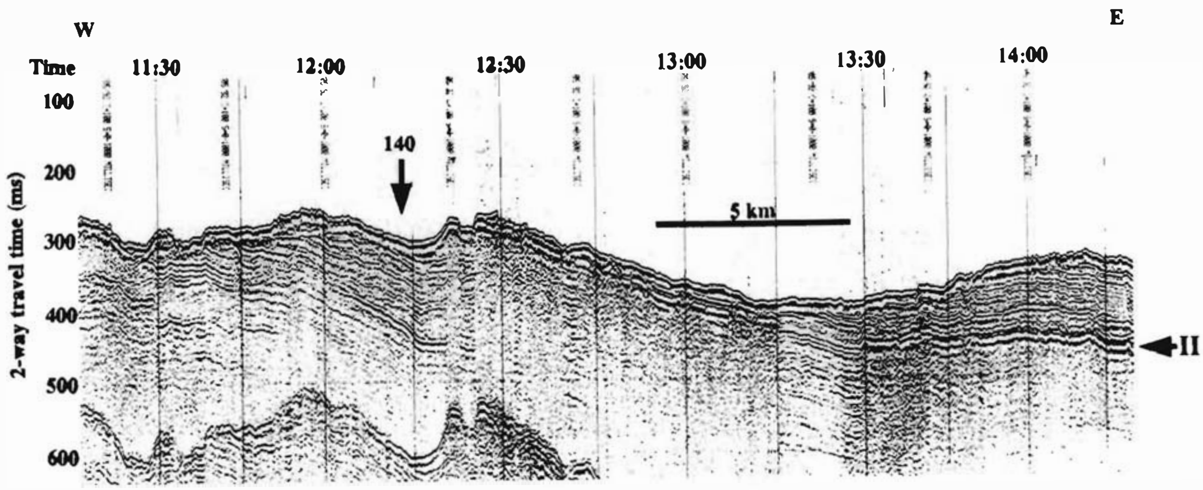

Fig. 7. Seismic record from line NP92-79A. Note the bathymetric depression at the stratigraphically lower side of reflector **II** subcrop. See figure 1B for location.

seismic stratigraphy of the east-west trending Olga Basin (Fig. 1A), which in the area west of 35°E mainly comprises Lower Cretaceous rocks exceeding 750 m in thickness. A narrow band of reflections forming a distinct unconformity, termed reflector **a** defines the base of these strata. The Olga Basin has possibly the largest post-Jurassic thicknesses known in the northwestern Barents Sea (Antonsen et al. 1991).

In the northeastern Barents Sea, predominantly Lower Cretaceous rocks occur in large synforms of the Northern Barents Basin (Fig. 1A) and other structural depressions. Regional uplifts comprise Jurassic and Triassic rocks (Dibner 1978; Gramberg & Pogrebitskyi 1984; Gramberg 1988; Okulitch et al. 1989; Musatov 1992). Carboniferous and clastic Paleozoic rocks, intensively folded during the Late Hercynian to Early Kimmerian tectonic phase (Johansen et al. 1993), are exposed near Novaja Zemlja (Fig. 1A). Lower Cretaceous basalts occur on the sea-floor near Franz Josef Land. Outcrops of a Triassic age are confirmed on the Admiralty High (Fig. 1A) by both deep and shallow drilling.

MATERIALS AND METHODS

The present study is based primarily on data from a joint Russian-Norwegian cruise in the northern Barents Sea in 1992 (Solheim 1993). Geophysical data were acquired using:

- Single channel seismic (SCS) system with an array of 2 x 40 cu.inch sleeve guns as source, and recording via a short single channel streamer towed at three meters depth, and filtering in the passband of 70 - 500 Hz. The sleeve guns were towed 20 m behind the vessel and fired simultaneously at 4 or 6 s intervals.
- "Ocean Research Equipment" (ORE) hull mounted low frequency echo sounder (PDR) operating at a frequency of 5.6 kHz during most of the cruise.
- Geometrics Model G-826A Base Station Magnetometer, supported by a graphical recorder and a marine sensor, towed approximately 150 m behind the vessel.

The three systems were used simultaneously for most of the time, and a total of 1200 km of geophysical profiles was acquired for this study. The seismic data were generally of good quality, with penetration of up to 500 ms (milliseconds, two-way travel time) in the sedimentary bedrock.

In addition to the data acquired in 1992, older SCS data from the northwestern Barents Sea have been used in this study (Fig. 1B). These are primarily sparker data, acquired by the Norwegian Petroleum Directorate in 1980 and 1982, and by Norwegian Polar Institute in 1987 (Solheim et al. 1988). In general, the quality of the recent sleeve gun data is significantly better than the older sparker data, particularly with regards to penetration. However, where possible, ties to the older SCS data have been performed using the interpretations of Antonsen & Flood (1987), Elverhøi et al. (1988) and Antonsen et al. (1991). For deeper stratigraphic control, we have had access to four regional MCS lines acquired by the Russian institution "Sevmornefte Geofyzika" (SMNG). These lines have been tied to exploration wells further south in the eastern Barents Sea, and the deeper stratigraphical units are therefore relatively well dated.

Sediment coring was carried out with standard 3 m and 6 m gravity corers with a barrel diameter of 110 mm and a total weight of approximately one ton. Twelve stations were cored for the present bedrock studies (Fig. 1B). Recovery did not exceed 1 m, and the main reason for this was that coring stations were chosen, based on the acoustic records, where the thickness of deglacial and postglacial sediments appeared the least, giving the highest possibility of recovering till or in situ bedrock. In situ bedrock was recovered from one site, NP92-142, possible till material was found in the base of cores NP92-137 and NP92-143C, while NP92-143A (Fig. 1B) contained only glacial marine sediments. In addition, other shipboard programs cored 15 stations for investigations of the Quaternary sediments (Solheim 1993).

The bedrock sample from station NP92-142 and clasts from cores with a significant number of clasts (> 2 mm) and a uniform lithological composition, were selected for palynological, petrographical and organic geochemical analyses. The organic geochemical study comprised Total Organic Carbon (TOC), Total Carbon (TC) and Rock-Eval analyses. In the Rock-Eval analyses, the Tmax, hydrogen index (HI) and oxygen index (OI) were determined. The samples were initially heated to 300 °C for three minutes, thereafter gradually heated to 500°C with a gradient of 25°C/min. as described by Tissot & Welte (1984). Vitrinite reflectance measurements and optical kerogen analyses were not performed, but according to Tissot & Welte (1984) and Leplat & Paulet (1985), the Tmax values permit estimates of organic maturation and burial depth.

RESULTS

Seismic character and stratigraphy

As most of the northwestern Barents Sea, the study area is covered by only a thin veneer (normally < 10 m) of Quaternary sediments. Over most of the area, the top of the underlying bedrock is easily identifiable as a distinct angular unconformity, the "Upper Regional Unconformity (URU)" (Solheim & Kristoffersen 1984).

The upper bedrock of the studied area can be divided into three different classes based on the seismic character observed in the SCS records (Figs. 2 and 3): a) chaotic character, b) stratified character, and c) intermediate character. The chaotic character is the stratigraphically deepest while the stratified character is found stratigraphically shallowest (Fig. 3).

The chaotic seismic character dominates in the western half of the study area, and is also found in a smaller, central area, with a northeastward trend towards Franz Josef Land (Fig. 2). In general, the chaotic character is found in those parts of the study area which have the shallowest water depth. Numerous inconsistent, low amplitude reflecting horizons, diffraction hyperbolae and faults are characteristic for this character, and individual reflecting horizons are often subparallel to the sea-floor. The seismic penetration is less in areas dominated by the chaotic character than in the other areas (Fig. 3).

The seismically stratified character is predominant in the eastern (Fig. 4) and southeastern parts of the study area, and is also present in the far west, southeast of Kong Karls Land (Fig. 1B). Here the penetrated section of up to 500 ms is generally well stratified, with laterally consistent, high amplitude reflecting horizons which can be followed for distances exceeding 100 km. Although locally undulating, the overall structural trend is a gentle dip towards the southeast.

The boundaries between the different seismic characters are indistinct and rather transitional, but a wide area in the central and northeastern parts of the study area is

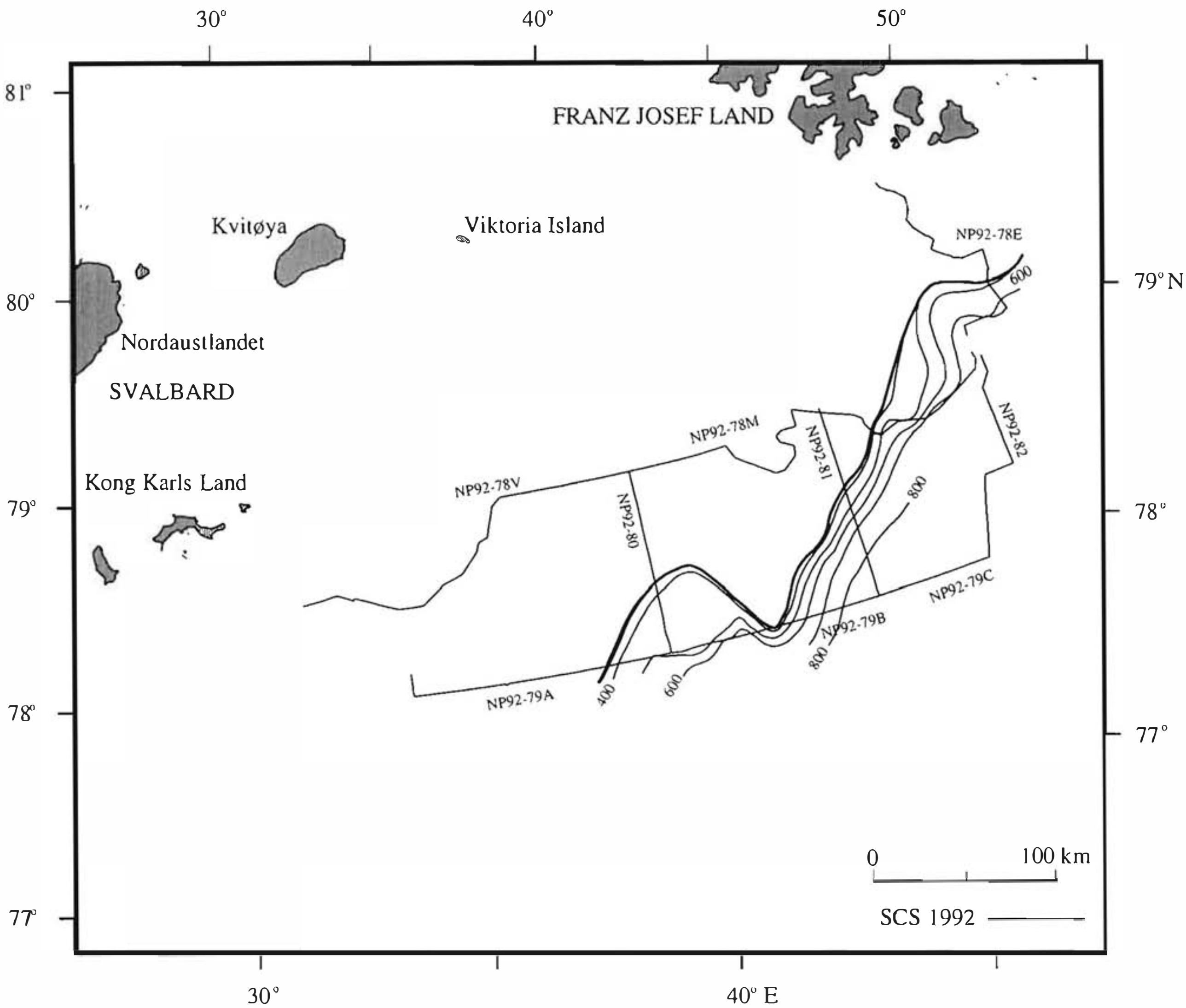

Fig. 8. Structural map of reflector II. Sea level is used for reference, and contours are in 100 milliseconds (ms) two-way reflection time.

identified as having an intermediate seismic character. In this area the seismic stratification shows the same overall structural trend as in the stratified area, but individual strata are less extensive, more undulating, and the reflecting horizons have more variable amplitudes. Faulting is more frequent than in the stratified area, while homogeneous rock bodies which reach the sea-floor and form distinct positive topographic features, are observed at two locations (Figs. 5 and 6).

Large magnetic anomalies associated with these rock bodies are taken as evidence for their igneous character. In addition, thin-section studies of clasts from NP92-143A near one of the structures (Fig. 6) show eroded basaltic material, also supporting the origin as lavas (Gustavsen 1995). In one area, seismic line NP92-78M crosses four major bodies within a distance of 18 km (Fig. 5). The largest one rises 180 m above the sea-floor. It has a width of nearly two kilometers and the steepest side has a slope of 18°. Bedrock depressions at the flanks of the topographic highs are another characteristic feature (Fig. 5). These depressions are filled with up to 75 m of acoustically transparent, homogeneous sediments. While stratified sedimentary rocks can be observed between the westernmost structure and the three eastern ones, the latter appear to be parts of one laterally extensive seismic structure. An older Russian sparker SCS line (Fig. 1B: MAGE87-236) (unpublished) crosses the area close to the observed igneous structures. In this line, positive topographic features with associated subsurface homogeneous seismic character, similar to the ones observed in the NP92 lines, seem to form a 25 km long continuous structure which, although data are sparse, appears to have a northwesterly orientation (Gustavsen 1995). In the eastern area with a seismically stratified character, 15 significant reflectors (**I-XV**) are defined. The most prominent of these are indicated in figures 3, 4 and 7. A distinct unconformity, reflector **II**, forms the base of the stratified character. Reflector **II** is frequently identified as a band of reflections (Fig. 3) which forms the northeast-southwest trending flank of a basin with increasing thicknesses towards the southeast (Fig. 8). A typical feature related to reflector **II** is a small depression often found on the stratigraphically lower side of reflector **II** outcrops (Fig. 7), indicating differences in competence between the rocks below and above reflector **II**. The general distribution of the reflectors above **II**, indicates younger strata toward the southeast. The recorded thickness of sedimentary rocks above reflector **II** is 660 ms, which is approximately 1 km, using a P-wave velocity of 3.0 km/s (Antonsen et al. 1991).

Approximately 500 ms below reflector **II** (extrapolated) another reflector, **I**, can be followed from 390 ms (585 m) below the sea-floor to subcrop at the base of a steep slope (Fig. 3). This reflector seems to mark the boundary between the chaotic and the intermediate seismic character, but is relatively indistinct compared to reflector **II** (Fig. 3).

Faults are clearly identified in areas of the stratified and intermediate seismic character. However, frequent faulting is most likely partly responsible for the chaotic seismic character. Fault throws vary between 10 and 60 ms (15 and 90 m) in the stratified seismic units, where they can be measured (Fig. 9). Reverse faults are common, particularly in the south central part of the study area, where they are associated with a wide antiform (Fig. 9). Normal faults seem to postdate the reverse faults and the antiform (Fig. 9). Most of the faults can be traced to the sea-floor, and they affect at least reflectors **I-IX**. The antiform strikes NNE, based on identification in two lines. Based on the distribution of identifiable faults on the east-west and north-south trending seismic lines, respectively, the main fault direction is also defined to follow a north-northeasterly trend. This is confirmed by a few faults that can be correlated between two lines. The seismic grid is, however, too sparse for a thorough discussion of tectonic trends.

In situ bedrock sample

The cover of unlithified sediments in the study area rarely exceeds 10 ms, which equals 8 m when using an average P-wave velocity of 1.6 km/s in these sediments (Solheim 1991). Only in local ridges or mounds, and in bedrock depressions (Fig. 5), does the unlithified sediment thickness significantly exceed this. Exact thickness is, however, often difficult to estimate. The vertical resolution of the seismic records is insufficient (approximately 5 m), and the 5.6 kHz signal hardly penetrates till. Iceberg plough marks, as identified over much of the study area, are, however, indicators of a minimum sediment thickness which is needed for plough marks to be formed. In areas of the thinnest Quaternary cover, the bedrock may be exposed in the troughs of individual plough marks, such as at site NP92-142 (Fig. 10). At this site, the bedrock strata are nearly horizontal, and the plucking action of glacial erosion has formed step-like terraces on the sea-floor (Fig. 10). The core site is situated on a terrace with a plough mark relief of only 1-2 m, while the ledge immediately to the north has plough mark relief of 5-10 m, suggesting thicker Quaternary sediments at the latter site. The 10 cm long rock sample filled the core cutter and had a horizontal, unbroken surface with the appearance of a true bedding plane (Gustavsen 1995). It was covered by 2 cm of gravel with the same lithology as the rock sample, and 34 cm of soft mud. The thin layer of mud indicates that the corer hit the trough of a plough mark, an area with minimum sediment thickness. Based on the appearance of the core and the combined seismic and 5.6 kHz record, it is most likely that the sample represents the *in situ* bedrock.

Petrography and organic geochemistry

Eight thin-sections studied from the bedrock sample of core NP92-142 show finely laminated sand-, silt- and claystones with angular to subangular quartz grains and several microscopical traces of bioturbation (Gustavsen 1995). Microsparitic and micritic carbonate (calcite and siderite) cements are commonly observed along the laminae, while clay minerals dominate the finer grained sediments. Framboidal pyrite and organic material are commonly observed along the fine grained laminae. Quartz (60%), normally well preserved feldspar (25%), particularly plagioclase, some chert, glauconite and occasional rock fragments (15%) occur in addition to the coarser grained beds, i.e. a feldspathic arenite, according to Dott (1964).

The porosity of the studied thin-sections is mainly of intergranular, primary type and reaches 25 % in the coarser parts. In the finer grained samples, porosities are normally found to be below 10 % (Gustavsen 1995).

The studied samples from NP92-142 and several of the clasts studied from other cores have a petrographical composition clearly resembling the Aptian - Albian Carolinefjellet Formation of Svalbard (Ramberg Moe 1980; Endresen 1985). The compositional variations mainly reflect variations in grain size.

Table 1. Results of the palynological investigations of the core material. In addition to one sample from core NP92-137, ten samples from core NP92-142 and three clasts from core NP92-143C were analysed. E. = Early, L. = Late, Alb. = Albian, Apt. = Aptian, Bar. = Barremian, Jura. = Jurassic, Rhaet. = Rhaetian, F. = Formation, rew. = reworked, ? = uncertain interpretation.

Site	Type material	Age	Depositional facies	Svalbard - correlation
NP92-137	clast	?L. Jura.	marine "hot shale"	Upper Agardhfjellet Fm.
NP92-142-1	*in situ*	Apt.-E. Alb.	marine inner shelf	Carolinefjellet Fm.
NP92-142-2	*in situ*	Apt.-E. Alb.	open marine shelf	Carolinefjellet Fm.
NP92-142-3	*in situ*	Apt.-E. Alb.	open marine shelf	Carolinefjellet Fm.
NP92-142-4	*in situ*	Apt.-E. Alb.	shallow marine	Carolinefjellet Fm.
NP92-142-5	*in situ*	Apt.-E. Alb.	marine	Carolinefjellet Fm.
NP92-142-6	*in situ*	Apt.-E. Alb.	marginal marine	Carolinefjellet Fm.
NP92-142-7	*in situ*	Apt.-E. Alb.	marginal marine	Carolinefjellet Fm.
NP92-142-8	*in situ*	Apt.-E. Alb.	marginal marine	Carolinefjellet Fm.
NP92-142-9	*in situ*	Apt.-E. Alb.	marine inner shelf	Carolinefjellet Fm.
NP92-142-10	*in situ*	Apt.-E. Alb.	marginal marine inner shelf	Carolinefjellet Fm.
NP92-143	clast	Apt.-E. Alb.	open marine shelf	Carolinefjellet Fm.
NP92-143A	clast	Rhaet., Bar.-Alb.	?	?
NP92-143C-1	clast	Rhaet., Jura., Apt.-E.Alb.	open marine inner marginal	Carolinefjellet Fm., rew. Wilhelmøya Fm.
NP92-143C-2	clast	Apt.-E. Alb.	open marine inner shelf	Carolinefjellet Fm.
NP92-143C-3	clast	?	?	?
NP92-143D	clast	Bar. or younger	? marginal marine	?

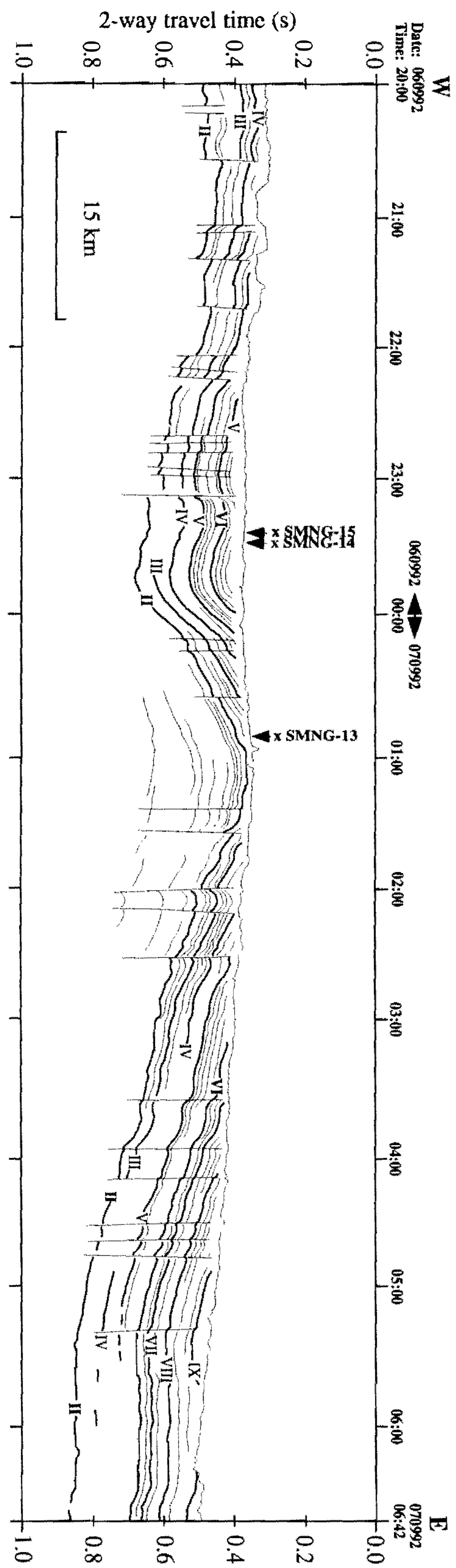

Fig. 9. Line drawing of seismic line NP92-79B. Reflectors **II-IX** of the stratified seismic character are marked and show evidence of both normal and reverse faults. Intersections with Russian MCS lines SMNG-13, 14 and 15 are indicated. See figure 1B for location.

Table 2. Results of the organic geochemical investigations. Note that eight samples from core NP92-142 were analysed. TOC: Total Organic Carbon (%), TC: Total Carbon (%), HI: Hydrogen Index ($mgHC/gC_{org}$), OI: Oxygen Index ($mgCO_2/gC_{org}$), Tmax (°C).

Site	Type material	Lithology	TOC	TC	HI	OI	Tmax
NP92-137	clast	coal	-	-	-	-	429
NP92-142-1	*in situ*	siltstone	2.52	2.85	31	160	437
NP92-142-2	*in situ*	siltstone	2.27	3.66	30	174	438
NP92-142-3	*in situ*	siltstone	0.81	1.12	16	414	451
NP92-142-4	*in situ*	siltstone	1.54	2.03	24	331	438
NP92-142-5	*in situ*	siltstone	2.36	2.72	33	201	436
NP92-142-6	*in situ*	siltstone	2.37	2.88	32	186	435
NP92-142-7	*in situ*	siltstone	4.21	4.79	38	139	432
NP92-142-8	*in situ*	siltstone	1.58	1.86	24	217	436
NP92-143A	clast	coal	65.80	-	178	22	423
NP92-143C	clast	siltstone	0.82	5.58	31	235	430
NP92-143D	clast	claystone	0.24	6.07	4	275	377

Ten palynological analyses of samples from NP92-142 give consistent Aptian - Early Albian ages (Table 1). The analyses also show assemblages comparable to those described from the Carolinefjellet Formation of Svalbard (Ramberg Moe 1980; Endresen 1985), and bear evidence of a shallow marine depositional environment.

Organic geochemical analyses were performed on eight samples from core NP92-142. The results (Table 2) show TOC values between 0.81 and 4.21 % (average 2.20 %), while the Tmax values vary between 432 and 451 °C (average 438 °C). HI ranges between 16 and 38 (average 29) and OI varies between 139 and 414 (average 228). This corresponds to a predominance of kerogen type III/IV, i.e. a mainly terrestrial kerogen (Tissot & Welte 1984). Applying a geothermal gradient of 35°C/km, as also used for the Olga Basin (Lie, 1993) these Tmax values correspond to a depth of maximum burial of approximately 2000 m (Leplat & Paulet 1985).

DISCUSSION

Reflector age

Given the Aptian - Early Albian age for the bedrock sample at site NP92-142 (Figs. 1B and 10), Lower Cretaceous rocks most likely subcrop in the southeastern parts of the study area. The age of the basal reflector **II** of the stratified seismic sequences is, however, a crucial point. Based on seismic character, reflector **II** seems to correspond to reflector **a** of Antonsen et al. (1991). It consists of a band of reflections, forms the base of a series of well stratified seismic units, and its subcrop is often associated with a small depression near the base (e.g. Fig. 7). Antonsen et al. (1991) interpreted reflector **a** to be of Oxfordian to Barremian age, and they suggested that it represented a late Kimmerian tectonic phase, covering the Jurassic - Cretaceous transition. There is, however, no direct correlation between reflector **II** of this study and reflector **a**. Correlation to regional Russian MCS lines which intersect the SCS lines of this study (Fig. 1B), on the other hand, indicates that reflector **II** represents an Early Cretaceous unconformity approximately 500 ms shallower than the Jurassic - Cretaceous boundary (SMNG, unpublished).

The regional MCS lines are tied to wells further south in the eastern Barents Sea. The seismic geometry along these lines is relatively simple, and if the well data are correct, the position of the Jurassic - Cretaceous boundary is well defined in this part of the study area. Antonsen et al's. (1991) age determination (Oxfordian to Barremian) of their reflector **a** is founded on palynological analyses of two *in situ* bedrock cores and till samples immediately below and above subcrop of the reflector, respectively, and must be considered reliable. These lines of evidence lead to the conclusion that reflector **II** does not correspond to reflector **a**, but defines an intra Early Cretaceous unconformity, also identifiable in MCS records.

Based on comparison, but no direct correlation, with the Cretaceous sections of Svalbard and Franz Josef Land, a Barremian age seems likely for reflector **II** (Fig. 11). In Svalbard, this corresponds to the boundary between the Rurikfjellet Formation (Ryazanian to Hauterivian) and the Helvetiafjellet Formation (Barremian) (Edwards 1978; Edwards et al. 1979; Nemec et al. 1988; Dypvik et al. 1991), the Kongsøya and Kong Karls Land formations, respectively, on Kong Karls Land (Smith et al. 1976; Pickton et al. 1979). The boundary on Svalbard is characterised by the coarse grained sandstones of the Helvetiafjellet Formation, covering shales and carbonates of the Rurikfjellet Formation. Such a situation may explain the depression often observed on the stratigraphically lower side of reflector **II** outcrop (Fig. 7). The lower sandstones of the Helvetiafjellet Formation may only be 20-30 m thick, and similar thicknesses may explain the banded appearance of reflector **II** in the study area.

On Franz Josef Land, the continental Tikhaya Bay and Salisbury formations form the equivalent of the Helvetiafjellet Formation (Fig. 11). The erosive lower contact of the Tikhaya Bay Formation, and the existence of volcanic rocks in this formation (Dibner 1998), also support a possible correspondence to reflector **II**.

Based on correlation with the MCS data, the relatively indistinct reflector **I,** identified 500 ms below reflector **II**, is interpreted to represent the Jurassic-Cretaceous boundary. The present SCS database is too sparse and the data are of too low penetration to firmly verify this. However, from this interpretation, post-Jurassic thicknesses exceeding 1160 ms (1740 m with P-wave velocity 3 km/s) are likely in the eastern-southeastern parts of the present study area (Gustavsen 1995), which forms a northwestern part of the North Barents Basin.

Both the palynological and lithological analyses of the in situ rock sample from site NP92-142, show good correspondence to the Aptian - Albian Carolinefjellet Formation on Svalbard. The bedded shales and sandstones of this formation may explain the layered character of the seismic section above reflector **II**, and also the formation of terraces on the sea-floor (Gustavsen 1995).

Hence, the suggested ages for the main seismic reflectors of this study are the Jurassic - Cretaceous boundary for reflector **I**, Barremian for reflector **II**, and Aptian - Early Albian for reflectors **III-X** (Fig. 11).

Tectonic and igneous activity

The tectonic development of the area can not be outlined in detail from the present data base. A few observations are important, however. The main structural directions clearly follow a north-northeasterly trend. This is in accordance with both the Caledonian directions

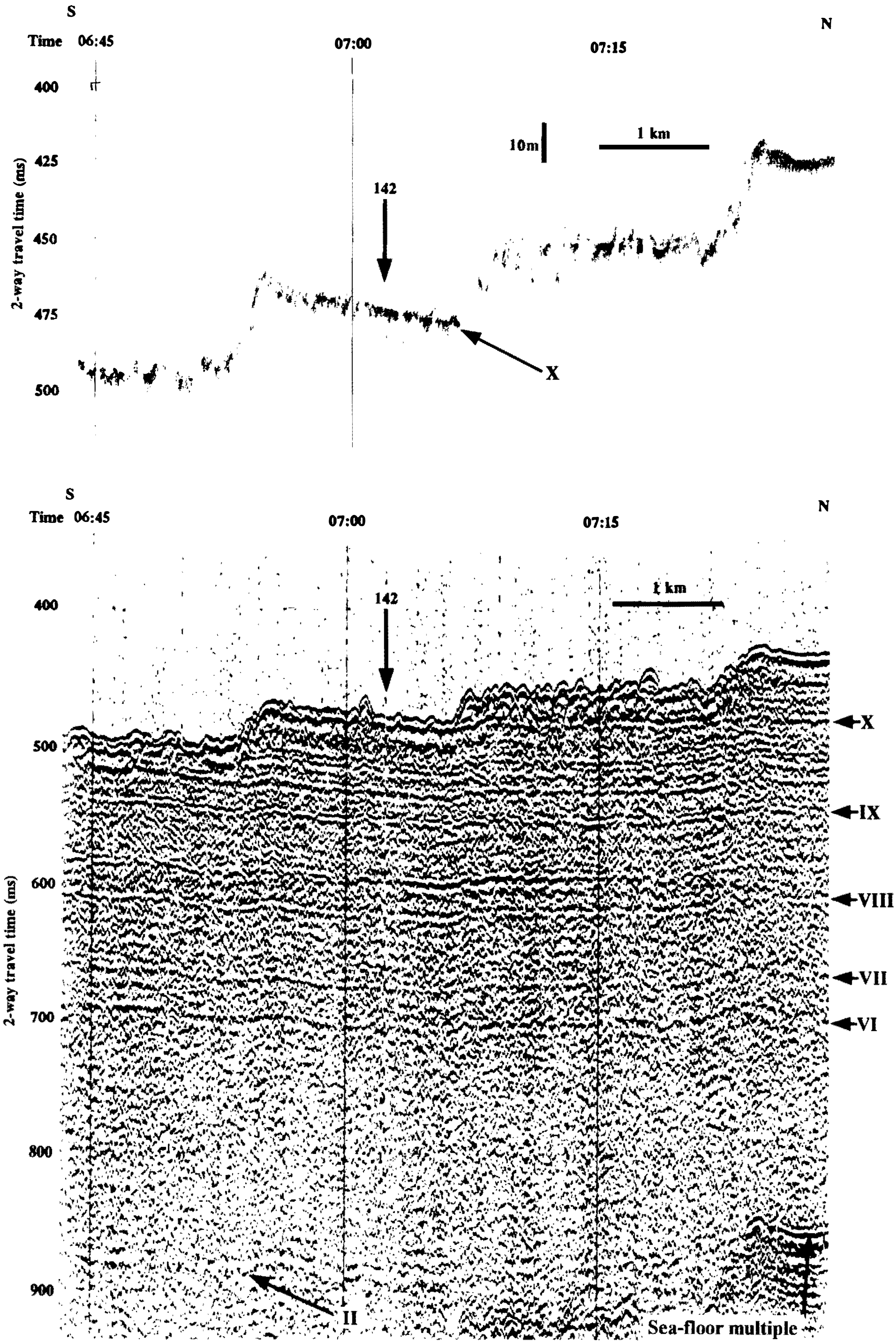

Fig. 10. PDR (upper) and seismic (lower) records from line NP92-81. Sediment coring site NP92-142 and reflectors **II**, **VI-X** are marked. Reflector **X** is observed to subcrop at the coring site. Note the small scale sea-floor topography, which is caused by iceberg ploughing. See figure 1B for location.

CHRONOSTRAT. Ep.	Per.	Age	Study area Reflectors	SVALBARD Sub.gr./Form.		FRANZ JOSEF LAND Formation
CRETACEOUS	LATE	Coniacian		NO RECORD		NO RECORD
		Turonian				
		Cenomanian				"Marine Sandstones"
	EARLY	Albian		Carolinefjellet		NO RECORD
		Aptian	X			Salisbury
		Barremian		Helvetiafjellet		Tikhaya Bay
		Hauterivian	II	Janus-fjellet	Rurik-fjellet	"Continental and marine coals and sandstones"
		Valanginian				
		Ryazanian				
JURASSIC	LATE	Volgian	I		Agardh-fjellet	"Marine sand- and mudstones"
		Kimmeridgian				
		Oxfordian				
	MID.	Callovian				
		Bathonian				
		Bajocian				
		Aalenian		NO RECORD OR STRONGLY CONDENSED		NO RECORD
	EARLY	Toarcian				
		Pliensbachian				
		Sinemurian				
		Hettangian		Wilhelmøya		Thegetthoff
TRIASSIC	LATE	Rhaetian				
		Norian		De Geerdalen		Vasilyev
		Carnian		Tschermakfjellet		Vilchekov
	MID	Ladinian		Barentsøya		"Marine shales and sandstones"
		Anisian				
	EARLY (Olen.)	Spathian				
		Smithian				
	EARLY (Ind.)	Dienerian				
		Griesb.				

Fig. 11. Stratigraphic correlation between the study area, Svalbard and Franz Josef Land (based on Ulmishek 1985; Miloslavskij et al. 1993; Dibner 1998). Stippled lines indicate uncertain stratigraphic position.

mapped in the western Barents Sea (Gabrielsen 1984; Gudlaugsson et al. 1994) as well as the Uralian directions on Novaja Zemlja (Otto & Bailey 1995).

Several of the observed faults show reverse movement, which together with the antiform in the south-central part of the study area indicate a period of compressional stress (Fig. 9). Based on the effect on the Aptian-Lower Albian sedimentary section, this tectonic phase took place in post-Albian time. Post-Albian compressional movements also affected e.g. Kong Karls Land (Smith et al. 1976), and the Sentralbanken High (Rønnevik et al. 1982) (Fig. 1A).

The compressional structures in the study area can be related to pre-opening tectonics in the Norwegian-Greenland Sea, near the Cretaceous-Tertiary transition (Faleide et al. 1993). However, reactivation of the Late Uralian lineaments observed in the Upper Triassic of Novaja Zemlja (Otto & Bailey 1995) can not be excluded as a cause for the compressional structures. Normal faults which appear to post-date the formation of the reverse faults, penetrate to the sea-floor, but do not form any relief indicative of neotectonic movements. Extensional movements related to post-Oligocene sea-floor spreading in the Norwegian-Greenland Sea and the Arctic Ocean (Fig. 1A) are likely causes for the normal faulting.

Based on the lateral extent of the observed igneous structures (Figs. 5 and 6), we suggest they represent remains of extrusive lavas, similar to the Barremian lavas found on Franz Josef Land and eastern Svalbard. Their dimensions correspond well to many small islands and skerries of Mesozoic basaltic lavas found in both archipelagos. On the other hand, these igneous structures could represent doleritic sills or dikes, which also are widespread on Franz Josef Land and form positive topographic reliefs clearly visible in aerial photos as well as satellite images (V. Dibner, pers. comm. 1994). However, the dimensions of the seismically observed structures, and the fact that some of them appear laterally connected as one body over up to 25 km along the seismic lines, argue against an intrusive origin.

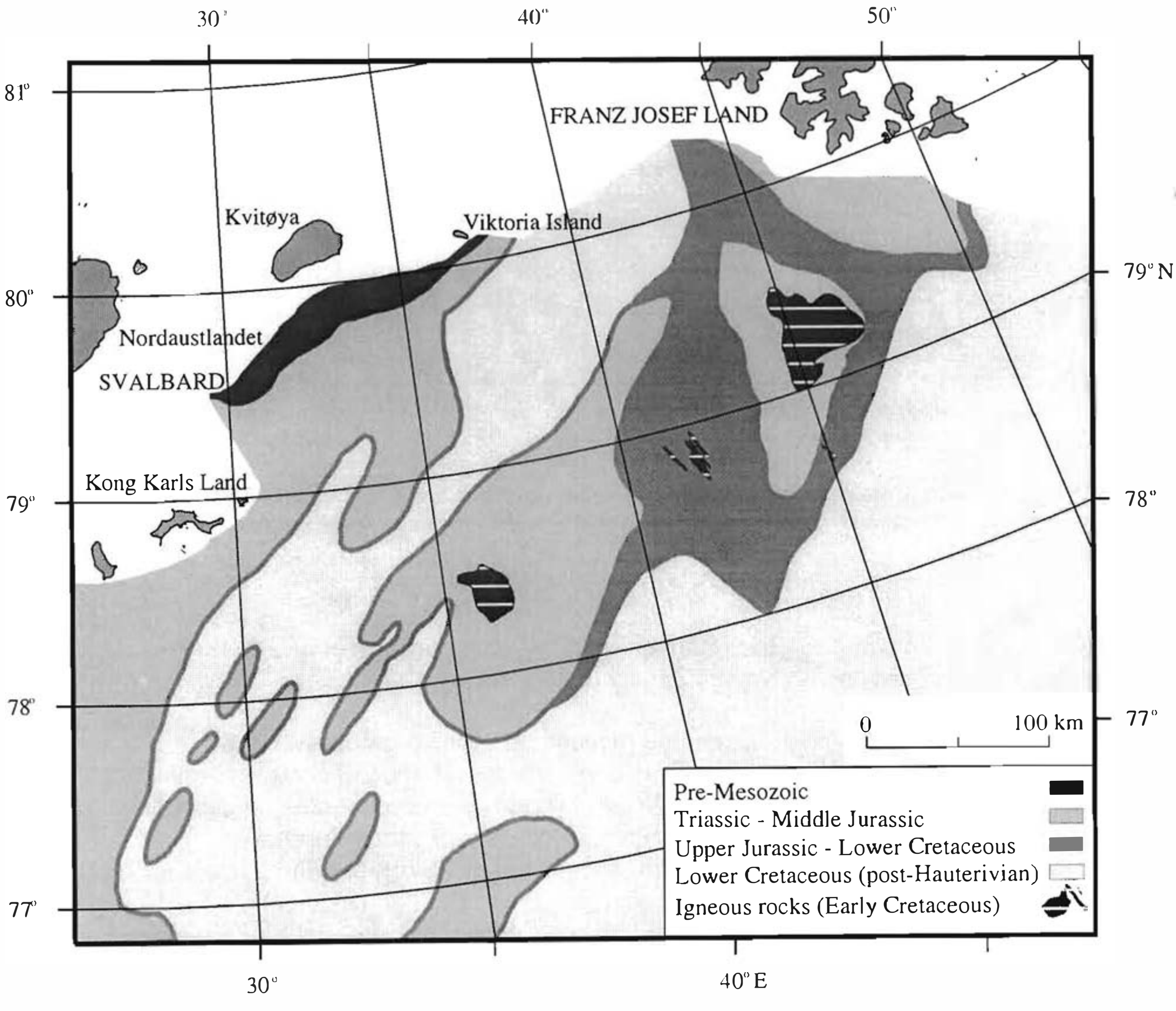

Fig. 12. Subcrop map of the northern Barents Sea. Based on Elverhøi et al. (1988), Sigmond (1992), Johansen et al. (1993) and the results of this study.

Tectonic causes for geological differences between Franz Josef Land and Svalbard are not apparent in the investigated area. However, Franz Josef Land may have been affected by the Late Triassic tectonism observed on Novaja Zemlja.

Subcrop geology

Based on the seismic stratigraphy and sedimentological as well as palynological results outlined above, a subcrop map for the study area has been constructed (Fig. 12). As the local bathymetry to a large extent is affected by the underlying bedrock geology (Elverhøi et al. 1989), the bedrock boundaries (Fig. 12) are drawn along the bathymetric contours in areas of poor seismic coverage. There is a close relation between the seismic character and the age of the subcropping bedrock. The seismically stratified units above reflector II of the eastern and southeastern areas, correspond to the post-Hauterivian rocks, while the mixed character most likely comprises Upper Jurassic - Lower Cretaceous (Volgian-Hauterivian) deposits corresponding to the Agardhfjellet and Rurikfjellet formations of Svalbard (Figs. 11 and 12). Thickness variations relative to Svalbard may be caused by different source areas. In particular, pre-rift uplift of the paleo-Lomonosov Ridge (presently located in the Arctic Ocean) northeast of Svalbard (Ziegler, 1988), and of adjacent areas along the continental margin north and northeast of Franz Josef Land, may have provided the source region for the sediments in the study area. Extensive erosion makes it impossible to estimate true thicknesses of the overlying Aptian - Albian sequence, corresponding to the Carolinefjellet Formation on Svalbard. The regions with chaotic seismic character represent the Triassic - Middle Jurassic rocks (Fig. 11), which have been strongly affected by Triassic and Jurassic faulting.

The estimate of up to 2000 m of post-Early Cretaceous erosion in this part of the Barents Sea, is in agreement with published erosional estimates from the Olga Basin area, approximately 350 km to the southwest of site NP92-142. Antonsen et al. (1991) measured Tmax values of 434° and 436°C, corresponding to a burial depth of 1.9 km. Lie (1993) estimated the burial depth in the Olga Basin based on vitrinite reflectance in Aptian coal fragments, to be 1.8 km ±200 m, while Nyland et al. (1992) indicated 1.5 - 2.0 km, also based on vitrinite reflectance as part of a regional survey. Based on seismic velocities Sanner (1995) estimated 2.0 - 2.2 km of erosion in the same area.

Recent studies indicate that a significant part of the total erosion in the Barents Sea has been caused by Late Cenozoic glaciations (Eidvin et al. 1993; Faleide et al. 1996; Rasmussen & Fjeldskaar 1996; Solheim et al. 1996). Glacial erosion varies from approximately 500 m in the south, to approximately 1700 m in the northwest, comprising at least half of the total Cenozoic erosion. By comparison with these areas, it is not unreasonable to assume that approximately 1 km of the erosion in the study area may be caused by Plio- and Pleistocene glaciations.

The interpretation of the subcropping bedrock geology of the northern Barents Sea is strongly hampered by a too widely spaced seismic grid, with regard to both MCS and to SCS data. The lack of stratigraphic tie points also make firm interpretations difficult, in particular in determining the age of the subcropping horizons. Over most of the investigated area, the bedrock is accessible with drilling devices capable of penetrating 5 - 10 m of unlithified sediments. The potential for bedrock sampling and thereby dating of key seismic horizons, is therefore significant in this region.

CONCLUSIONS

Based on high resolution single channel seismic data and gravity cores, combined with older data from the northern Barents Sea and geological information from the Svalbard and Franz Josef Land archipelagos, the following conclusions can be drawn:

- Mesozoic fine grained clastic rocks and basaltic lavas subcrop in the entire study area. The subcropping sedimentary rocks are progressively younger towards the east and southeast, and post-Jurassic thicknesses exceed 1700 m.
- Seismic character varies between chaotic, intermediate and stratified. These characters roughly correspond to the age of the subcropping bedrock, with the stratified character representing Lower Cretaceous (Barremian and younger) rocks, the intermediate character representing Upper Jurassic - Lower Cretaceous rocks and the chaotic character Triassic - Middle Jurassic rocks, affected by early Mesozoic tectonism.
- The uplifted areas of the paleo-Lomonosov Ridge and shelf margins north of Franz Josef Land are suggested as a northerly clastic source area for the Lower Cretaceous sediments of the northern Barents Sea. This may explain thickness differences between the study area and Svalbard.
- Igneous rocks mapped in the study area probably represent basaltic lavas and are closely related to the Jurassic and Cretaceous volcanic rocks mapped both on Franz Josef Land and in eastern Svalbard.
- Reverse faults, associated with antiforms, indicate a period of compressional stress in the Late Cretaceous/early Tertiary.
- Differences in the post-Paleozoic succession between Svalbard and Franz Josef Land may be ascribed to differences in distance to source areas, differences to the adjacent rifting and spreading ocean basins, and to Cenozoic erosion, which appears to have been stronger in the western parts of the study area, near Svalbard. A maximum of 2000 m post-Early Cretaceous erosion is estimated for the study area.
- Shallow rock core drilling has a significant potential as a tool for further bedrock investigations of this area, as the cover of unlithified sediments rarely exceeds 10 m.

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5. THE TRIASSIC SUCCESSION OF FRANZ JOSEF LAND, STRATIGRAPHY AND SEDIMENTOLOGY OF THREE WELLS FROM ALEXANDRA, HAYES AND GRAHAM BELL ISLANDS

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ABSTRACT

The three cores studied from, Alexandra, Hayes and Graham Bell islands, cover most of the Triassic periode. In this study the sedimentological and paleontological composition of the more than 3000 m thick Triassic succession is presented. It is found to consist of sedimentary facies spanning outer shelf to nearshore marine units in the Induan to lower Carnian successions, while the youngermost Carnian beds are made up of more lagoonal sedimentary developments. The youngest Triassic beds present, of possible Norian age, consist of shallow shelf to nearshore deposits.

The sequences T2 - T5 of Van Veen et al. (1992) have been recognized, and make a tie to other circum Arctic localitites possible. A connection which also is underlined by the paleontological compostion of the samples. The lower Triassic sediments are characterized by fish remains (*Boreichthys shkolai* Selezneva), bivalves (*Posidonia*), as well as a calcareous foraminiferas.

The palynological assemblages found in the Lower Triassic beds are poor, while the assemblages of the Middle Triassic successions are somewhat better preserved in both Anisian and Ladinian species (*Leiofusa/Veryhachium* spp., *Aratrisporites* spp.). The Middle Triassic macrofossils are dominated by *Daonella*, ammonites (*Frechites*) and bivavles, e.g. *Mytilus* cf. *eduliformis.* Late Anisian correlation to Canada and Svalbard is possible. The Ladinian deposits are also characterized by *Daonella*, represented by typically oppressed forms. Micropaleontologically the agglutinated foraminiferas dominated in the Anisian beds, with a faunal change in Late Ladinian when calcareous forms play a more significant role.

The youngermost Triassic rocks are dominated by nodosariids, a few species of agglutinated foraminiferas are also present (*Ammodiscus* sp.,*Glomospira* sp.and *Textularia* sp.). The palynological composition of the uppermost parts of the succession, e.g. in the Hayes Island, displays none-marine to shallow shelf palynomorphs in the late Carnian part of the succession. The macro fossile assemblage in the Carnian part is rather poor, while the Norian beds contain marine indicators such as *Halobia* and the ammonite *Pterosirenites* sp.

GEOLOGICAL BACKGROUND AND PREVIOUS WORK

The Triassic succession of the Franz Josef Land archipelago (Fig. 1) is only moderately known, in spite of its regional importance and a total thickness of about 5 km (Preobrazenshaya et al.1985a, 1985b). Dibner (1998) claims the total thickness of the sedimentary cover in the Franz Josef Land area to be at least 10 to 12 km. Based on information from several publications (Dibner et al.1962; Mørk et al. 1982, 1989, 1992;

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Fig. 1. Geographical setting of Franz Josef Land..

Preobrazehenskaya et al. 1985a, 1985b) a general stratigraphical column (Fig. 2) has been constructed, also including correlative Triassic developments in Svalbard.

Through Triassic time shallow marine shelf to terrestrial sedimentation dominated in the eastern Barents Sea and Timan Pechora Basin. In contrast, Novaja Zemlja was probably dry land, with a high, mountainous landscape, representing the southern extention of a possible eastern clastic source area for the Franz Josef Land basin. The topographic relief of this region was, however, mainly levelled out at the end of the Early Jurassic (Preobranzenskaja et al. 1985a, 1985b; Ulmishek 1985). On Franz Josef Land the continental, lagoonal and

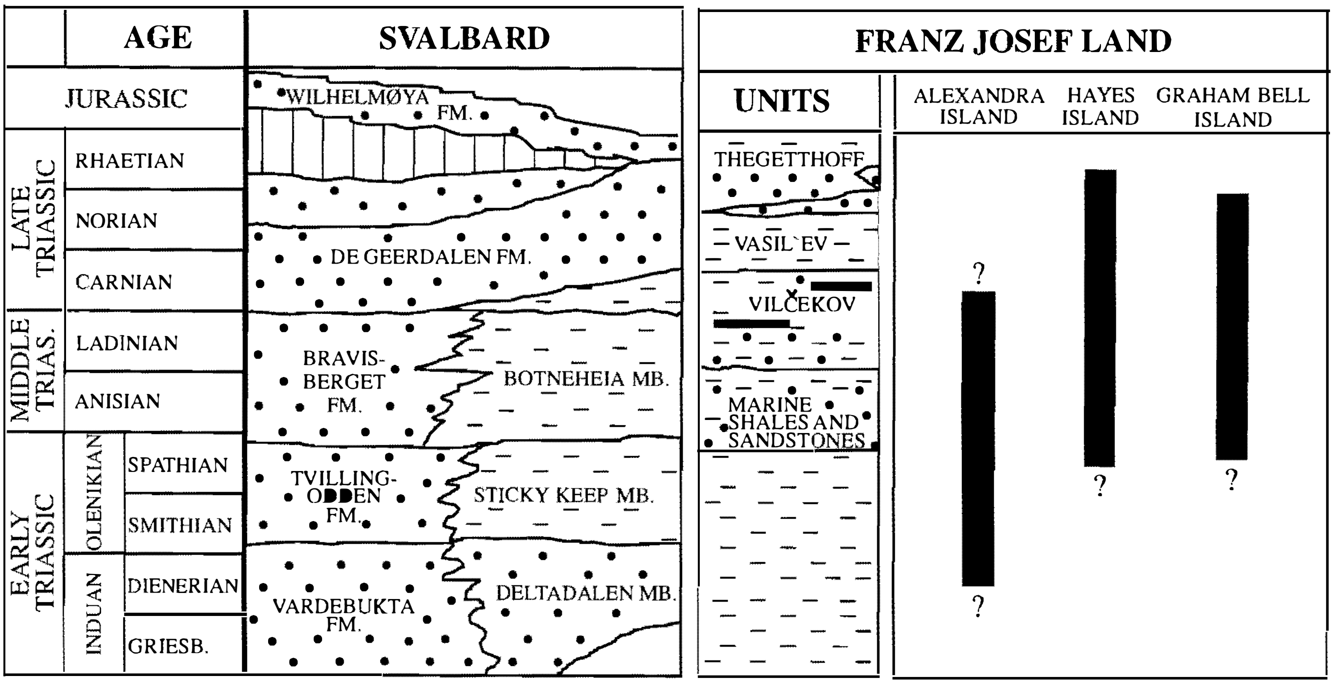

Fig. 2.The stratigraphy of Franz Josef Land compared to the general stratigraphy of Svalbard.

deltaic-marine Late Triassic to Early Jurassic deposits are overlain by Middle to Late Jurassic marine shales. These shales are succeeded by offshore marine Berriasian-Valanginian deposits which are followed by a coal-bearing Hauterivian-Barremian succession (Dibner & Schulgina 1960).

The Franz Josef Land archipelago was affected by complex faulting (e.g. Solheim et al. 1998), but the Mesozoic formations generally rest in an almost horizontal position. On the eastern islands, mainly Triassic and Jurassic deposits are exposed, while the western ones are dominated by magmatic Early Cretaceous formations.

The volcanics and dolerites of Franz Josef Land may be related to an extensive Arctic period of volcanic activity, now being studied in detail by Amundsen et al. (1998). At least three magmatic generations have been noted (Dibner 1970;1998; Dibner et al.1962), with individual dykes/sills up to 100 m in thickness. Dating of these sills, from the Alexandra Island well, indicates Early Jurassic to Tertairy ages (Sinemurian-Oligocene, 203 my-34.5 my) according to Dibner (1998). On Hayes Island the magmas were intruded during the Middle Jurassic to Late Cretaceous period, while on Graham Bell Island intrusions were formed both in the Cretaceous and the early Paleocene (Dibner 1998).

During 1976-1981 three wells were drilled and cored on Franz Josef Land, located on Alexandra Island, Hayes Island and Graham Bell Island (Figs. 1 and 3). The wells, which were part of a large Arctic drilling programme (Gramberg et al.1985) have earlier been studied paleontologically and stratigraphically with results published by Kasatkina (1985), Korcinskaja (1985) and Preobrazenskaja et al.(1985a, 1985b), while Vojcechovskaja (1985) presented an organic and inorganic geochemical study. Neither sedimentological nor diagenetical data have been made available so far.

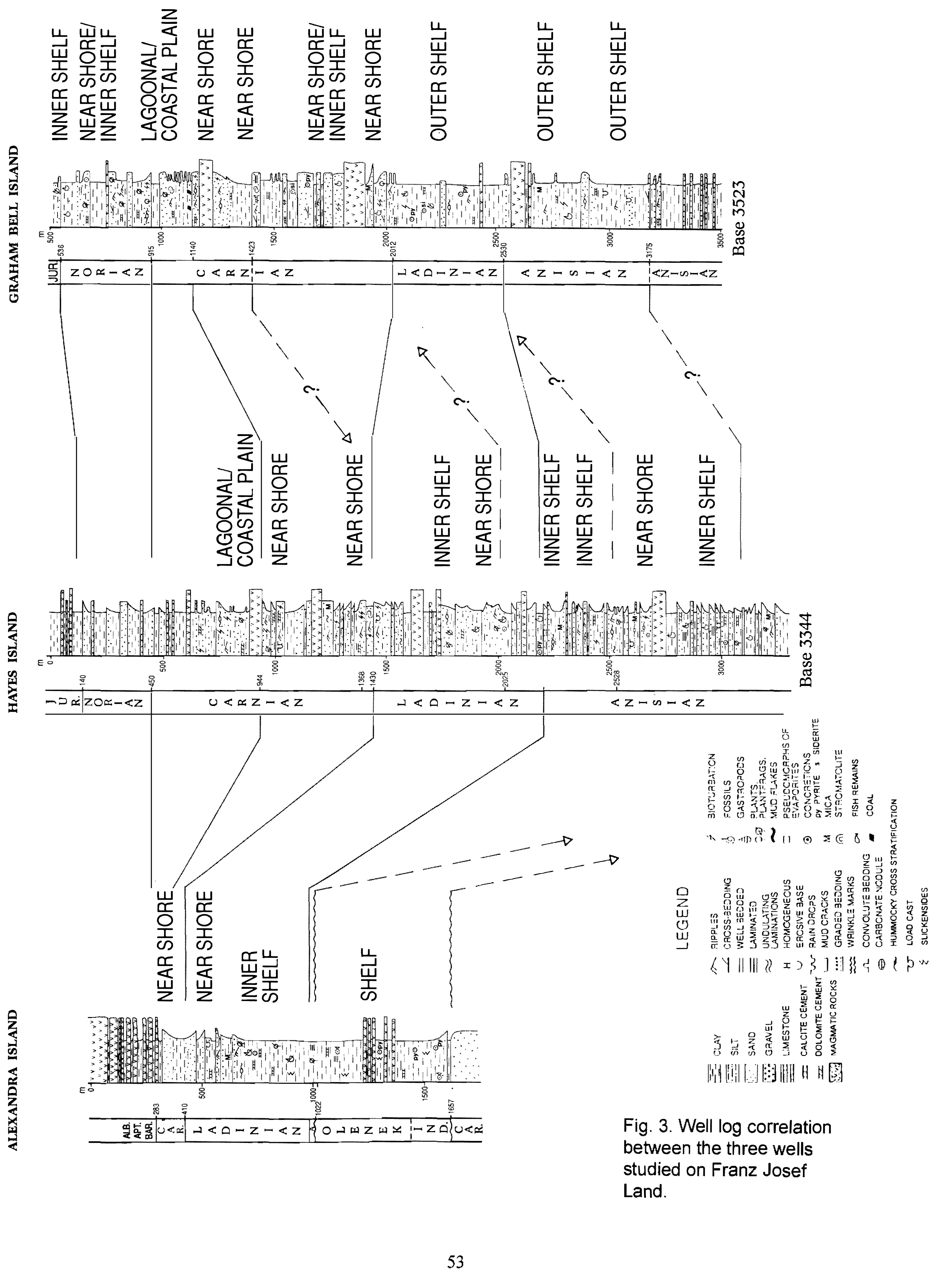

Fig. 3. Well log correlation between the three wells studied on Franz Josef Land.

The present study

This paper provides a general sedimentological and stratigraphical overview of the Triassic of Franz Josef Land, based on the published record and renewed studies of the three wells mentioned above. The succession penetrated by the wells is docu-mented by conventional cores and by continuously run petrophysical logs (gamma, calipher, resistivity and self potential). The interpretation of these, together with sedimentological core logs and paleontological analyses (macropaleontology, micro-paleontology and palynology) form the basis of this stratigraphical presentation. Additional organic geochemical, mineralogical and diagenetical studies have been performed and the results of these are partially presented elsewhere in this volume (Dypvik et al. 1998).

The Alexandra Island well (named Nagurskaja) (Figs. 1 and 3), reached down to 3200 m depth, penetrating a Triassic sedimentary column (with veins of dolerites) terminating at 1657 m, below which Late Carboniferous beds were found. The Triassic succession (interval 283-1657 m) in this well is marked by several tectonic breaks, and is dominated by dark shales, with thin sandstone beds occurring in the lower and upper parts of the well. In contrast the Triassic successions of the Hayes Island and Graham Bell Island wells are dominated by thicker, more continuous successions than the break-dominated Alexandra Island well succession.

The Hayes Island well, (Figs. 1 and 3) was drilled to 3344 m depth. The penetrated succession consists of Late and Middle Triassic shales, siltstones and sandstones, commonly forming coarsening-upwards sequences. The cores from this well are comparatively rich in sandstones, and contain only few dolerite veins.

The Graham Bell Island well (called Severnaya) was drilled to a depth of 3523 m and its sedimentary column consists of Late and Middle Triassic beds. The lower part is dominated by shales with some few sandstone interbeds, while the upper part is characterized by more sandstone-dominated facies. Veins of dolerite, up to 79-88 m thick, are commonly found in these cores.

This presentation includes the more than 3000 m of Triassic sediments cored at Franz Josef Land, a hugh thickness compared to the 250-1200 m thick sequences found outcropping in Svalbard to the west (Mørk et al. 1989). This paper describes the first Anisian and Ladinian occurrences observed on Franz Josef Land, since those units up until now have not been found in outcrop.

TRIASSIC SUCCESSION

The subdivision applied is based on the new core studies and correlations with out-crop data from Hayes and Wilczek Islands (south central Franz Josef Land) (Fefilova, Korscinskaja, Pcelina & Sokolov 1995 pers. comm.). The major stratigraphical dis-coveries compared to earlier core (Preobrazenskaja et al.1985a) and outcrop descrip-tions (Dibner & Sedova 1959; Ditmar & Tarachovski 1995 pers. comm.) are the following:

1. The boundary between Early Jurassic and Norian-Rhaetian beds are moved down core (i.e. the formely called Vasilevskaja Suite are given an Early Jurassic time of formation).
2. The Carnian/Norian boundary has been lowered in the cores compared to Preobrazenskaja et al.1985a).
3. Formerly dated Early Ladinian deposits are now believed to be Anisian
4. A break in sedimentation has been recorded during late Olenekian and Anisian.

ALEXANDRA ISLAND

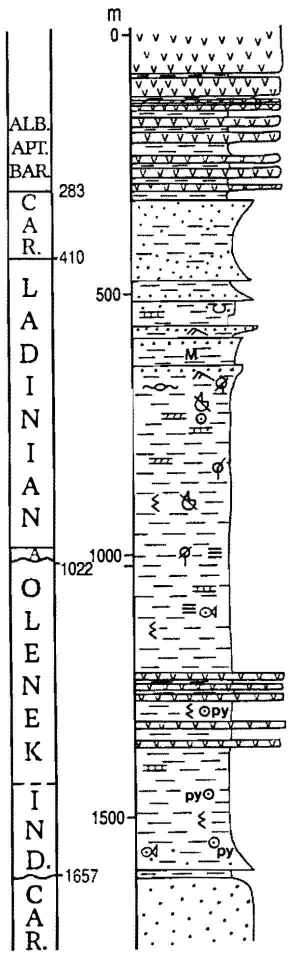

Fig. 4. Sedimentological log of the Alexandra Island well. A = Anisian.

Induan and Olenekian stages

Triassic deposits were penetrated in all three wells, but only in the Alexandra Island well, were beds as old as Induan and Olenekian (interval 1657-1022 m) distinguished (Fig. 3). Intrusions of dolerites and gabbrodolerites up to 70-88 m in thickness were recorded in the interval.

The Induan deposits (interval 1657-1450 m) (Figs. 4 and 5), which unconformably overlie Upper Carboniferous limestones, are composed of heavily slickensided, black and dark-grey mudstones with few thin, scattered layers/lenses of grey, fine-grained horizontally- and wavy-laminated silt- and sandstones. Thin, characteristic flaggy fracturing of the rocks, probably caused by the accumulation of phytoplankton, are now found pyritized. Interbeds of calcareous mudstones occur, and in the upper parts of the Induan section laminated clayey siltstones with thin interbeds of grey, fine-grained sandstones containing disaggregated organic debris are common. Large amounts of pyrite are typically observed in the core from intervals 1624-1610 m and 1554.6-1538.6 m. The mutual appearance of diagenetically formed calcite may be related to magmatic activity.

The Lower Olenekian deposits compose the interval 1450-1022 m of the Alexandra Island well, terminating in an unconformity. This part of the succession is represented by rather monotonous black and dark-grey, laminated mudstones and clayey siltstones. Thin horizontal, as well as wavy, lamination is commonly found in more silty, slickensided beds. Dispersed calcareous beds and diagentic pyrite nodules occur.

Anisian Stage

Middle Triassic deposits are represented in all three wells (Fig. 3). Anisian beds are present in the Hayes Island well (interval 3344-2164m) (Figs. 6 and 7), the Graham Bell Island well (interval 3523-2530 m) (Figs. 8 and 5b), and conditionally in the Alexandra Island well (1022-985 m) (Fig. 4) where they mainly consist of dark-grey mudstones. At 1022 m in the Alexandra Island well a thin layer of homogenous calcareous mudstone with rare foraminiferas is recorded, most likely showing the first influence of the Middle Triassic transgression.

In the easternmost two wells (Hayes and Graham Bell islands) the Anisian section is represented by units of dark-grey/black mudstones and clayey siltstones, separated by units of grey and light-grey, often calcareous siltstones and sandstones. The clayey units display reduced thicknesses in the upper parts of the Anisian succession. In the Hayes Island well the upper boundary of the Anisian (depth 2164 m) was recognized at the top of a 3 m thick micaceous sandstone bed. In the easternmost well, on Graham Bell Island, the number and thickness of sandstone beds increase rhythmically upwards in the Early Anisian in contrast to the more silty beds in the Hayes Island well. In the Graham Bell Island well a regressive unit of a possible late Middle Anisian age (no index-fossils found) is indicated. The succeeding transgressive Late Anisian interval is recognized by a reduced sand content with lenses and interbeds of carbonates (e.g. siderite) and pyrite.

The silty, Anisian claystones commonly grade into clayey siltstones and are found interbedded with siltstones and sandstones in coarsening upwards sequences. The layering, most clearly developed in the sand dominated intervals, is usually caused by original selective accumulation of mica and coalified plant detritus. Very fine plant detritus and diagenetically formed siderite are commonly found in several of these beds. The upwards coarsening units often show sandstones with uneven, erosional bases and with pockets of coarser material towards underlying fine-grained beds. The sandstones, commonly carbonate cemented, are generally rather homogenous, but parallel and undulating lamination as well as possible hummocky cross stratification are found in the normally 5 m to about 20 m thick units. The discrete sand units are in several cases found to consist of thin, upwards fining beds with ripple lamination, convolute lamination and loading structures along the bases. Various unidentified bioturbation traces have been found in these Anisian beds. Several fossils are also observed and are recorded elsewhere in this paper. A storm influenced shelf sedimentation is most likely, with the coarser grained beds of Hayes Island indicating higher energy regimes or a more marginal position. The strata forming the upper (regressive) part of the Anisian succession were earlier assigned to the Lower Ladinian (Preobrazenskaja et al.1985a, 1985b).

Ladinian Stage

The Ladinian deposits have been recognised in the well on Alexandra Island (985-410?m) (Figs. 4 and 5), Hayes Island (2164-1430 m) (Figs. 6 and 7) and Graham Bell Island (2530-2012 m) (Fig. 8). The three intervals (Fig. 3) can be correlated by regional transgressive developments.

Fig. 5a. The upper photo shows finely laminated dark, grey, shelf shales from Induan of the Alexandra Island well, 1541.0 m. Scale, 1:1.6. The lower photo shows finely laminated, dark grey shales from the Ladinian of the Alexandra Island well, 935.0 m. Scale 1:1.6.

Fig. 5b.Hummocky cross lamination from Anisian, outer shelf sediments form the Graham Bell Island well, 2834.5 m. Scale 1:1.6.

In the studied core from Hayes Island the lower beds are dominated by lenses and layers of sandstone within siltstone and mudstone units. These are succeeded by dark grey, homogeneous mudstones, interbedded with darkgrey siltstones. Along the bedding planes small imprints of *Daonella* are commonly found.

In the Hayes and Graham Bell island wells, fossil-rich, parallel laminated mudstones form the main part of the Ladinian interval which displays an upwards increasing silt content suggesting a faint regressive development. Dispersed sandstones are also present. The mudstones contain *Planolites* and *Chondrites* type trace fossils. The Late Ladinian boundary is in the Hayes Island well characterized by the appearance of light-grey sandstones, with clay clasts and faint undulating lamination. Load casts and convolute lamination are also commonly found in the normally rippled sandstones. Lenses, interbeds and nodules of carbonates (mainly siderite) and calcareous mudstones as well as concretional aggregates of calcite and oxidized pyrite, occur. Light brownish-grey phosphate and siderite nodules with abundant remains of echinoids, are found as interbeds carrying remains of non-carbonate, planktonic blue green algae. Plant detritus and a thin lens of coal were recognized in the siltstones at a depth of 1897 m in the Hayes Island well. Coalified plant detritus, mica and oxidized siderite may in several cases exaggerate the bedding planes. A generally low-energy shelf setting is indicated by the sedimentological composition of these Ladinian beds, which are apparently of most marginal character in the Hayes Island cores.

In the Alexandra well, which is the the most westerly situated well, the Ladinian interval (985-410 m?) (Figs. 4 and 5) differs from that of the other two wells. The lower part of the core is composed of dark-grey, pyrite bearing, poorly slickensided mudstones with faint horizontal or wavy lamination and abundant small crushed *Daonella* shells. At some levels lamination is well developed in alternating claystones and plant- and mica-enriched siltstones. Mica and carbonate cemented beds are also commonly observed.

HAYES ISLAND

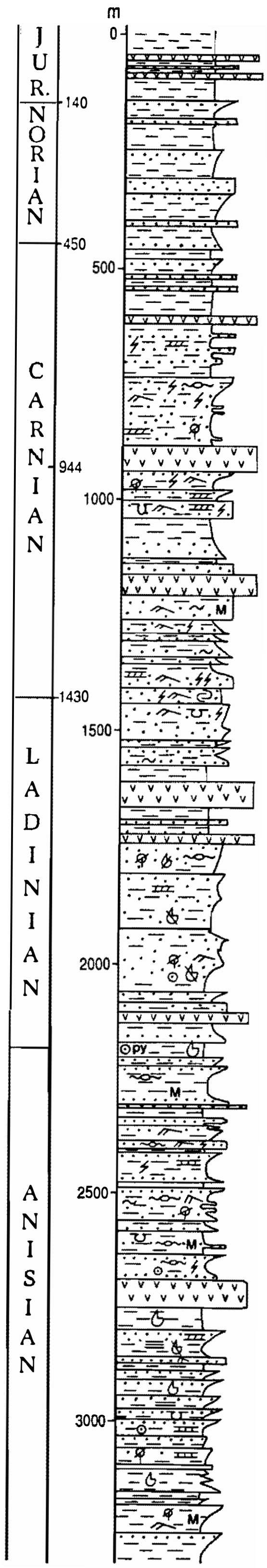

Fig. 6. Sedimentological log of the Hayes Island well.

At level 720 m thin interbeds of a laminated, fine-grained sandstones occur. Higher up a regressive unit (660-540 m), marking the end of the Early Ladinian regression, appears. These regressive beds are dominated by grey and light-grey, fine- to coarse-grained often carbonaceous, bioturbated siltstones. Interbeds of fine-grained, rippled sandstones (about 0.1 m thick) partly with wavy contacts are common, while mudstones are of subordinate importance. Typical for this unit are lenses, inclusions and small nodules of siderite together with scattered bioturbation of unspecified, *Planolites*-looking traces and plant debris. Poorly preserved shells of marine ostracodes and bivalves have been recorded in this upper regressive part of the Early Ladinian interval. It is overlain by transgressive, Late Ladinian grey, silty claystones with marine bivalves (Ladinian *Daonellas* were recorded up to a depth of 447 m), foraminifera and ostracodes.

Carnian and Norian Stages
In the Alexandra Island well a thin interval of Carnian age (no cores available) may be present between the Ladinian mudstones and the unconformably overlying Lower Cretaceous terrigenous-volcanogenic units. Based on the petrophysical log characteristics the Ladinian sequence may end at 283 m, and a Carnian succession (? 410-283 m) may have been overlooked by previous inspection of this log. In the Alexandra Island well the thin Carnian stage may, according to well log data, be present as mudstones with siltstone interbeds. In contrast the thick Carnian sections from the easternmost wells are represented by rhythmical, commonly coarsening-upwards units of grey siltstones, mudstones and sandstones, often calcareous, with more coal-bearing beds in the younger sections. Plant detritus and coal beds are found in these upper parts (Graham Bell Island, above 1600 m and Hayes Island well, above 1090 m), commonly with some late diagenetic siderite cementation.

The Late Triassic stages, Carnian and Norian, were penetrated in both the Graham Bell Island (interval 2012-536? m) (Figs. 9 and 10) and Hayes Island (interval 1430-140 m) wells (Fig. 3). The Carnian deposits can be distinguished in Graham Bell Island (interval 2012-915 m), Hayes Island (interval 1430-450 m) and possibly in the Alexandra Island (interval 410?-285 m) wells. The Carnian sedimentation represents a gradual basinal shallowing, and the globally developed Early Carnian transgression is consequently poorly expressed here. In the Carnian successions bivalves (usually only fragments) and foraminifera were rarely recorded. The lower boundary, in the eastern well (Graham Bell Island), is drawn at the base of dark-grey mudstone with shells of bivalves, which upwards grades into a unit of interbedded siltstones, sandstones and mudstones. In the lower Carnian interval (2012-1423 m) penetrated by the Graham Bell Island well, 5m to 30 m thick coarsening upwards, cross bedded and commonly highly to completely bioturbated units dominate. The trace fossil assemblage includes *Skolithos, Diplocraterion,* but also *Planolites*, *Helmintoidea, Terebellina* occurrences are common. In the grey to light grey sandstones and siltstones shells of *Halobia* sp. shells occur. Rippled beds with partly oxidized upper layers are also seen. The most coarse-grained clastic material is recorded at the base of the Carnian section in Graham Bell Island. There lenses and interbeds (commonly about 10 m in thickness) of coarse-grained sandstones with clasts and gravel of carbonaceous sandstones, occur dispersed in the marine, micaceous, silty, bivalve bearing mudstone units.

In the upper part of the Carnian in both the Hayes (760m) and Graham Bell (1200 m) Islands wells (Figs. 3 and 10), fining-upwards developments are found, within an overall upwards coarsening succession, dominated by convolute lamination, ripple lamination and cross-bedding (commonly of hummocky affinity). Three to ten meter thick upwards coarsening units are found and loading structures, and high degrees of bioturbation are

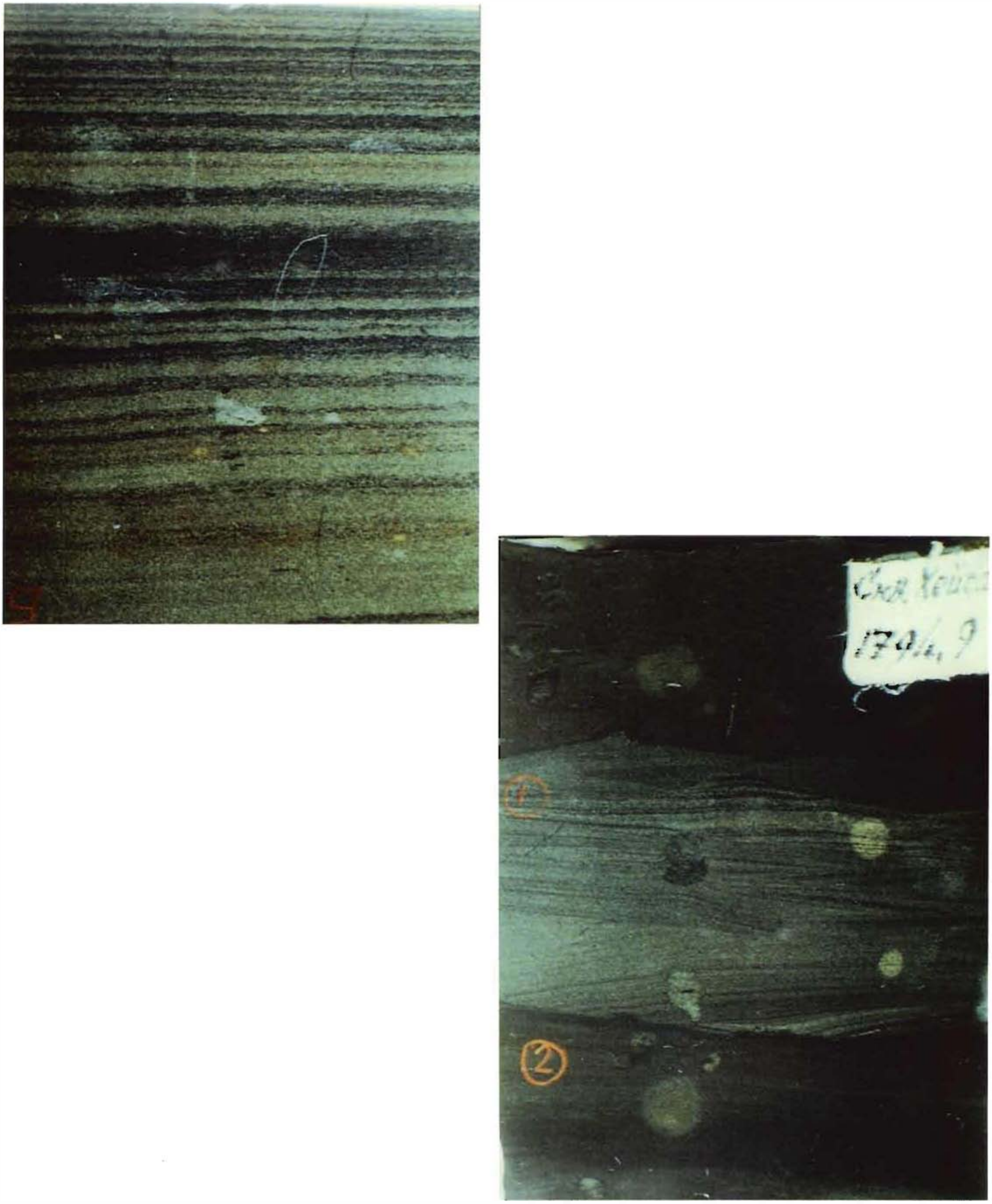

Fig. 7. The upper photo shows finely laminated Anisian, inner shelf sandstones from the Hayes Island well, 2377.6 m. Scale 1:1,5. The lower photo shows hummocky laminated sandstone from the Ladinian inner shelf deposits of Hayes Island well, 1794.9 m. Scale 1:1.3.

characteristic of these possible nearshore deposits. As below, plant detritus is commonly seen associated with siderite cementation. Similar highly bioturbated developments are observed in the Hayes Island well, where also mudflakes are found along the soles of the coarser grained sandstones. These sandstones are highly rippled, partly bioturbated and contain plant detritus.

The Norian deposits were distinguished in the Graham Bell Island well by means of both core and petrophysical logs (interval 915-536m) and in Hayes Island well by means of petrophysical log data (interval 450-140 m) alone (Fig. 3). In the Graham Bell Island well the lowermost Norian beds were indicated at the level of disappearance of the coaly deposits (Fig. 8), by analogy with Svalbard (Pchelina 1980). The upper boundary was established in the wells discounting the data on the outcrops in Hayes Island (Ditmar & Tarachovski 1995, pers. comm.). In the "Late Triassic" claystones (according to V. Dibner 1995, pers. comm.) (the lower part of the ?Vasilevskaja Suite) as well as in the uppermost cored clayey unit in Graham Bell Island, the presence of Early Jurassic(?) foraminiferas and ostracodes, indicates a break in sedimentation. As a whole these formations are composed of sandstones with clayey and silty units and gravelly interbeds. It includes white to greenish-brown sandy units, numerous pyrite nodules, stem debris, coal lenses and is similar to the Lower-Middle Jurassic Tumlingodden Member in the north-east of Svalbard (Pcelina 1980) and the Svenskøya Formation in Kong Karls Land (Smith et al.1976).

Three Norian depositional units are clearly developed in the core from Graham Bell Island. The lower one (interval 915-750 m, with a minor 8-10 m thick intrusion at the top) is composed of dark-grey to grey siltstones and light-grey sandstones with thin mudstone interbeds, developed in two coarsening upwards sequences. The sandstones are fine-grained, with rare interbeds of medium-grained sand and dispersed clasts of gravel. Parallel lamination and wavy cross bedding prevail in the siderite cemented sandstones, where also tabular crossbedding and ripple lamination occur. This part of the section is time-equivalent to the upper part of the De Geerdalen Formation in Svalbard (the Isfjorden Formation of Pcelina 1980).

At the base of the middle cycle (interval 750-610 m) a 27 m thick mudstone unit is interpreted from the petrophysical logs. This unit is probably a time equivalent to the transgressive mudstone unit with calcite nodules, described from Cape Ganza (Wilczek Land, East central Franz Josef Land, eastern neighbour to Graham Bell Island) by Piroznikov (1958), and the Bjørnbogen Member in Svalbard (Pcelina 1980). Early Norian ammonites and bivalves were recorded from the Cape Ganza locality (Korcinskaja 1985). The upper, major part of this cycle is represented by dark grey, clayey siltstones and light grey sandstones. In the Graham Bell Island core at a depth of 650-632 m, beds of poorely sorted fine to medium grained sandstones with clasts of gravel occur. These strata are in part highly bioturbated by *Planolites*, but possible traces of *Skolithos* and *Rhizocorallium* have also been observed. Dominant parallell lamination is recorded in commonly upwards fining beds. Occurrences of siderite and pyrite nodules are common.

The upper interval (610-536? m) has not been fully cored at Graham Bell Island. According to the available petrophysical information, the lower part of the cycle consists of clayey sediments, while siltstones and sandstones are found in the upper parts.

The core pieces studied from the interval 536-546 m (core recovery only 2.4 m) probably represent the base of a new transgressive cycle (Fig. 3). Higher in the section a 35 m

GRAHAM BELL ISLAND

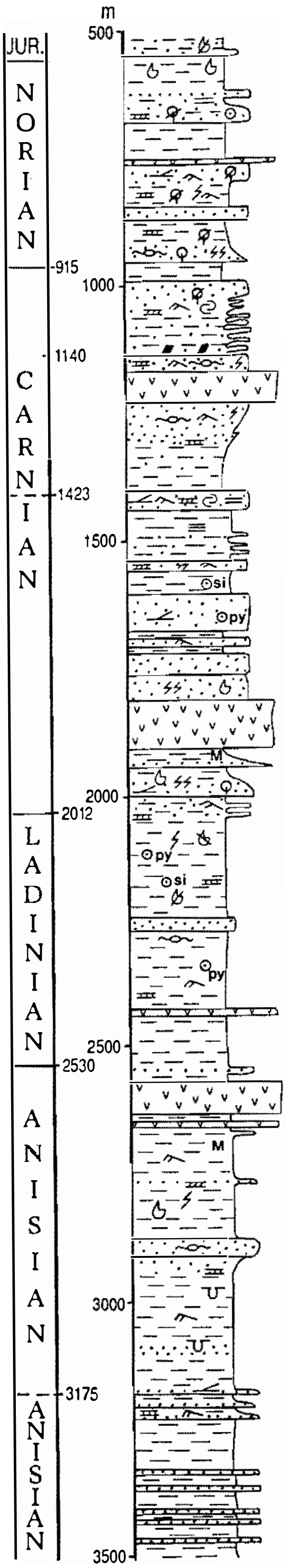

Fig. 8. Sedimentological log of the Graham Bell Island well.

thick clayey unit occurs according to petrophysical log information. Weakly lithified, dark-grey, thin-bedded clayey siltstones with thin calcareous fine-grained sandstone interbeds are typical. Along the base of the section numerous shell fragments of Early Norian bivalves and ammonites occur. The foraminifera and ostracodes, however, make up a typical Early Jurassic assemblage. An Early Jurassic reworking of Late Triassic beds is not unlikely. The Triassic/Jurassic boundary could accordingly be placed at the level of 536-538 m in the Graham Bell Island well. The succeeding Jurassic beds, in both the Graham Bell and Hayes Island wells, are most probably represented by clayey sediments.

SEDIMENTOLOGY

The sedimentary columns of the three Franz Josef Land wells can be divided into several major facies associations, characterized by common sedimentary structures and lithological compositions which are typical features for shallow marine depositional environments. In the following the various litho-facies will only be briefly summarized, since a thorough lithological presentation has already been made above.

Dark grey shales with sandstone beds

The shales are generally well-laminated, dark greyish to almost black in colour, and commonly contain shells of ammonites, accumulations of *Daonella* and other bivalves, some plant remains are found dispersed. These shales (Fig. 5) show relative high TOC contents (>1%) (Dypvik et al. 1998) and can be interpreted to represent partly dysaerobic to anaerobic depositional conditions in a middle to outer shelf setting. The depositional environments are characterized by moderate bottom water ventilation, with interbedded sandstones reflecting a possible storm/high wave origin, and periods of more turbulent bottom conditions. The sandstones contain ripple lamination and a few units with possible hummocky cross stratification (Fig. 5b), representing possibly storm-generated beds (Dypvik et al. 1991; Phillips & Swift 1985). Traces of *Chondrites* and *Planolites* have also been observed. Pyrite concretions of mm size and siderite concretions of cm size are commonly seen, while phosphate concretions are rare. The geochemical studies of Sershar (1996) show that only very few and modest P_2O_5 concentration enrichments have been found; in one Induan (1611.5 m) and one Ladinian (720 m) sample from the Alexandra Island well, and one Norian sample (542 m) from the Graham Bell Island well.

Dark grey to black shales of this type are found in the Alexandra Island Well (Fig. 4) and in the lower, Anisian-Ladinian part of the Graham Bell Island well (Fig. 8). The lithology of these shales partly resembles the Anisian interval of the Botneheia Member in Svalbard.

Interbedded shales and sandstones.

This facies association is characterized by shales with intercalated beds of fine-grained sandstones. The relative amounts of sandstone and shale vary, and these lithologies normally form coarsening upwards sequences. Intervals with increased sand content may reveal ripple lamination and hummocky cross stratification (Figs. 4, 5b, 7 and 10), indicating commonly storm-influenced sedimentation. The larger grain sizes, higher sand contents and increased number of plant fragments, compared to the dark grey shale facies association, indicate a more proximal, storm-influenced sedimentation during shallow, more ventilated bottom conditions.

This facies association is found in the upper part of the Alexandra Island well (Fig. 4), and in the lower units of the Hayes Island and Graham Bell Island wells. It represents a transitional facies of middle to inner shelf developments, somewhere between offshore clay sedimentation and nearshore marine to beach environments.

Fig. 9. Upper photo shows vertical burrow (*Monocraterion*) and bioturbated and laminated sandstones from the Carnian nearshore sediments of the Graham Bell Island well, 958 m. Scale 1:1.2. Lower photo shows rippled laminated Carnian nearshore facies from the Graham Bell Island well, 1436.4 m. Scale 1:1.6.

Sandstones

The shallow marine nearshore sandstone facies found in the wells studied, contains several trace fossil assemblages. In the more clay-rich intervals *Planolites* and *Chondrites* are typical, while *Skolithos, Helmithoidea, Zoophycos, Paleophycos, ?Teichinus, Terebellina, Thalassinoides* and *?Rhizocorallium* (Fig. 9) have been observed in the more sand-rich lithologies. The sandstone dominated facies is in addition, often characterized by the presence of ripple lamination and hummocky cross stratification.

The sandstones grouped in this nearshore facies, can be divided into at least two subfacies, representing lower shoreface and foreshore situations of possible barrier island/bar associations, comparable to the examples of Schurr (1984) and Tillman &Martinsen (1984) from the Shannon Sandstone of USA. It should, however, be noted that no structures typical of tidal activity have been observed so far in these beds.

The sandstones of the lower shoreface subfacies are associated with intervals of increased clay content, and commonly display loading structures and convolute lamination. The sandstones are typically interbedded with sandy shales and bioturbation traces of *Chondrites* and *Planolites* are observed. This facies association is found in the Alexandra Island well (Fig. 4), in the middle part of the Hayes Island well (Fig. 7), but only with dubious appearance in the Graham Bell Island well.

The sandstones attributed to the foreshore subfacies resemble the strata discussed above, but are somewhat thicker, better sorted and may contain wave ripples and planar cross bedding. In a few cases these rather massive sandstones appear homogeneous. *Skolithos* type of trace fossils are typically found in these beds. This foreshore subfacies development has been observed in the Hayes Island and Graham Bell Island wells.

Plant rich shales and associated sandstones

In the upper parts of the Hayes Island and Graham Bell Island wells, transitions towards more organic rich shales can be seen. These often highly bioturbated beds are found succeeding the nearshore (shoreface/foreshore) sandstones described above. Dispersed plant material and coal fragments are often found in these, usually dark grey, silty shales. Coarser grained strata, of both coarsening and fining upwards developments are also present. A washover fan related origin is possible, in association with a more generally lagoonal depostional environment.

This late Carnian probably back barrier, lagoonal setting, marks the end of an extensive coarsening upwards “megasequence” which lasted throughout the Middle Triassic (Anisian, Ladinian), and the lower parts of the Late Triassic (Carnian) of Franz Josef Land. The sedimentological development in the overlying Norian beds is more speculative due to the lack of cores, and interpretations based on only petrophysical logs are available. The presence of well developed coarsening upwards units, rippled sandstones and a few plant fragments, along with some *Skolithos* and *Planolites* type bioturbation, indicate nearshore/shallow shelf depositional environments.

PALEONTOLOGY

This chapter presents macropaleontological (mainly bivalves and ammonites), micropaleontological (foraminifera and ostracodes) and palynological data. The discussion focuses on the distribution of faunal and floral assemblages, combined with the stratigraphical and paleoenvironmental information derived from them. Anisian to Norian formations are descriebed from the wells studied. According to Dibner (1998) the Norian-Rhaetian outcrops are overlain by Lower Jurassic beds, which only can be distinguished by detailed palynological analyses.

Macrofossil assemblages

Previously only Late Carnian-Norian, predominantly non-marine deposits and Early Norian marine strata were known from the surface exposures of Franz Josef Land. The fossil assemblages obtained from the studied core samples, demonstrate unique subsurface occurrence of the Induan(?), Early Olenekian, Late Anisian, Ladinian, Early Carnian and Early Norian formations.

During the Triassic, Franz Josef Land together with North-East Asia, Svalbard and Arctic Canada belonged to the Boreal zoogeographic province. In general, the ammonites and bivalves observed in the Franz Josef Land wells are characteristic of synchronous deposits of North-East Asia, although some endemic bivalve species are also recorded.

Early Triassic

The presence of Induan strata in the Alexandra Island well is suggested by the occurrence of fish remains, depth 1610-1616 m, belonging to *Boreichthys shkolai* Selezneva. Comparison of these fossils with other representatives of the family Colobodontida clearly indicates a Triassic age for the enclosing strata (Selezneva 1982). The position of these strata, far below Olenekian dated deposits, suggests an Induan age.

Early Olenekian deposits are identified by disarticulated shells of the bivalve *Posidonia* cf. mimer Øberg at a depth of 1126.5 m in the Alexandra Island well. The species is widespread in Early Olenekian (Smithian) deposits in all regions of the Boreal realm. Late Olenekian (Spathian) sediments were not found, and their probable absence can be explained by the disconformity between the Early and Middle Triassic in the Alexandra Island well.

Middle Triassic

Early Anisian fossils were not found in the analysed cores, while Late Anisian is observed both in the Graham Bell Island and Hayes Island wells. The Late Anisian is best documented in the Hayes Island well, where the first appearence of *Daonella dubia* Gabb is observed at 3204 m depth, while the ammonite *Gymnotoceras* sp. (= G. cf. *lagueatum* Bytschkov)(Korchinskaya 1985) is present at level 3154m. In an even higher interval, 3044-3074 m, the ammonites *Frechites* cf. *nevadanus* Hyatt and Smith and *Frechititoides* (= *Beyrichites*) migayi Kiparisova are found associated with the bivalves *Mytilus* cf. *eduliformis* Schlotheim and *Daonella dubia* Gabb.

The position and faunal composition of the last two fossil occurrences indicate that the Hayes Island well contains analogues of the Late Anisian *Frechites nevadus* and *Gymnotoceras* rotalliformis zones of North-East Asia. These two zones are readily correlated with the *chisha* and *deleeni* zones, respectively, of the Late Anisian of Canada. In Svalbard the F. nevadus Zone corresponds to the F. lagueatum Zone, while an analogue to the G. rotelliforme Zone has not been found (Dagys & Weitschat 1993; Weitschat Dagys 1989).

In the Hayes Island well at a level of 2740 m an assemblage consisting exclusively of bivalves, contains the following species: *Bakevellia* sp.nov., B. cf. *ladinica* Kurushin, B. cf. *lapteviensis* Kurushin, *Dacriomya scorochodi* Kiparisova, *Mytilus* cf. *eduliformis* Schlotheim, *M. hayesensis* Korchinskaya and *Meleagrinella* sp. This stratigraphical level is referred to Late Anisian, although the correlation is somewhat provisional, because ranges of the species extend below and above this substage. The assemblage consists mainly of infaunal and epifaunal attached species, which were confined to well ventilated, marine shelf waters.

A bivalve assemblage, similar to that one described above, is found in the Graham Bell Island well at level 2838-2778 m. It contains *Daonella* cf. *dubia, Mytilus_eduliformis, Neoschizodus* cf. *laevigata* Zietel, *Dacryomia scorochodia* and *Bakevellia* sp. (Campbell 1994).

The Ladinian deposits of the Franz Josef Land wells are characterized by comparatively rich assemblages of *Daonella.* Typical boreal representatives of this genus in the three wells are: *D. subarctica* Popov, *D. prima* Kiparisova, *D.* aff. *prima* Kiparisova, *D. frami* Kittl and *D.* cf. *nitanae* McLearn. A peculiar feature of the assemblages is that this geneus is represented by oppressed forms. A common feature for all three wells is also the abundance of the typically small species D. *parva* (Korchinskaya 1985). The shells of this species usually form nest-like accumulations, while the larger species (as *D. subarctica* and *D. prima*) occur as single shells. In the Graham Bell Island well species of *Daonella* are associated with a few occurrences of *Nathorstites* cf. *lenticularis* (Whiteaves), an ammonite typical of the Late Ladinian Substage.

Fig. 10. Finely laminated fine sand, silt and shale, cut by a calcite filled fracture in the Carnian nearshore sediments of Graham Bell Island well, 1164.8 m. Scale 1: 0.7.

Late Triassic

The macrofossil record documenting the Carnian is rather poor. At the base of the supposed Carnian interval in the Graham Bell Island well poorly preserved shells of *Entolium* sp., *Paleopharus* sp. and *Cardinia (?)* sp. occur. Approximately about 60 m above the base of the interval (depth 1950 m) the shells of *Halobia* cf. *korkodonica* Polubotko, a species described from the Early Carnian of North-East Asia (Polubotko 1980), were recorded.

The presence of Early Norian marine deposits is indicated by occurrences of *Halobia* cf. *aotii* Kobayashi and Ichikawa in the Graham Bell Island well (level 537 m) (Campbell 1994). The species was originally described from Carnian-Norian strata of Japan, but is also well known from the Early Norian of North-East Asia. This horizon of the Graham Bell Island well in addition contains a fragmentary ammonite, *Pterosirenites* sp. (Dagys & Weitschat 1993). The horizon is possibly correlative with an exposure (Capa Ganza) on Wilczek Land containing a similar fauna (Korcinskaja 1985), originally attributed to the Early Carnian (Popov 1958).

So far, the youngest Triassic substage recognized in Franz Josef Land is the Early Norian. The presence of Middle to Late Norian and Rhaetian is not yet proven recognized on the basis of macrofossil evidence.

Microfossil assemblages.

The first data of Triassic microfaunas of from Franz Josef Land were published by Dibner & Sedova (1959). A few papers devoted to microfossils appeared after the completion of the three wells discussed here (Kasatkina 1985, 1991; Preobrazenskaja et al. 1985a, 1985b). In the present study about 250 samples were selected for microfaunal analyses. Both slides and thin sections were inspected for microfossils, but most of the samples were barren of both foraminifers and ostracodes.

In general, Triassic foraminifera assemblages of Franz Josef Land are poor, both with regard to assemblage size and richness in taxa. Primitive agglutinated species of *Saccammina*, *Hyperammina*, *Ammodiscus* and *Glomospira*, commonly with small, fine-grained, poorly preserved shells prevail. Calcareous taxa are rare, and identified species belong to the nodosariid genera *Pseudonodosaria*, *Nodosaria*, *Dentalina* and *Marginulina*. This faunal trend changes somewhat in the Late Ladinian, when calcareous forms play a more significant role.

Induan-Olenekian.

Thin section from Induan sediments of the Alexandra Island well from 1610 m revealed single tests of *Saccammina* sp. juv. and Polymorphinidae(?) gen. et sp. ind. The interval 1539.1-1546.1 m contains (in thin sections) *Psammosphaera* sp., *Turritellella* aff. *mesotriassica* Kochu-Zaninetti, *Reophax* sp., *Spiroplectammina*(?) sp., *Digitina* sp., *Pseudonodosaria* sp., *Nodosaria* spp., N. ex gr. *crotovi* (Tscherdynzev) and *Dentalina* sp.

These assemblages, which include relatively abundant calcareous species, suggest marine inner shelf conditions, not very favourable for foraminifera. Similar associations, consisting of simple agglutinated taxa, are known from Induan deposits of northern central Siberia (Bulatova 1984).

In the Olenekian deposits of Franz Josef Land microfossils have not been found. It should be noted that in Olenekian strata of Kotelny Island foraminifera are practically absent except for rare tests of *Ammodiscus* cf. *filiformis* (Reuss).

Anisian-Ladinian.
An *Ammodiscus* sp.-*Lagena* sp. assemblage is recognized in Late(?) Anisian deposits of the Hayes Island well, in the interval 2851.5-3207.0 m (Kasatkina 1991). In thin-section, the assemblage is relatively diverse (compared to the Early Triassic faunas), and consists mainly of agglutinated taxa with small and fine-grained test. Observed species include *Psammosphaera* sp., *Saccammina* sp., *Hyperammina* sp., *Ammodiscus* sp., *Glomospira* ex gr. *gordialis* (Parker and Jones), *Turritellella* sp., *Comuspira* sp., *Reophax* sp., *Haplophragmoides*(?) sp., *Ammobaculites* A (?) sp., *Textularia* sp. and *Lagena* sp.

The Hayes Island well, at a depth of 2853.8 m, contains the ostracod *Ogmoconchella ordinata* Gerke & Lev, a species initially described from the Carnian of the Nordvik region (Northern part of Anabar Bay, Eastern Siberia). Absence of calcareous foraminifera and dominance of simple agglutinated forms indicate a shoreface/inner shelf depositional environment.

Samples from the Alexandra Island well at 1009.4 m and 1010.5 m contain rare *Haplophragmoides* sp., *Trochammina*(?) sp. and undeterminable tests of other agglutinated taxa. The interval 937.5-944.5 m containing Late Anisian and transitional Anisian-Ladinian palynomorphs, also includes single tests of *Ammodiscus* sp. and *Haplophragmoides* sp. associated with rare fragments of nodosariids.

In the Graham Bell Island well single sections of *Lagena*(?) sp. and *Pandoglandulina*(?) sp. were found in a sample from 2686.6 m. The Late(?) Ladinian *Ammodiscus* ex gr. *filiformis* - nodosariid assemblage was established both in disintegrated samples and in thin-sections in the Alexandra Island well through the interval 509.0-934.5 m. The assemblage may be further subdivided into the following three associations:

1. The lower association with relatively numerous and diverse nodosariids is developed in the interval 860.5-934.5 m. It is characterized by very small and fine-grained agglutinated tests of species belonging to *Ammodiscus*, *Haplophragmoides*, *Ammobaculites* and *Trochammina*. Other typical components are very small and often broken tests of uniserial nodosariids, such as *Lagena* sp., L. ex gr. *pseudoclavata* Gerke, *Nodosaria* spp., *N.* ex gr. *subprimitiva* Gerke, N. ex gr. *biloculina* Franke, N. ex gr. *claviformis* Terquem, *Dentalina* spp., D. ex gr. *quadrata* Issler, D. ex gr. *tortilis* Franke, *Lingulina* sp., L. ex gr. *laevissima* (Terquem) and *Marginulina* spp., etc. The composition of the fauna indicates an open middle to inner shelf environment, but the stunted character of the assemblage suggests unfavourable conditions i.e. low salinities or reduced oxygenation. The same interval (861.5-934.5 m) contains rare shells of the ostracodes *Ogmoconchella* ex gr. *ordinata* Gerke & Lev, *O.* ex gr. *acuta* Gerke & Lev, *Ogmoconcha*(?) aff. *limbata* (Reuss), *Triassocypris*(?) sp. and *Acratia*(?) sp. Among these, *O. limbata* is known from the Ladinian of north-east Alaska, while such genera as *Triassocypris* and *Acratia* are Tethyan faunal elements.
2. This association of small and fine-grained agglutinated taxa with low diversity characterises interval 562.4-797.8 m. It includes *Ammodiscus* sp., A. ex gr. *filiformis* (Reuss), *Glomospira* sp., *Turritellella* sp., *Comuspira*(?) sp., *Reophax* sp., *Haplophragmoides* sp., *Ammobaculites* sp., *Recurvoides* sp., *Trochammina* sp. and *Vemeuilinoides* sp. The upper part of the interval contains rare shells of the ostracodes *Ogmoconchella acuta* Gerke & Lev, *O. ordinata* Gerke & Lev, *O. fabacea* Gerke & Lev.

The composition of this association presumably indicates a change from open shelf to more near-shore conditions. The Upper Ladinian deposits of the Hayes Island well in the interval 2033.0-2049.9 m contain rare tests of *Ammodiscus* sp., *Glomospira* sp., *Reophax* sp., *Haplophragmoides*(?) sp., *Ammobaculites* sp., *Recurvoides* sp. and *Trochammina* sp., associated with single shells of the ostracodes *Gavussurella* sp. and *Ogmoconcha uniserata* Sohn (level 2049.9 m). The last species is known from the Shublik Formation (Ladinian - Norian) of north-eastern Alaska, while species of Gavussurella are recorded from Late Ladinian - Early Carnian deposits of the north-western Barents Shelf (Hochuli et al. 1989). This association can probably be correlated with the fauna found in the Alexandra Island well through the interval 562.4-797.8 m.

3. The *Ammodiscus* cf. *filiformis-Dentalina* ex gr. *tortilis* association was recognized in the Alexandra Island well in the interval 509.0-516.0 m (Kasatkina 1985; Preobrazenskaja et al. 1985a). It is characterized by the reappearance of calcareous foraminifera, though in rather subordinate amounts. The association includes *Saccammina* aff. *inanis* Gerke & Sosipatrova, *Psammosphaera* cf. *bulla* Voronov, *Hyperammina* sp., H. aff. *affectus* Voronov, *Ammodiscus* ex gr. *filiformis* (Reuss), A. aff. *septentrionalis* Gerke, *Glomospira* ex gr. *gordialis* (Parker & Jones), *Haplophragmoides* sp., *Ammobaculites* sp., A. aff. *trochaminoidiformis* Gerke (in coll.), *Recurvoides* sp., *Trochamminoides*(?) sp., *Gaudryina* aff. *triassica* Trifonova, *Nordosaria* sp., *Dentalina* sp., D. aff. *vetustissima* Orbigny, D. ex gr. *tortilis* Franke and the ostracodes *Cytherella*(?) sp., *Ogmoconchella acuta* Gerke & Lev, O. *ordinata* Gerke & Lev. The composition of this association indicates shallow inner shelf environments.

It is likely that the assemblage with nodosariids and numerous ostracodes recorded from the interval 1767.8-1894.8 m of the Hayes Island well (Kasatkina 1985, 1991; Kasatkina & Fefilova 1990) corresponds to the third association of the Alexandra Island well described above. The dominance of calcareous foraminifera indicates normal marine conditions.

In the Graham Bell Island well one ostracod shell named "Healdia" sp.1 (Sohn 1987) occurs at 2147.6m. The species was initially recorded from the Shublik Formation (Ladinian-Norian) of Alaska. The Late Ladinian associations of Franz Josef Land reveal several compositional affinities with the Late Ladinian *(Nathorstites macconelli* Zone) *Dentalina* cf. *splendida* - *Pseudobolivina* sp. assemblage of Svalbard, recorded by Kasatkina & Fefilova (1990). Uniserial nodosariids and small, thin-walled tests of ammodiscids dominate the Spitsbergen association, which is regarded to indicate normal marine conditions.

Carnian - Norian

The Carnian to (?) Early Norian *Marginulinopsis* ex gr. *prima* - *Dentalina gladioides* assemblage was established in samples taken from surface outcrops on Wilczek Land (Kasatkina 1991). Its salient feature is dominated by various nodosariids, including Nodosaria ex gr. mitis (Terquem & Berthelin), *Dentalina gladioides* Gerke, D. ex gr. *tenuistriata* Terquem, *Neogeinitzina* ex gr. *alaskensis* (Tappan), *Marginulinopsis* ex gr. *prima Orbigny* and *M.* aff. *bergquisti* Tappan, etc. The composition of the assemblage is similar to Western European faunas. The abundance and diversity of nodosariids in the Wilczek Land assemblage reveal an optimal environment for calcareous foraminifera, although in rather cold waters. The assemblage reflects the culmination of normal marine shelf conditions during the Induan to Norian history of the Franz Josef Land area.

The Early (?) Norian *Dentalina* ex gr. *matutina* - *Vaginulinopsis* spp. assemblage occurs in the Graham Bell Island well, interval 535.0-545.0 m. Nodosariids dominate in this association, while agglutinated forams are represented by a few tests of *Ammodiscus* sp. *Glomospira* sp. and *Textularia* (?) sp. Among the calcareous forms *Nodosaria* spp., N. ex gr. *columnaris* Franke, N. ex gr. *radiata* Terquem, *Frondicularia* aff. *brisaeformis* Bornemann, *Dentalina* spp., D. ex gr. *matutina* Orbigny, *Astacolus* spp., *Marginulina* spp., *Marginulinopsis* spp., *Vaginulinosps* spp. and *Saracenella* (?) sp. were found. All tests are of a "normal" size in contrast to the very small, oppressed shells composing the Early through Middle Triassic associations. The composition of this assemblage resembles European Early Jurassic associations. The 535.0-545.0 m interval additionally contains several shells of the ostracodes *Ogmoconchella* aff. *danica* Michelsen, *Ogmoconcha* aff. *pseudospina* Hervig & Klingler 1962; morphologically close to species described from Early Jurassic open shelf environments (Hettangian-Pliensbachian) of Europe.

Palynology

Material.

The three wells were covered by a total of 86 samples, with 17 samples from the Alexandra Island well, 39 samples from the Hayes Island well, and 30 samples from the Graham Bell Island well. Due to the limited number of samples and the partly low productivity, no continuous stratigraphical breakdown can be established on the basis of palynological data. The interpretation must be regarded as identification of certain characteristic horizons. The final correlation is therefore based on a broad lithostratigraphical subdivision of the sections within the framework defined by fossil distribution.

Alexandra Island well

Seventeen samples were examined from this well covering the inteval 565-1022.5 m. Diagnostic assemblages were recorded giving an Early Carnian to Ladinian age. *Illinites chitinoides* occurs as a common element throughout the interval in association with *Camarozonoporites rudis* and *«Eochasmatosporites» magnus.*

Hayes Island well

The 39 samples examined from this well covered the interval 761.6 m to 3225.5 m.

Anisian

The deepest samples produced assemblages too poor for a reliable age assignment. The presence of *Duplexisporites problematicus* down to 3048.5 m suggests, however, an Anisian age at least down to this level.

The downhole appearance of assemblages characterized by the acritarch genera *Veryhachium*, *Leiofusa, Baltisphaeridium* and *Micrhystridium* at 2018 m, is taken as evidence of an Anisian age from this depth (next sample higher at 1900 m). This is supported by the downhole appearance of *Aratrisporites tenuispinous* at 2049.2 m.

Ladinian

The presence of the Ladinian is demonstrated by the occurrence of *Echinitosporites illiacoides* at 1900 m. The downhole appearance of several varieties of *Aratrisporites* (including *A.Macrocavatus, A.wollarinensis*) at 1802 m , probably represents the increased representation of this genus known to characterize the Ladinian.

Carnian
The uppermost samples at 761.6 and 785 m produced assemblages with abundant *Dictyophyllidites mortonii* associated with *Leschikisporis aduncus, Iraquispora speciosa, Zebrasporites interscriptus* and *Camarozonosporites rudis.* The age of these assemblages is regarded as Late Carnian.

A Carnian age is also demonstrated by the downhole appearance of *«Eochasmatos-porites» magnus* and *Triadispora verrucata* at 1026 m.

An Early Carnian age is assigned to the assemblages recorded at 1386.5 m and 1442.3 m with the downhole appearance of *Podosporites amicus* and *Illinites chitinoide.* The presence of *Camarozonosporites laevigatus* down to 1442.3 m supports an age no older than the Carnian at this depth.

Graham Bell Island.
??Anisian
Assembalges recorded below 2739 m were too poor for a reliable dating. At 2423 m the presence of characteristic specimens of *Leiofusa* spp. may suggest an Anisian age, probably correlating with the 2018 m level in the Hayes Island well.

Carnian
Samples between 2423 m and 1423 m produced non-diagnostic assemblages. At 1423 m a relatively rich assemblage containing *«Eochasmatosporites» magnus* and *Illinites* spp. suggests an Early Carnian age. A Late Carnian age is demonstrated for the interval 871.7 to 1138.5 m with abundant *Leschikisporis aduncus* and *Dictyophyllidites mortonii.*

Norian
The interval 538 m to 799 m has been assigned to the Norian. Diverse and diagnostic assemblages were recorded over this interval. The uppermost part is dominated by abundant *Veryhachium* spp. and *Annulispora folliculosa*. A maximum in *Iraquispora speciosa* was recorded at 647.8 m. The maximum in *Protodiploxypinus ornatus* at 799 m suggests an Early Norian age at this level.

DISCUSSION AND CONCLUSIONS

In the late Permian through Triassic times the basinal development of the Timan Pechora Basin and the eastern Barents Sea area (Fig. 1) were primarily controlled by the formation of the Ural Mountain Belt (Morachovskaja et al. 1977; Ulmishek 1982; Ustrickij 1981). This is reflected by the termination of marine sedimentation along the developing mountain chain. In the Alexandra Island borehole a major break is found between early Triassic and Carboniferous beds, reflecting episodes of uplift and erosion, a possible response of the plate collision and mountain building in the Ural to the south-east. The wells from Hayes and Graham Bell islands represent more complete stratigraphical sections, with the 3400 m to 3500 m of Anisian to Upper Triassic beds. In outcrops on the neighbouring islands Triassic beds are overlain by Lower Jurassic units (Dibner 1998).

Based on the paleontological and sedimentological information presented on the preceding pages it has been possible to correlate internally the three wells (Fig. 3), as well as to give a possible correlation to the well known succession on Svalbard. The correlation lines show sedimentological ties and explain mutual facies relations. Based on these stratigraphical analyses the relative thin, but shale dominated Alexandra Island successions generally display more distal, open shelf depositional conditions, however with possible severe breaks, compared to the other two, more complete, sand-rich eastern wells (breaks at Olenekian/Anisian, Carnian ?/Ladinian, post Carnian). The Hayes Island well may represent the most marginal position, at least in the Anisian part of the successions.

The established stratigraphical developments indicate an overall regressive Anisian to Carnian evolution, internally composed of minor trangressive and regressive developments. During the same interval in Svalbard, possibly two sedimentary progradations from the west were succeeding fast transgressions.

The marine shelf deposits of Franz Josef Land are typified by strong terrestrial influence in their palynological assemblages, and show highly internally comparable micropaelontological, macropaleontological and palynological stratigraphical zonations. In the Alexandra Island well, where the oldest Triassic beds are encountered (Fig. 3), an Early Triassic transgressive development is succeeded by an Olenekian/Anisian unconformity. This break in sedimentation is followed by a general Anisian/Ladinian regressive development.

The Anisian succession of the Hayes and Graham Bell islands, time-equivalent to the Botneheia Member of Svalbard, is characterized by possible transgressive intervals, internally including minor regressive units. The normal marine, paelontological composition, displayed in both macro- and microfossils is also underlined by the paleoenvironmental intepretation. The samples from the Hayes Island generally seem coarser grained and with a lower pyrite content compared to samples from the other two wells, indicating more ventilated, possibly marginal depositional environments. The Ladinian to Carnian beds are in both Hayes Island and Graham Bell Island wells recognized by a transition from marine dominated deposition towards more nearshore and even lagoonal environments. The succeeding Norian beds again display more open marine conditions than the coastal Carnian beds below.

The organic geochemical studies by Dypvik et al. (1998) indicate complex organic maturity distributions, which have been interpreted to indicate minor intra-Triassic breaks in sedimentation in addition to an overall, about 700 m post-Triassic, erosion. Dypvik et al. (1998) estimated the Olenekian/Anisian break in Alexandra Island to represent about 600 m of erosion, while there is a possible 500 m sequence lacking above the Anisian in the Hayes Island well.

Paleogeography and correlation

The grey, siliciclastic Triassic sediments in Franz Josef Land were deposited during relatively warm and humid climatic conditions (Ulmishek 1985), and a possible 45-60°N Triassic paleo-latitude, as suggested for Svalbard (Mørk et al. 1982), seems likely. During that period the eastern part of the archipelago clearly represented a basin with a high sedimentation rate. Here a 5 km thick succession was formed (Dibner 1998), compared to the possible 1.2 km of Svalbard (Mørk et al. 1982). The western part of the archipelago represents a tectonically more active area, reflected by discontinuous sedimentation (Dibner 1998). Dibner(1970) suggests a northwesterly, northerly and easterly source area for the Triassic-Liassic sections of Franz Josef Land. In contrast, Preobrazenskaja et al. (1985a, 1985b) in their study of the sequential building of the Triassic successions, emphasize the increased grain sizes and polymictic character of the sediments towards the east, and suppose a sedimentary source area in that direction. The present study supports this view, but suggests a possible additional minor, more northerly provenance.

During Induan, succeeding the late Permian break in deposition, marine shelf sedimentation dominated in the western part of archipelago, comparable to the circumarctic early Triassic transgression of Mørk et al. (1989). During comparatively shallow marine conditions, a succession of predominantly clayey and silty-clayey deposits was formed. At the end of the Induan, during a regressive development, thin interbeds of fine-grained sand with plant detritus and rare floristic remains were formed. The Induan sea was populated with fishes, foraminifera, scarce bivalves and abundant algae. The stage is represented by relatively homogenous sequences of shales and shaly siltstones. Interbeds of calcareous mudstones are commonly found, often with thin layers of siltstone, most likely of storm origin. These facies developments continued upwards into the gradually shallowing Olenekian succession, which is characterized by scattered bivalves, foraminifers and algae. These regressive developments can very well be correlated with the time-equivalent evolution of the Vardebukta (Induan) and Tvillingodden (Olenekian) formations of Svalbard (Mørk et al. 1982, 1989). The Tvillingodden Formation and the distal equivalent, the Sticky Keep Member, form in Svalbard a well developed coarsening upwards succession within a dominant dark grey shale unit characterized by types III and II kerogen (Mørk & Bjorøy 1984). The comparable Early Triassic shales from Franz Josef Land are typically of type III composition and suggests more terrestrially influenced sedimentation.

The early Triassic sedimentation took place during stable, marine conditions (Vojcechovskaja 1985). The post-Olenekan break which lasted into the Anisian, was succeeded by a transgressive Anisian episode that can be correlated to the circumarctic Anisian transgression of Mørk et al. (1989). Preobrazenskaja et al. (1985a) claim the early to middle Triassic to be dominated by marine to lagoonal depositional conditions. The organic geochemisty data published by Vojceschovskaya (1985) show differences in composition between the Graham Bell Island well and Alexandra and Hayes islands, the samples from the Graham Bell Island core being more oxidized. This match the presents palynological indications of possibly more shallow marine Anisian beds in the Graham Bell Island core. The Anisian palynomorphs, however, normally show poor preservation.

During Middle Triassic times (middle to late Anisian) the eastern part of the archipelago was characterized by rather stable, uninterrupted, shallow marine shelf sedimentation. The faunas, both micro and macro, suggest normal marine depositional conditions. Varying hydrodynamical conditions resulted in rhythmic sedimentation of mostly clayey, silty-clayey deposits with interbeds of clayey-silty and silty-sandy beds. In all three wells the Anisian generally shows fining upwards transgressive developments, but each are internally made up of several minor regressive units. Compared to the commonly anoxic depositional conditions of the Botneheia Member of Svalbard, the dark grey Anisian shales of Franz Josef Land display more ventilated deposition of less organic rich and more bioturbated silty clays. They have lithologically more in common with the Tschermakfjellet Formation claystones of Svalbard, typical of more terrestrially influenced sedimentation. Pcelina (1972) and Mørk et al. (1990) have described similar relations in the Skuld Formation of Bjørnøya. Only a minor bed at level 2370 m in the Hayes Island well shows characteristic black, laminated shales, high in TOC (10.9%) and with type II kerogen. The rest of the 185 samples analysed shows low TOC values and kerogen of type III and IV (Dypvik et al. 1998).

This clearly indicates the very easterly limits of the fringes of the «Botneheia basin» towards more ventilated, terrestrially influenced Anisian sedimentation. The increased circulation of the watermasses may be the result of shallowing of the basin, increased storm influence as well as a more marginal basinal position closer to the clastic source araeas. The Bravaisberget Formation (Mørk et al. 1982, 1989) forms the coarser clastic, terrestrially dominated westerly equivalent to this famous "Botneheia" basinal domain.

During the numerous minor regressive Anisian developments increasingly more silty/sandy deposits with ripple, undulating and parallel lamination are seen, in addition to hummocky cross stratifacation and parting lineation. The structures show the increased importance of both current and wave/storm activity in the coarser grained beds. Periods characterized by high rates of sedimentation, resulted in intervals showing synsedimentary deformation structures as well as load casts, ball-and-pillow structures and dish structures. During the regressive development of the upper half of the Anisian succession present, a unit of poorly sorted silty-sandy and silty-clayey strata, with conglomeratic lenses enriched in plant detritus, were deposited. These sediments, with hummocky cross bedding and intraformational clay clasts, are in accordance with the relative high energy that controlled much of the sedimentation, including formation of storm-beds, in a highly ventilated shelf sea. The content of sand in these commonly bioturbated beds (*Thalassinoides*, *Chondrites*, *Terebellina?*) is highest in the Hayes Island well. Maximum thicknesses have so far (lower limitations not known) been found in the Graham Bell Island core, where the shale dominated succession indicates outer shelf depositional environments. The Anisian sea was populated by sparse faunas of bivalves, ammonites, foraminifera, echinoderms and a diverse algal flora, in a well ventilated, marine depositional environment.

The thickest Anisian succession have been observed in the central and eastern parts of the archipelago, in the Hayes Island well 1180 m and in the Graham Bell Island well 2000 m. Probably syncronously with the maximum Late Anisian uplift of the archipelago, as demonstrated by the about 500 m erosion at the top of the Anisian in the Hayes Island well, the western paleohigh subsided (Alexandra Island area) and the sea transgressed the region. It is supposed that about 30 m of finely laminated Anisian shales and calcareous muds with foraminiferas, accumulated in the west (Alexandra Island).

The early Ladinian transgression expanded over the archipelago, as all over Arctic as indicated in the Sverdup Basin (Embry 1988) and in Svalbard (Mørk et al. 1989; Mørk 1994). It is developed in the Graham Bell Island core at level 2500, while the possible intra Anisian T2/T3 sequence boundary of Van Veen et al. (1992) (SB1 of Rasmussen et al. 1992) may occur at level 2800 in the Graham Bell Island core and possibly at 2500 in the core from Hayes Island.

The facial zonality continued through Anisian, a parallel to the development in Svalbard. In the eastern area predominantly clayey and silty beds, with higher sand contents in the uppermost beds, were deposited during shallow marine conditions. The beds consist of laminated silty shales rich in fossils (*Daonella*), organic matter and pyrite, visually resembling the Botneheia Member (Barentsøya Formation) in Svalbard, but with a poorer kerogen quality (type III) (Dypvik et al. 1998). The Early Ladinian micropaleontology of the Alexandra Island well indicates extreme or changing environmental conditions, e.g. reduced salinities or reduced oxygen content in the water masses.

The succeeding Late Ladinian regression, which began in the second half of the stage, can be correlated with the De Geerdalen Formation of Svalbard. It is clearly reflected by upwards increasing contents of sand, silt, plant detritus and coal fragments. When comparing the organic matter of the Ladinian from Franz Josef Land with that from Svalbard, several similarities are apparent. Both areas show high terrestrial input, moderate to low kerogen quality and suggest shallow shelf conditions.

The silt and sandstones are rich in plant fragments, and commonly show bioturbation (*Planolites, Chondrites, Thalassinodes*), ripples, undulating lamination and hummocky cross stratification. In the more sandy beds cross bedding occur. Some of the sandstone units also form fining upwards developments.

The marginal or more high energetic depositional conditions are found in the uppermost Ladinian in the Hayes Island well, characterized by *Skolithos* and *Rhizocorallium*, and several unidentified ichnofossils. Vojcechovskaja (1985) claims the Ladinian of Hayes Island to represent unstable hydrochemical conditions, with high planktonic blue green algal productivity. It can, however, be suggested that the boundary between Carnian and Ladinian beds should be drawn somewhat higher in the Graham Bell Island, above level 2012 m. In that case the young, shallow marine beds are correlative with the similar deposits in the Hayes and Alexandra islands.

In the western and eastern parts of Franz Josef Land the composition of the Ladinian succession is to some extent different from that of Hayes Island. In the west and east predominantly clayey deposits accumulated during the Ladinian, and the stage makes up a regressive silty unit. Parallel lamination is common in the lower parts and possible wave ripples and hummocky cross stratification in the upper part, characteristic of shallow-marine environments. The finer grained appearance may indicate somewhat deeper conditions than in the central locations.The Ladinian basin of the Franz Josef Land archipelago was populated by bivalves, rare ammonites, ostracodes, foraminifera and several algal species. In the Late Ladinian the calcareous foraminifera group starts to develop to an important part of the microfaunal assemblages. Most typical of this basin, however, are the echinoids and oppressed thin-walled *Daonellas*, numerous in some of the early Ladinian layers.

In Svalbard the Ladinian-Carnian includes a clearcut boundary between the Bravaisberget Formation (Botnheia Member) and the Tschermakfjellet Formation, which is a change from fine grained bitumenious anoxic shales to more silty, terrestrially dominated, partly prodeltaic shales (Mørk et al. 1982, 1989). On Franz Josef Land no such changes were developed and a general "Tschermakfjellet" type facies dominates.

Significant paleogeographical changes that took place in the paleo Barents Sea shelf situation at the Middle - Late Triassic transition (Ladinian - Carnian boundary), may be connected to the circumarctic, Early Carnian transgression (Embry 1988; Mørk et al. 1989). In the central and eastern parts of Franz Josef Land the stable marine sedimentation ended in Ladinian, while the first Carnian sediments were formed during a shallowing development, a part of the regressive regime which started in Late Ladinian.

The Early Carnian transgression was weakly developed in the archipelago, possibly in the Graham Bell Island core at level 1800 m, forming a thick, marine, bivalve-bearing succession of poorly-sorted clayey silty deposits. The Ladian/Carnian boundary is located somewhat lower in the Graham Bell Island core, at level 2012 m and could possibly be correlated to the boundary between sequences T3 and T4 of Van Veen et al. (1992). Ulmishek (1985) claims that the marginal marine configuration of this part of the Franz Josef Land succession may resemble the upper parts of the Tschermakfjellet Formation in Svalbard (Mørk et al. 1982). The coarsening upwards sequences clearly look similiar, but their texture displays more wave and open basinal influence. The early transgressive development was succeeded by a general regressive Carnian evolution, expressed in nearshore sedimentation. During Carnian mainly coarse, sandy material with grains of gravel and a few bivalves accumulated in the east (Graham Bell Island). Early Carnian palynomorphs are recorded from the Graham Bell Island well, while possible Middle Carnian marine to marginal marine palynomorphs characterize the Hayes Island samples (around level 1100 m).

In contrast to the deltaic origin of the Svalbard succession (Mørk et al. 1982, 1989) a more barrier island related enviroment can be suggested for the Franz Josef Land area. Sedimentary rhythms composed of sands, silts and clays with interbeds/lenses of coaly clays dominated. In the upper, coal bearing beds, ripples, convolute lamination, bioturbation with traces of *Skolithos*, ?*Teichichnus* are typically found in the Hayes Island and Graham Bell Island wells. In Graham Bell Island the upper Carnian shows dispersed red staining of iron oxides. It is of interest to note that the ripple crests have been observed stained, showing partial exposure for air and local oxidation. Several coarsening upwards sequences, normally about 6 m thick, are very well developed, especially in Graham Bell Island.

The Carnian basin was populated by relatively few marine bivalves and a diverse algal flora. Vojcechovskaja (1985) suggested reduced marine influence in the depositional area during Upper Triassic, as indicated by apperance of thin coals (found in Hayes Island). Our palyonlogical investigation of the Late Carninan in Hayes Island also supports well a non-marine, possibly delta-top origin, in accordance with the red staining occurring in comparable beds in Graham Bell Island. Preobrazenskaja et al. (1985a, 1985b) claim this to be the case in all three wells, while Vojcechovskaja (1985) says that especially in the Graham Bell Island well a transition between marine and lagoonal conditions is shown by the mixture of carbonatized phytoplankton and coal remains. A period is characterized by transition from marginal marine to more deltaic conditions. This to some extent also matches the indications of Dibner et al. (1962), the exsistence of a possible high between Svalbard and Franz Josef Land at that time.

It should be mentioned that this Late Carnian shallowing and erosion, as seen in the Alexandra Island cores, could represent the opposite side of the easterly sedimentary source area that suddenly appears in the Svalbard region (Birkenmajer 1981; Mørk et al. 1982, 1989) at the time of the deposition of the De Geerdalen and Wilhelmøya formations.

Late Triassic deposits have not been recorded in the western part of Franz Josef Land. It is, however, possible that late Ladinian and early Carnian may have been deposited but was later removed by erosion, as reflected in Ladinian bivalves, spores and pollen observed in cuttings from 447 m in the Alexandra Island well. The petrophysical logs indicate a rather homogeneous, regressive claystone unit topped by sandstones, possibly resulting from a later reworking phase. According to Preobrazenskaja et al. (1985a, 1985b) the uppermost cycles in all the three wells show transitions from marine to more lagoonal - coastal conditions. Ulmishek (1985) suggests that a large sedimentary source developed in the northern part of the paleo Barents Sea at this time, and that this area had a great influence on the sedimentation.

In the Norian a transgressive phase marks the of change in sedimentation from the Carnian coal-bearing terrestrial domain, towards more inner shelf nearshore conditions. This is clearly developed in the Graham Bell Island well and can be correlated with a similar development in the Sverdrup Basin and the MFS between sequences T4 and T5 of Van Veen et al. (1992). According to Ulmishek (1985) the importance of the northern source was reduced at this time. Once again our palyonlogical analyses of Graham Bell Island samples show shallow shelf assemblages. This stage is made up of a short transgressive period containing some shallowing episodes which terminate in a break in sedimentation, with a hiatus spanning the Middle(?)-Late Norian and Rhaetian. This unit may resemble the first transgressive part of the shallow marine Wilhelmøya Formation of Svalbard. In Early Norian an about 140 m thick unit of predominately lagoonal sands and silts, with clayey interbeds, was deposited in the central and eastern areas of the archipelago. Later, in the second half of Early(?) Norian, increased subsidence and a regional transgressive episode (Mørk et al.1989) changed the depositional conditions. This Norian transgression in Franz Josef Land is clearly expressed by a 25 m thick clay dominated unit containing ammonites, bivalves and foraminifera. It was deposited in a shallow shelf environment.

The Early Norian transgression was later followed by a regressive trend, through the deposition of a 115 m thick package of clayey silts and sands. In the upper part of this unit in the western (Graham Bell Island) layers of poorly sorted gravelly sandstones appear. They are overlain by fine-grained sands and clayey silts with numerous fragments of bivalve shells and ammonites. Norian sedimentation terminated in a break in deposition, which was transgressively overlain by the Early Jurassic clays containing both foraminifera and ostracodes.

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6. THE DIAGENESIS OF THE TRIASSIC SUCCESSION OF FRANZ JOSEF LAND

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ABSTRACT
Three cores from the Triassic of Franz Josef Land (Alexandra Island, Hayes Island and Graham Bell Island) have been studied diagenetically by thin section, X-ray diffraction, electronmicrospically and with respect to stable isotopes. Organic geochemical screening analyses (Rock Eval) have also been performed.

The Triassic sediments (Olenekian-Norian) most likely were formed in shallow shelf to nearshore environments derived from a northerly to easterly source area. The immature, rather feldspar rich sediments show complex diagenetic and metamorphic formation, controlled by burial to more than 3 km, later tectonic movements and intense Late Jurassic/ Early Cretaceous magmatic activity.

Siderite and calcite are the most common diagenetic phases, both with a dominately late diagenetic origin. The stable isotope analyses indicate an origin partly related to the magmatic activity. In addition minor amounts of quartz, feldspar and kaolinite are found, as well as early diagenetically chlorite. The kaolinite is suggested to have a rather early diagenetic origin, while the small amounts of diagenetic quartz may be related to deeper burial and pressure solution.

INTRODUCTION

The three Franz Josef Land cores studied (Figs. 1 and 2) from Alexandra Island, Hayes Island and Graham Bell Island are presented and described sedimentologically, paleontologically and stratigraphically by Dypvik et al. (1998). In the present paper the sedimentpetrographical/diagenetical evolution of these Lower to Upper Triassic successions will be discussed, based on detailed mineralogical and geochemical analyses. Diagenesis is here defined as the chemical, physical and biological changes undergone by a sediment from its initial deposition, during and after its lithification, exclusive of surfical alteration and metamorphism (Bates & Jackson 1980). This would be covered by the sum of the expressions «diagenesis» and «catagenesis» as defined by Strachov (1953,1969). The applied definition would also include diagenesis, catagenesis and metagenesis as commonly understood in organic geochemistry (Tissot & Welte 1984).

The studied, dominately siliciclastic, sediments represent shelf to shallow marine, lagoonal and terrestrial depositional conditions (Figs. 2 and 3). The sand, siltstone and shale sequences commonly form numerous coarsening upwards units of different thicknesses.

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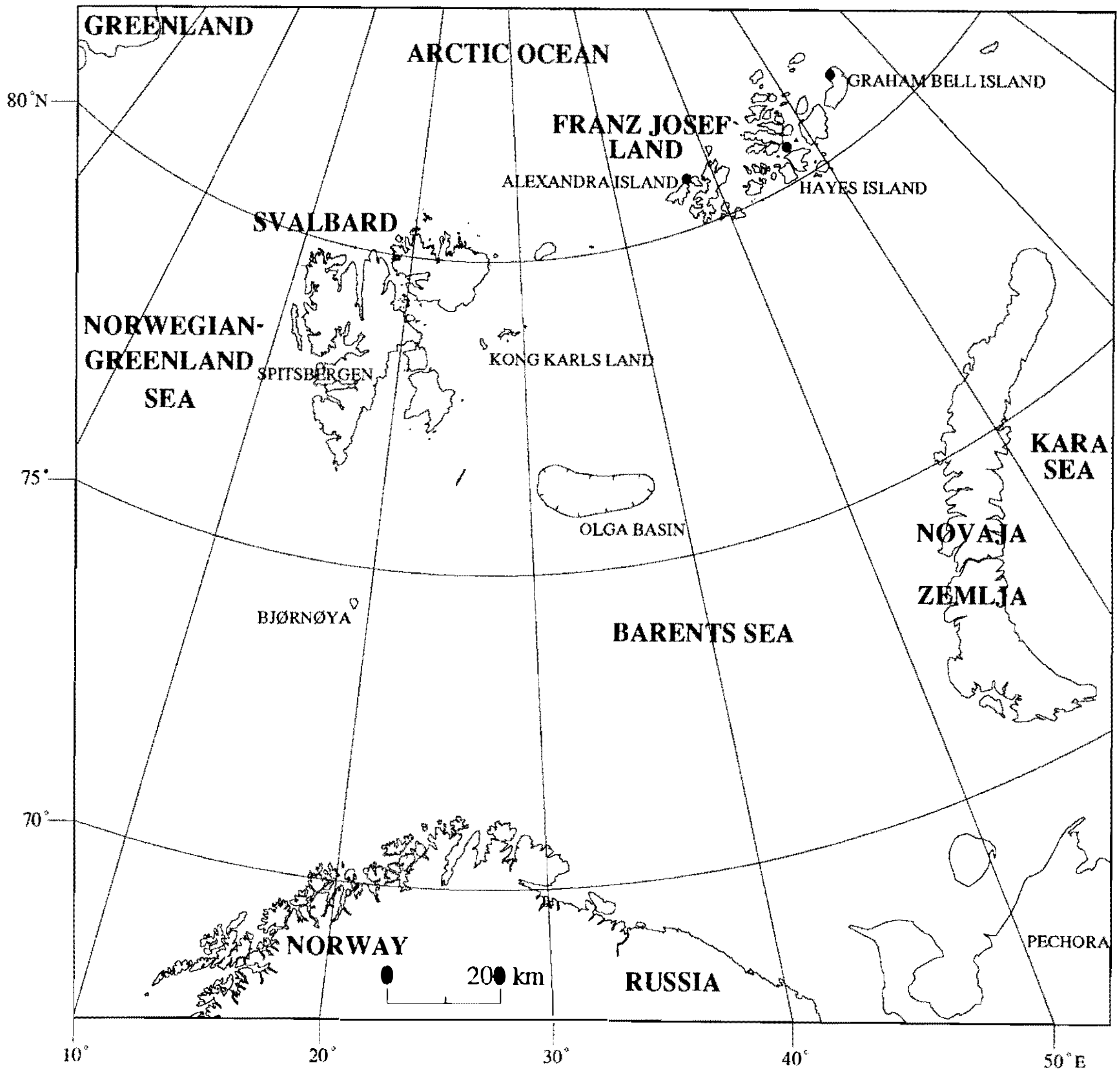

Fig. 1. Geographical setting of Franz Josef Land.

The shallow marine sediments were sourced from northerly to easterly situated provenances, as e.g. indicated by coarser grained, feldspar enriched samples from the Graham Bell and Hayes Island cores, compared to those studied from Alexandra Island (Table 1). The sedimentary succession suffered several episodes (?Jurassic to Tertairy) of magmatic activity and associated metamorphism, which in addition to the influence of burial diagenesis, have changed the original mineralogical composition of the sediments.

Both the burial history and the magmatic influence have left their imprints on the sediment and in the present study the various effects, as expressed in the petrographical composition, is discussed mineralogically and geochemically. Preobrazenskaja et al. (1985a) presented and discussed the first general petrographical and geochemical descriptions of the cores. They found clay minerals (illite, chlorite and kaolinite) as common cements (authigenic and clastic) (3-30%) in the beds. In addition the studied samples where found to contain carbonate cement (calcite and siderite) in amounts from 1% to 50%. The occurrences of pyrite and glauconite were also mentioned. Vojcechovskaja (1985) described the diagenesis/katagenesis of the organic matter,

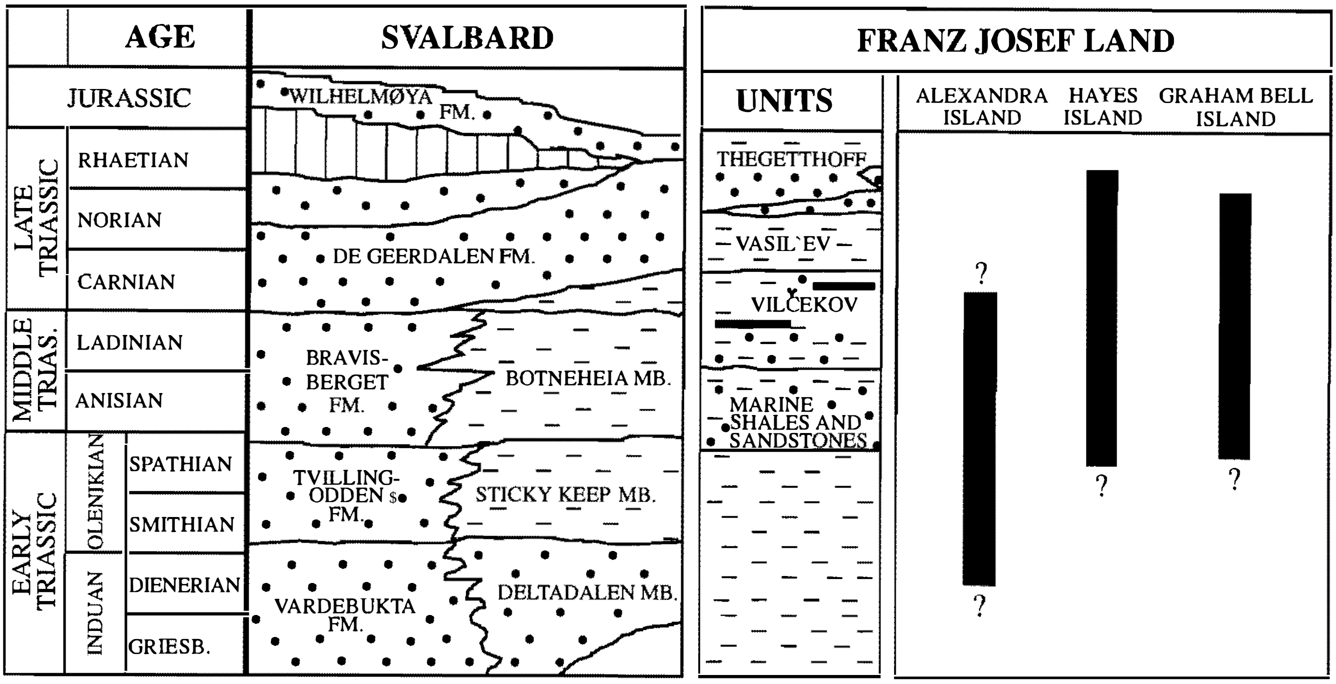

Fig. 2. The stratigraphy and cores of Franz Josef Land compared to the general stratigraphy of Svalbard.

partly in relation to selected inorganic geochemical variations. Her results show the organic matter to be composed of both higher and lower plant material, with more terrestrial dominance in the uppermost Triassic layers.

METHODS

About 80 samples have been studied in thin section (polished sections after blue stained epoxy impregnation) (polarization microscope, cathodoluminesence) and by scanning electron microscopical techniques (JEOL JSM 840)(secondary, backscatter) (Table 1). The samples were also routinely run by X-ray diffraction analyses (Philips 1710). Standard organic geochemical screening analyses (TOC, Rock Eval) (Tissot & Welte 1984) (Table 2) were run on 185 samples in order to extract better general mineralogical understanding, kerogen characterization and estimates of temperature influence.

Selected carbonate cemented zones were in addition analysed with respect to carbon and oxygen isotopes. The carbonates were dissolved in phosphoric acid in evacuated reaction containers at 25°C. Isotope analyses on extracted CO_2 were performed on a Finnigan MAT 251 stable isotope mass spectrometer (Fjellså 1993).

RESULTS

The sand, siltstones and shales of the Franz Josef Land wells (Fig. 3) have been studied in great detail by applying a number of analytical methods, mainly comprising organic geochemistry and petrographical techniques.

Table 1. Point count results (%) of thin section analyses from the three wells analysed. R.F.=rock fragmens, ϕ = porosity

Alexandra Island Well

Depth	*Qtz*	*K fsp*	*Plag*	*Cal.*	*Sid.*	*Pyr.*	*Matrix*
565-720	17	2	9	13	12	1	46
1325 -1622	10	1	4	12	2	9	62

Hayes Island Well

Depth	*Qtz*	*K-fsp*	*Plag*	*Cal.*	*Sid.*	*Pyr.*	*Matr.*	ϕ
757 -1242	36	9	16	8	3	1	27	+
1279 -2020	31	6	15	3	6	2	37	+
2167 -3200	34	2	16	7	11	1	29	+

Graham Bell Island well.

Depth	*Qtz*	*Kfsp*	*Plag*	*R.F.*	*Cal.*	*Sid.*	*Pyr.*	*Matr.*	ϕ
542 -1019	23	8	10	1	13	6	3	35	1
1166	31	8	13	1	13	0	2	30	2
1607 -2346	30	6	11	+	6	6	3	36	2
2688 -3220	35	6	17	+	4	4	2	31	1

The Organic geochemistry

The organic geochemical analyses comprise TOC determinations along with Rock Eval pyrolyses (Tissot & Welte 1984) (Table 2). During the Rock Eval pyrolyses the kerogen characterization (HI,OI) and the organic maturity (T_{max}) of the different samples were determined (Figs. 4 and 5). The very low T_{max} values (below 400^{0}C) (Table 2) should not be used. During extreme thermal effects, e.g. severe magmatic baking of the organic material and hornfelsization of sediments close to the contact, the extractable (S1) and pyrolysable (S2) organic matter sizzle off; S2 and T_{max} can therefore not be measured properly.

The extreme high as well as the very low values are clearly the results of high intrusive activity and should be omitted. Based on the other T_{max} values, breaks in the temperature distribution are indicated at the Olenekian/Anisian boundary in the Alexandra Island core (Fig. 4), with a possible erosion of at least 600 m of sediments, when compared to T_{max} estimates given by Tissot & Welte (1984). At the same level a sedimentary break and a paleontological distributional gap (Anisian) have been noticed (Dypvik et al. 1998). In the Hayes Island well, a minor break in the T_{max} distribution is seen at level 2000 m, the Anisian/Ladinian boundary. There a drop from about 452^{0}C to 447^{0}C T_{max} suggests an erosion of 500 m in late Anisian or early Ladinian. No clearcut sedimentological breaks or available paleontological information, however, support such an explanation. The Graham Bell Island distribution is even more complex, but no breaks have been observed at the Anisian/Ladinian boundary in that case (Fig. 4).

The thermal influence of the intrusions dramatically changed the composition of the organic matter, while the mineralogy has changed to a lesser extent. Similar observations have also been found in Svalbard, where a 55 m thick sill baked the Triassic shales at least 100 m away (Dypvik 1979). The T_{max} values found in the samples studied from Franz Josef Land, suggest vitrinite reflectivities between 0.7% and 1.2% representing a burial depth to about 3-3.5 km (Tissot & Welte 1984). Compared to the present depth of occurrence, a possible uplift of at least 1500 m is indicated in the Alexandra Island well (see also Solheim et al.1998). Interpolated and estimated T_{max} values at the Carnian/Norian boundaries show T_{max} between 440^{0}C and 435^{0}C (similar to

Table 2. TOC and Rock Eval analyses of samples from the three wells analysed.
Method in Tissot & Welte 1984.

Alexandra Island Well

Sample level	*No. of samples*	*TOC*	*Tmax*	*HI*	*OI*
565 -799	9	0.94	440	51	126
860-942	5	1.09	441	66	32
1010-1325	4	1.08	453	32	28
1467-1622	6	0.58	299	6	103

Hayes Island Well

Sample level	*No. of samples*	*TOC*	*Tmax*	*HI*	*OI*
749 - 785	5	0.91	452	51	142
882 - 977	2	1.24	442	16	99
1023-1028	2	0.52	449	66	60
1252-1279	3	0.98	444	42	72
1368-1448	7	0.66	436	41	52
1675-1900	11	0.72	433	41	80
2008-2057	7	0.72	460	32	49
2158-2188	5	0.60	335	22	158 baked
2333-2405	6	0.90	440	65	63
2528-2564	6	0.66	406	23	77 baked
2636-2677	1	1.26	479	38	23
2849-2881	4	0.84	407	23	34 baked
2931-3048	5	0.98	473	26	21
3132-3222	8	0.64	477	20	102

Graham Bell Island Well

Sample level	*No of samples*	*TOC*	*Tmax*	*HI*	*OI*
538 - 651	7	0.74	429	27	93
799 - 956	7	1.27	449	48	86
1019-1038	2	1.51	466	43	24
1138-1141	2	6.97	449	54	36
1305	1	0.53	403	28	75
1417-1436	3	0.75	446	50	82
1607-1690	2	0.68	446	31	48
1798-	1	0.19	288	15	52 baked
1940-2171	9	0.85	397	27	38 baked
2239-2346	7	0.76	388	25	24 baked
2423-2427	2	0.97	463	5	14
2739-2888	8	0.61	305	3	30 baked
2909-3450	7	0.46	465	38	53

about 1200 m overburden, Tissot & Welte 1984) presently at about 500 m of burial depth, indicating an erosion of 700 m.

Compared to the Triassic succession of Svalbard (Forsberg & Bjorøy 1982; Mørk et al. 1982; Mørk et al. 1989; Mørk & Bjorøy 1984) the visual appearance as well as the TOC content and kerogen typification of the Franz Josef Land dark shales (TOC values around 1% and kerogen type III) are more akin to the Tschermakfjellet Formation than the Bravaisberget (Botneheia Member) and Tvillingodden (Sticky Keep) formations of Svalbard. This faintly indicates an eastern extention of the Triassic basins in the Northern

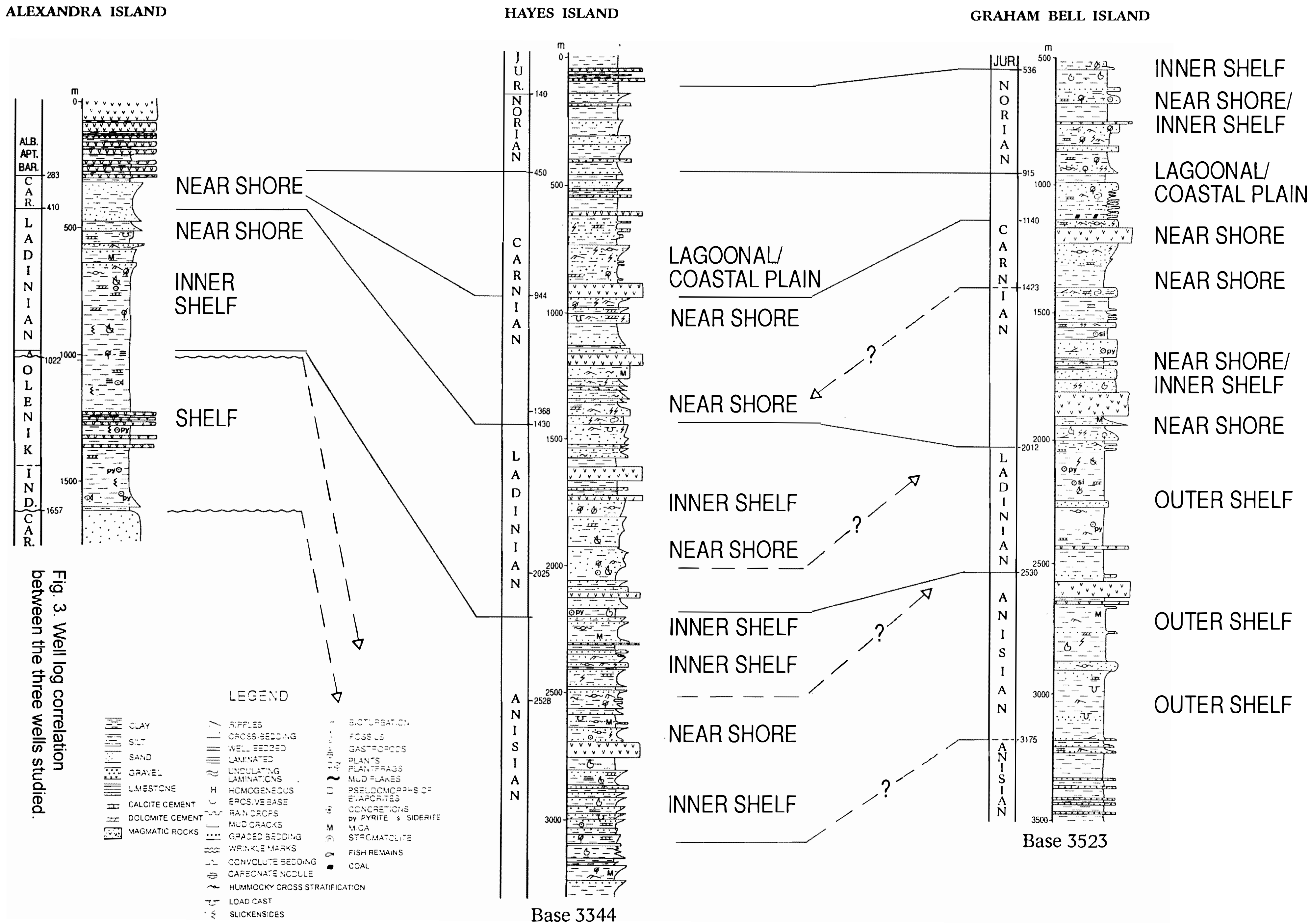

Fig. 3. Well log correlation between the three wells studied.

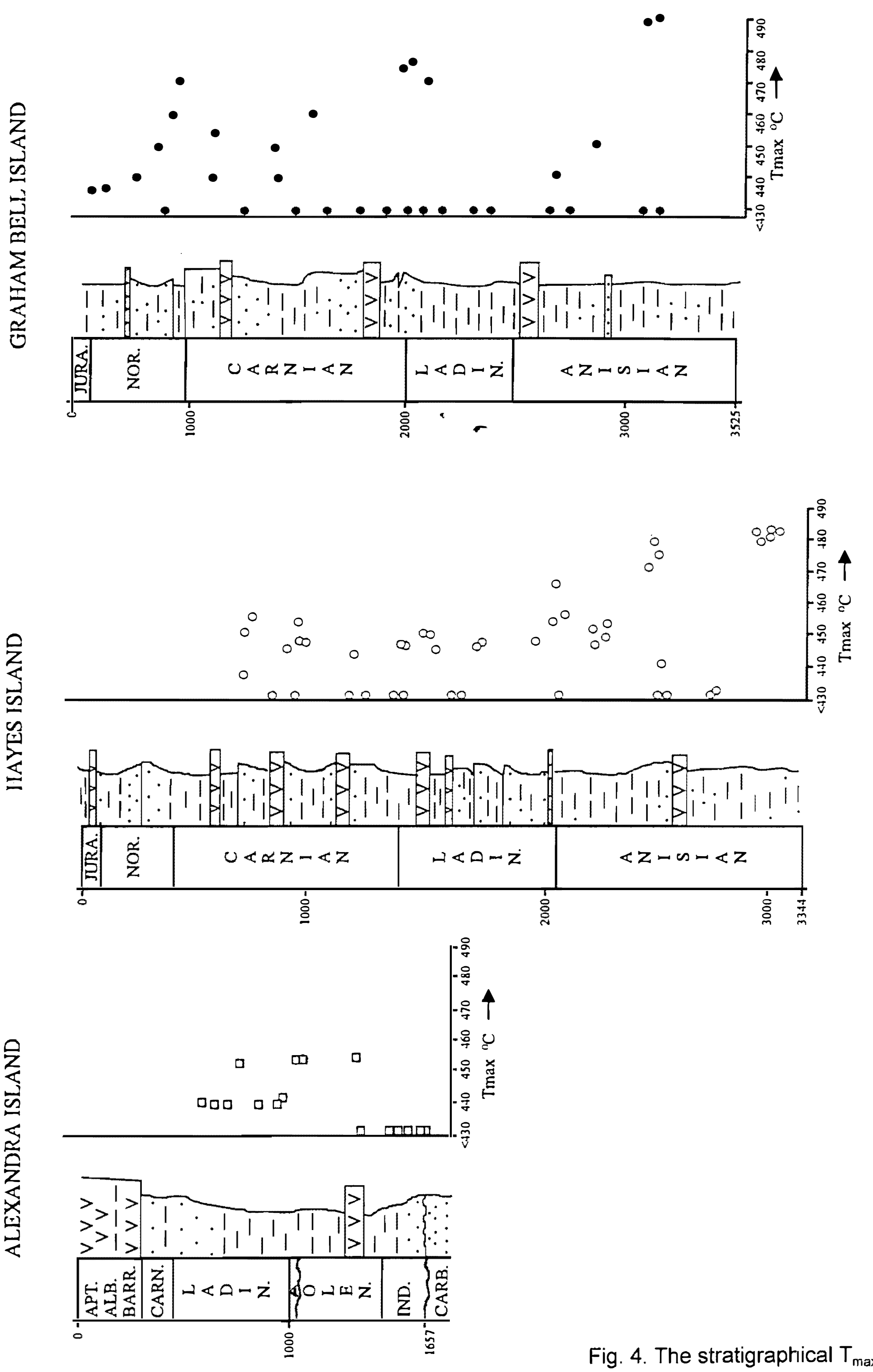

Fig. 4. The stratigraphical T_{max} (°C) distribution in the three cores analysed.

Barents Sea. The only bitumenous «Botneheia Type» of black shales have been encountered in a thin zone at level 2375 m in the Hayes Island well.

The Rock Eval analyses show that kerogen type III (Tissot & Welte 1984) dominates. No particular stratigraphical variations in kerogen quality is apparent. In contrast the T_{max} values (the near intrusion-baked samples omitted) clearly demonstrate a downward increase (Fig. 4). The average TOC content in the three wells vary around 1%, only two samples show high values (Hayes Island 2377.7; 10.9% and Graham Bell Island 1138.5; 13.8%). The TOC distribution is most likely a result of both original depositional conditions superimposed by the localized magmatic-baking of the sediments.

Optical kerogen analyses (Vojcechovskaja 1985) show the existence of two main kerogen types:

- a blue green algal, sappropelic variety commonly replaced by carbonate is seen in thin section as rosettes and small clusters, and
- remnants of higher plants are also seen, they are not replaced with carbonate and are mainly represented by vitrinite. Vojcechovskaja (1985) also mentions the presence of migrated hydrocarbons in the coarser, porous beds.

Diagenetic minerals

The clay-rich Triassic arkosic arenites/wackes (Dott 1964) from Franz Josef Land are generally well-cemented, commonly by carbonates. In thin section the sandstones from the Alexandra Island well appear somewhat finer grained than the samples studied from the other two cores, the Hayes Island and the Graham Bell Island wells. The original sediment composition displays an immature appearance with varying contents of rock fragments and feldspars, and high plagioclase concentrations are typically found in some samples (Table 1). Such composition indicates an original moderate transportation distance, from the source area to the sites of deposition. The most coarse grained and feldspar rich material were found in the two easterly situated wells (Hayes Island and Graham Bell Island), indicating a more provenance-close location.

The degree of compaction is partly reflected in a downhole, weak decrease of the amount of tangetial contacts, which are dominating in the younger beds. The studied samples are relatively poor in sutured grain contacts (Fjellså 1993). In the lowermost parts of the succession mica flakes are also seen to be folded and splaying (Fig. 6), and microcracks occur in the clastic grains. The compaction development is as well partly demonstrated in the finer grained sediments, which turn into firm claystones/shales at about 500-600 m of core depth.

In addition to the dramatic alterations due to the magmatic activity, also diagenesis and sediment burial resulted in mineralogical and geochemical changes. Calcite and siderite are commonly observed cements, but minor amounts of authigenic quartz, feldspar, kaolinite and illite have also been seen (Fig. 7). In the silty and sandy sediments, especially close to the intrusions, authigenic calcite is typically found, while the claystones at the contacts are metamorphosed to hornfelses with high degrees of recrystallisation and loss of primary sedimentary structures. Calcite (commonly between 0 and 25%), quartz (normally below 1%), and chlorite (below 1%, detrital chlorite up to about 5%) are found as secondary minerals in these beds too (Fjellså 1993). The secondary diagenetic and metamorphic calcite, fills the web of near-contact cracks and fractures and partly replaces the primary grains (e.g. feldspar) and clay mineral cements (Fig. 8).

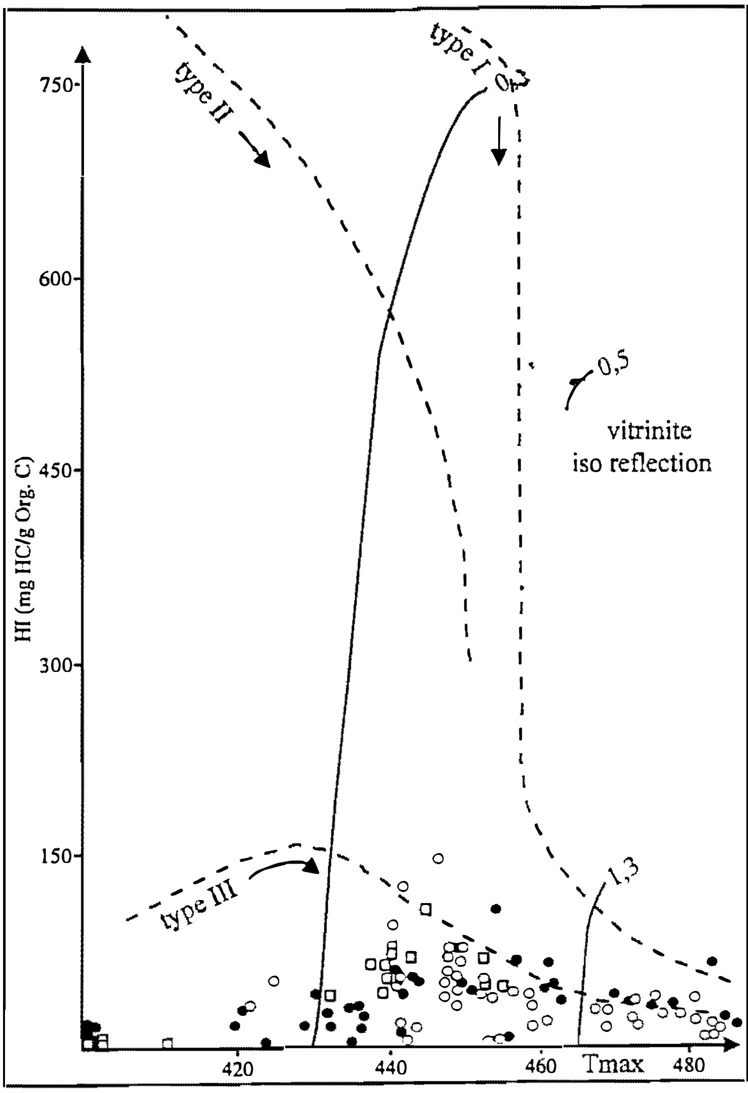

Fig. 5. A kerogen classification diagram based on T_{max} vs HI plots. Modified from Tissot & Welte (1984).
○ Samples from Hayes Island
● Samples from Graham Bell Island
□ Samples from Alexandra Island

The amounts of diagenetic calcite present varies from around zero to more than 50% of the total rock-volume. The calcite is commonly found in a sparitic appearance, but may also locally have a poikilotopic texture. The internal diagenetic relations of the various calcites are difficult to resolve, but the poikilotopic cement is clearly of late origin, since it is surrounding all other cements. The youngest carbonate phase is the crack/fracture filling calcite (Fig. 8).

The siderite cements found were normally between 5% and 15%, but amounts up to about 25% have been observed (Table 1). The siderite has a sparitic morphology and may be found associated remnants of thin, laminated possible algal structures (Preobrazenskaja et al. 1985 b) (Fig. 9).

The diagenetic relations within the carbonates seem complex and have been difficult to disclose visually and consequently stable isotopic analyses (carbon and oxygen) were performed. Studies of stable isotope distributions may be used to estimate temperature

Fig. 6a. The first phases of mica splaying and alteration in a sample from the Graham Bell Island well, level 3220 m. The length of the micrograph is 1.3 mm.

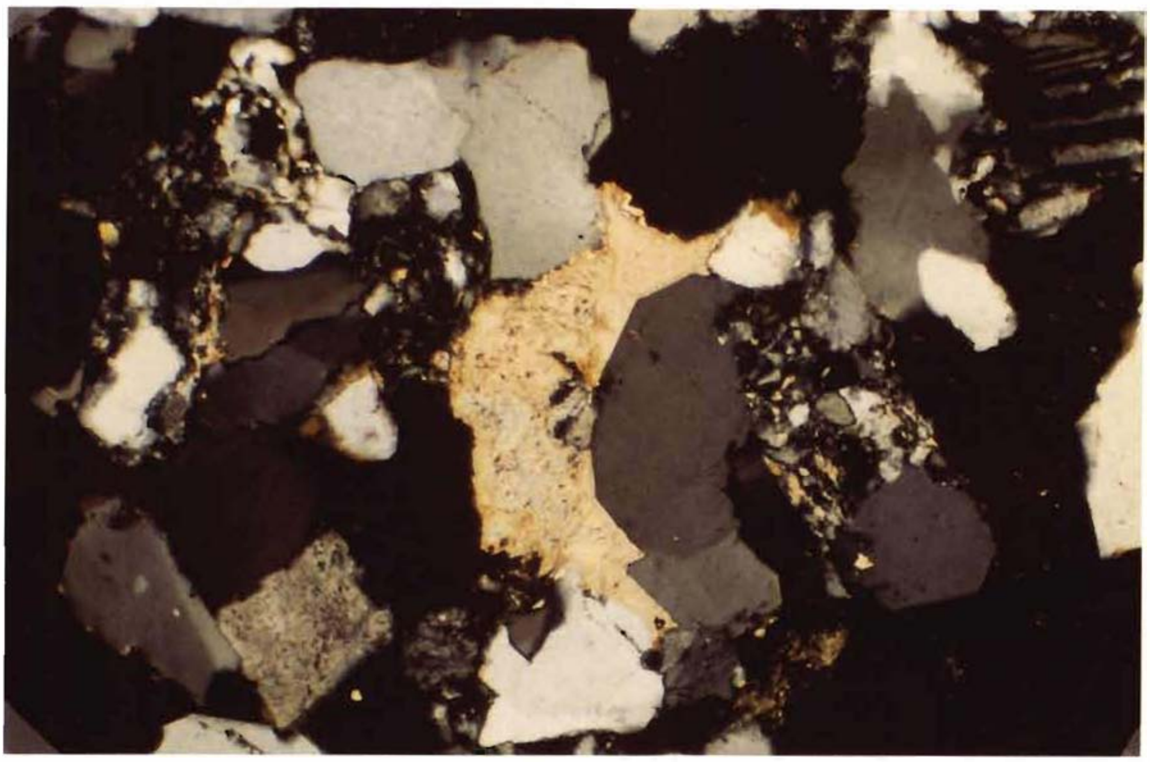

Fig. 6b. Authigenic quartz with euhedral surfaces are postdated by sparittic calcite cement. The sample is from the Hayes Island well, level 1430 m. The length of the micrograph is 1.3 mm.

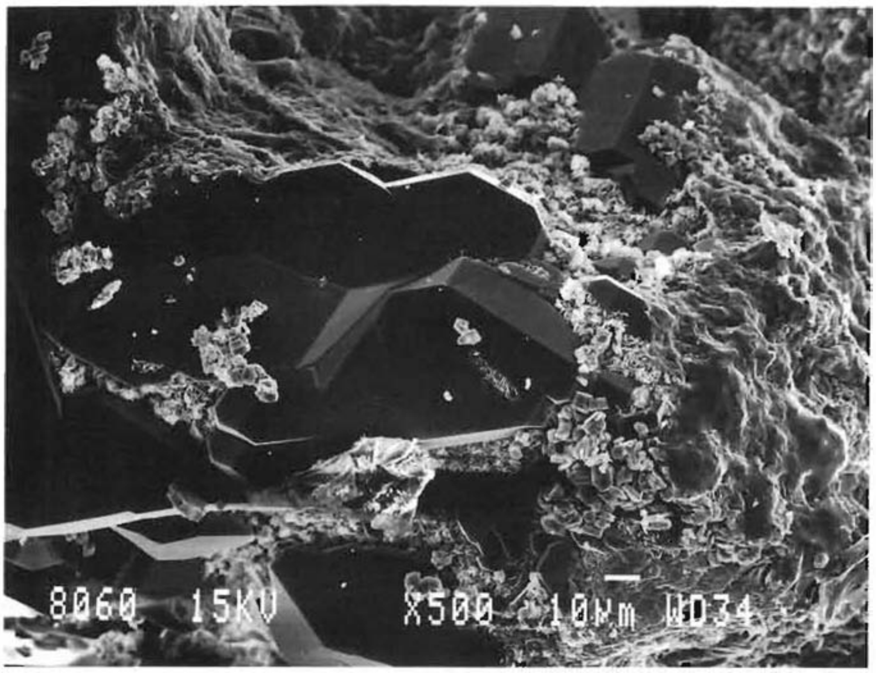

Fig. 7a. Authigenic euhedral quartz crystals including authigenic kaolinite crystals as seen in a SEM micrograph of sample 1430 m from the Hayes Island well.

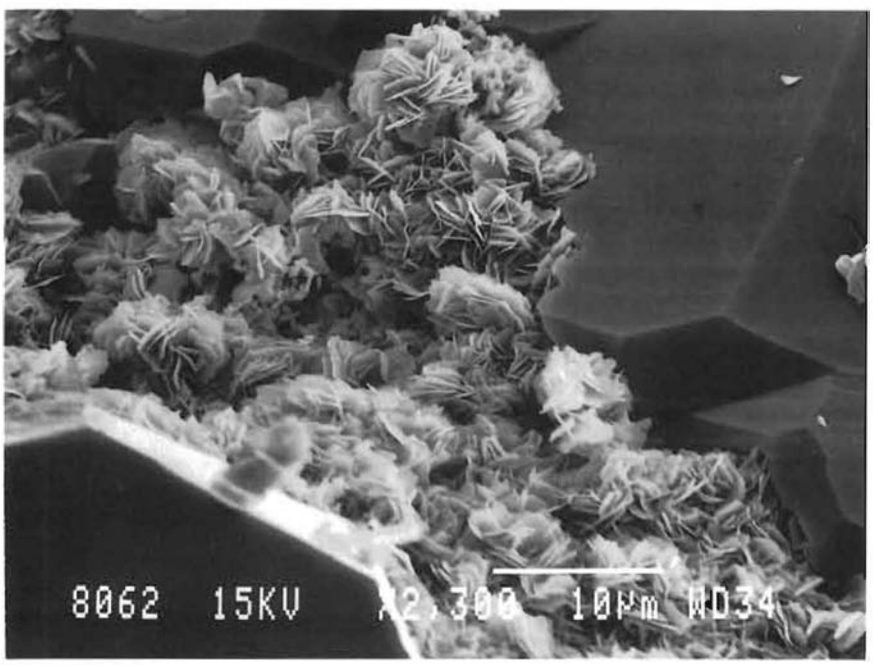

Fig. 7b. Rosettes of authigenic chlorite seen by the SEM analyse of sample 1430 m, from the Hayes Island well. The quartz has partly grown through the chlorite.

at the time of formation (oxygen) as well as giving an indication of the origin (carbon) (e.g. Buchardt 1983; Irwin et al. 1977; Longstaffe 1983).

The carbon isotopes show no particular stratigraphical distribution and vary generally between +2‰ and -20‰ in the calcites (Fig. 10). The results can further be subdivided into two groups +2‰ to -5‰ and -10‰ to -20‰. The heavier group (+2‰ to -5‰) most likely represents original composition of marine derived carbonates, representing $CaCO_3$ reprecipitation from dissolved marine skeletal fragments and calcareous algaes. A minor magmatic influence may be present (normally around -7‰), but the original depositional marine influence seems to be the dominating one, since normal marine carbon reservoirs typically have values around 0‰. The lighter group (-10‰ to -20‰) may reflect calcite cement with carbon supplied from late alteration of organic matter and a possible contribution from sulphate reduction. According to Irwin (1977) such values may represent the products of thermal alteration reactions, aerobic bacterial oxidation and sulphate reduction (-25 ‰). Low isotope ratios indicate CO_3^{2-} possibly sourced from magmatically related destruction of organic matter. According to Irwin (1977) this may resemble thermal decarboxylation reaction of her zone IV, i.e. depths greater than 1km. These values are clearly in contrast to commonly higher values characteristic of bacterial fermentation (+15‰) which may be reflected in the higher values of Graham Bells and Hayes Island samples around level 1200 m. The carbon isotope variations are probably to some extent both dependant on facies variations and changing magmatic activity. Both in the Hayes Island and the Graham Bell Island samples the increase in the $\delta^{13}C$ follow the change towards nearshore sedimentation in combination with the reduction in magmatic activity. It is presently difficult to estimate the magnitude of the two contributing factors.

The $\delta^{13}C$ values in the siderites vary from -5‰ to -30‰ (Fig. 10). The cluster of -5‰ to -7‰ ratios show, as for the calcites above, a possible marine sourced carbonate, skewed towards lighter values due to magmatic influence or related hydrothermal activity. The lighter values measured (-10‰ to -30‰) resemble alteration products of organic matter, either by bacterial oxidation/reduction or decarboxylation reactions.

The $\delta^{18}O$ values (-10 to -17 ‰) of the calcites, typically found in the calcite samples (Fig. 11) from below 2000 m, indicate precipitation temperatures somewhere between 60°C and 115°C (Faure 1977). The temperature estimate can in this case not be given more precisely because the $\delta^{18}O$ value of the formation at the time of calcite formation is difficult to acess. For the temperature bracket given above meteoric water values of -7‰ and marine water values -1.2‰ have been applied. The temperatures achieved match the organic maturation values gained in the Rock Eval analyses (T_{max}), showing burial depths between 2 km and 4 km, when applying thermal gradients of 30°C/km (which may be too low). It is, however, difficult to estimate the possible burial depths more precisely, because the thermal flux in the area has be measured to 57.7 mW/m^2, higher than the mean value for the earth. In addition the metamorphic rocks below possess high heat conductivity, securing both vertical and horisontal transport of heat.

The few samples, from above the 2000m level, recognized with lower $\delta^{18}O$ values (-20-25‰) representing even higher precipitation temperatures, may show high thermal influence caused by magmatic activity. Dolerittic intrusions are found dispersed within the sedimentary deposits in the three wells studied (Dypvik et al. 1998).

The siderites typically have $\delta^{18}O$ ratios between -8‰ and -24‰ (Fig. 11). Based on these values and the temperature estimates for siderites (Carothers et al. 1988), the siderite precipitation took place at least at 70°C or burial depth of more than 2 km. The lowest values measured (indicating more than 150°C of formation temperature) may reflect recrystallisation from original siderite cements in relation with the thermal effect of the magmatic activity. The isotopic results indicate that early diagenetic siderite is rather sparse within the cores.

The studied samples are in addition found to contain early diagenetic framboidal pyrite and siderite, most likely of bacterial origin, and at least partly developed on biotite and related organic material. The pyrite enrichments are well established in the lower, clay-rich offshore facies of the Alexandra Island and parts of the core from Graham Bell Island, while the Hayes Island core and the upper part of the Alexandra Island core are poor in pyrite. This show Hayes Island to represent more ventilated, maybe marginal conditions, compared to the Alexandra and Graham Bell islands. Some of the pyrite may have been formed late in the diagenetic evolution.

Siderite has originally a cryptocrystalline to microgranular appearance, associated organic matter which controlled the amounts of related pyrite formed. In this connection small amounts of leucoxene (a Ti-oxide mineraloide) are found. Leucoxene is seen as weathering/alteration products of biotite and terrestrial plants, relatively rich in Ti, where the Ti admixtures in the biotite and plant remains formed centers of crystallisation.

The early diagenetic leucoxene, which in several cases later recrystallized to anatas and brookite, is found in varying amounts, from 0% to more than 50% of the total heavy mineral fraction. High contents of Ti-minerals are characteristic of the regressive Carnian facies. In those coal-bearing units the amount of authigenic leucoxene sometimes reaches up to 76% of the heavy mineral fraction (Graham Bell Island core, level 939 m).

Minor amounts of diagenetic quartz and feldspar cements have been found in samples from both Hayes and Graham Bell islands. The authigenic quartz and feldspar phases are recognized by euhedral surfaces, commonly surrounded by later formed calcite cements (Fig. 6). The thin section results (Table 1) indicate down-well increasing amounts of quartz in all the three wells studied. In detail the quartz formation may seem to be represented by two different phases (Fig. 6); one early associated K-feldspar dissolution and formation of authigenic kaolinite and a late formed as a result of increased burial and early stages of pressure solution. In the thin sections, however, no signs of pressure solution have been observed so far.

Minor amounts of diagenetic feldspar cement have been observed in one sample from Graham Bell Island (level 1166.5 m). The feldspar is, as the quartz cements, surrounded by authigenic calcite, showing that both authigenic feldspar and quartz are older than the major part of calcite cementation. Albittization of K-feldspar was observed only in one sample from Hayes Island (level 1430 m), where the bulk contents of K-feldspar (XRD-analyses) generally are found to decrease down-core, as in Graham Bell Island samples. Only a few, dispersed grains of K-feldspar have been observed in the thin sections studied from Alexandra Island and no particular distributional trends have been found. The thin section and XRD analyses may reflect increasing chemical dissolution of K-feldspar downcore, associated a mutual rise in both diagenetic kaolinite and quartz. It should be noted that the extent of feldspar dissolution is minor and consequently the porosities are normally low (<5%).

In addition to their clastic fractions, diagenetic kaolinite, chlorite and illite (Fig. 7), have been found as porefilling and porelining phases. The associated increase in kaolinite

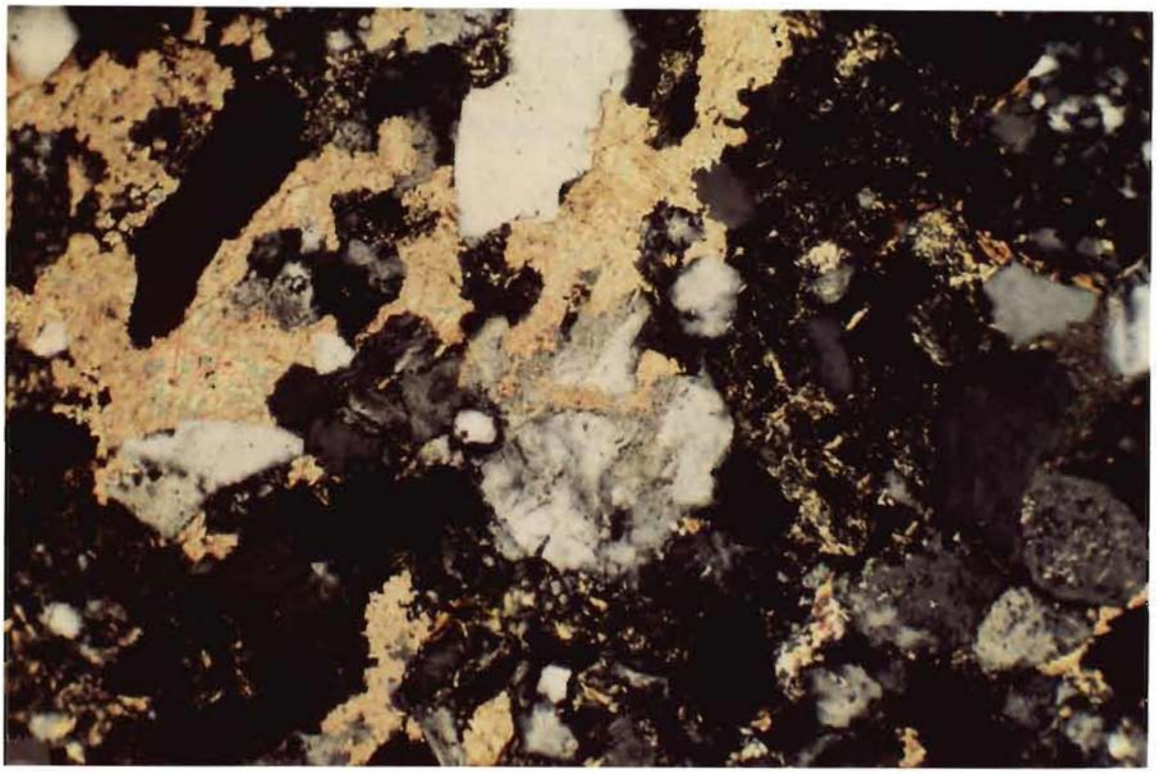

Fig. 8a. Large sparittic/poikilotopic calcite crystals in coarse grained sediments from the Graham Bell well, level 1166.5 m. The calcite precipitation happened after K-feldspar dissolution. The length of the micrograph is 1.3 mm.

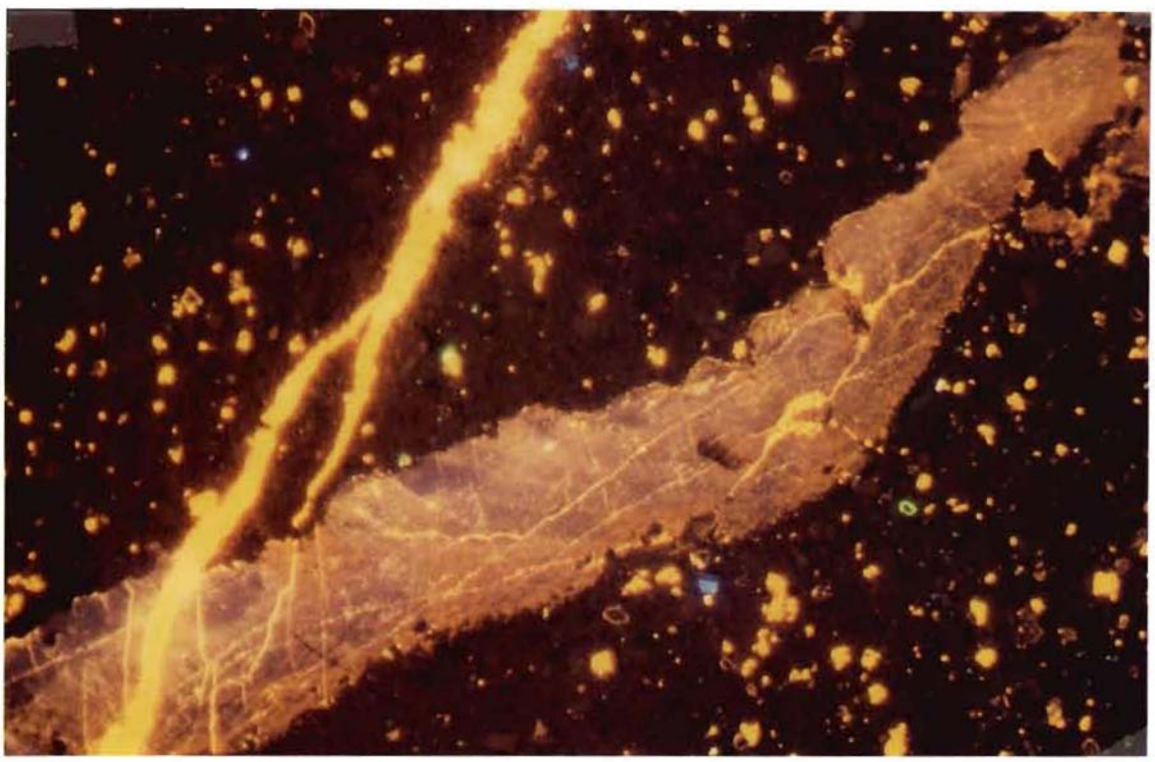

Fig. 8b. A cathodoluminescence micrograph of sample 1540 m from the Alexandra Island well. Two different phases of fracture filling calcite cement is seen along the major fractures. In addition a possible third phase of sparitic calcite cement is seen in the brigth yellow spots.

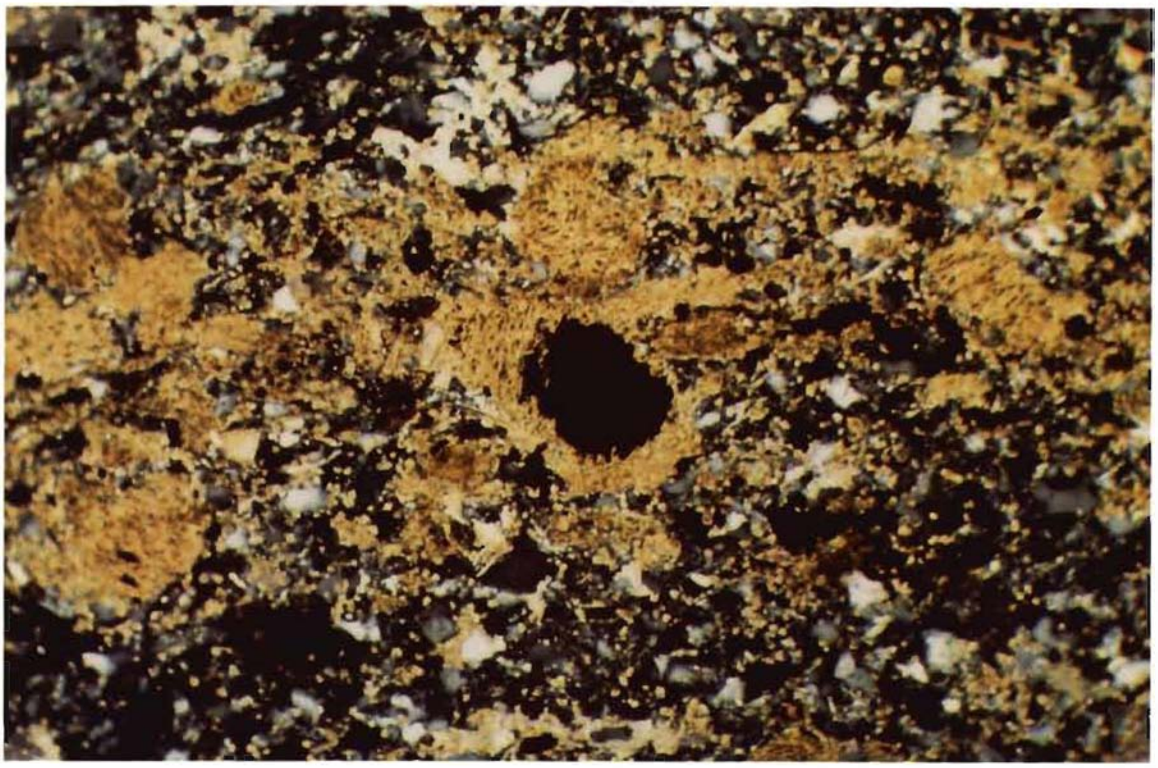

Fig. 9a. A large framboidal pyrite, surrounded by late diagenetic siderite cement. The length of the micrograph is 1.3 mm. Alexandra Island well, level 720 m.

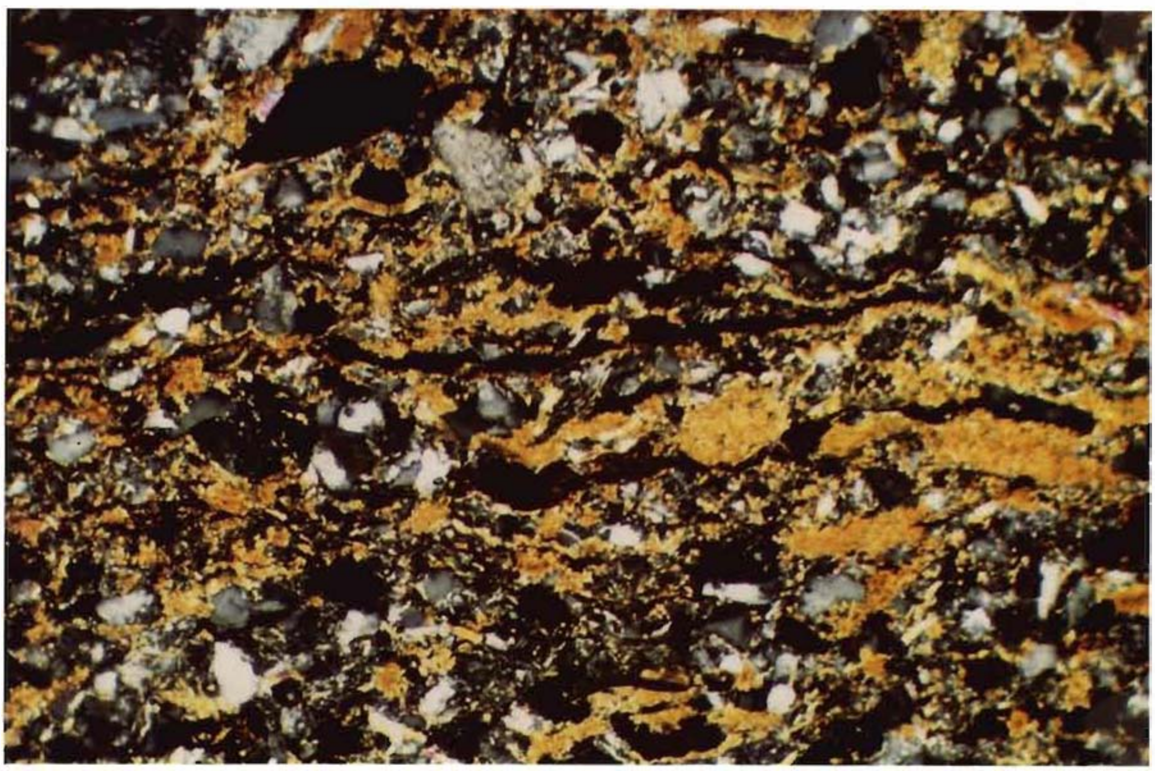

Fig. 9b. Pyrite and organic matter in a sample from the Hayes Island well, level 749 m. The length of the micrograph is 1.3 mm.

towards the depth (XRD-analyses), together with the reduction of feldspar, may indicate (as stated above) feldspar alteration/dissolution as a possible kaolinite source.

An overall downhole temperature and pressure increase explain additional illitization of smectite, as reflected in increasing amounts of illite and reduced smectite/illite ratios downhole (Fjellså 1993). In the Graham Bell Island well the smectite/illite ratio at 2000 m has been measured to about 3, while at 3000 m it is closer to 1. This formation mechanism of illite from smectite (Curtis 1985; Dypvik 1983), is more likely than a kaolinite derived origin, due to low burial temperatures (see e.g. Bjørlykke et al. 1991; Ehrenberg & Nadeau 1989).

Faintly developed chlorittization (Fig. 7) have been observed in some few grains of biotite, along with rosettes of authigenic chlorite. The chlorite is also in the Franz Josef Land samples, as commonly encountered in the North Sea region, surrounded by authigenic quartz, indicating a relatively early time of formation (Fig. 7).

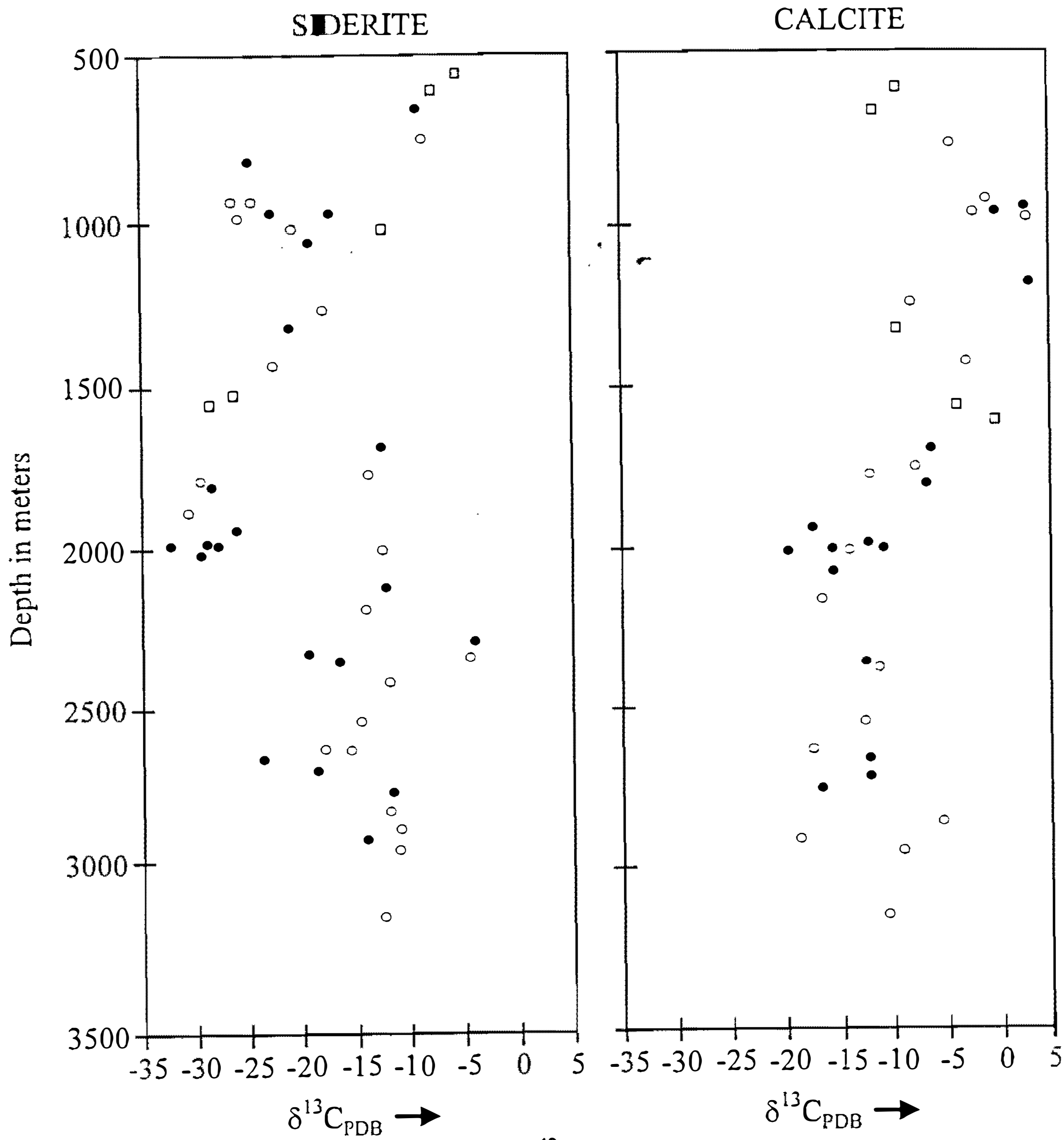

Fig. 10. The stratigraphical variation in the $\delta^{13}C$ values in siderite and calcite from the three wells studied. ● Samples from Graham Bell Island. ○ Samples from Hayes Island. □ Samples from Alexandra Island.

DISCUSSION

The Triassic sediments of Franz Josef Land suffered, during burial close to 4 km of depth, mechanical and chemical compaction, resulting in both low porosities and permeabilities. The Rock Eval analyses show the thermal effects of burial down to at least present levels (about 500-700 m possibly removed by post-Triassic erosion) in addition to the superimposed magmatic baking effects. These thermal alterations is also mirrored in some of the stable isotopic variations as well as in the downhole increase in illite, a result of smectite-illite transformations at temperatures above 50°C.

The shallow marine, shelf setting of the area, has been presented by Dypvik et al (1998) and is well supported by the present kerogen analyses, showing dominance of kerogen III (typical terrestrial origin). Its presence together with marine fossils, mirror the dominating clastic sedimentation and short distance between terrestrial source areas and site of deposition.

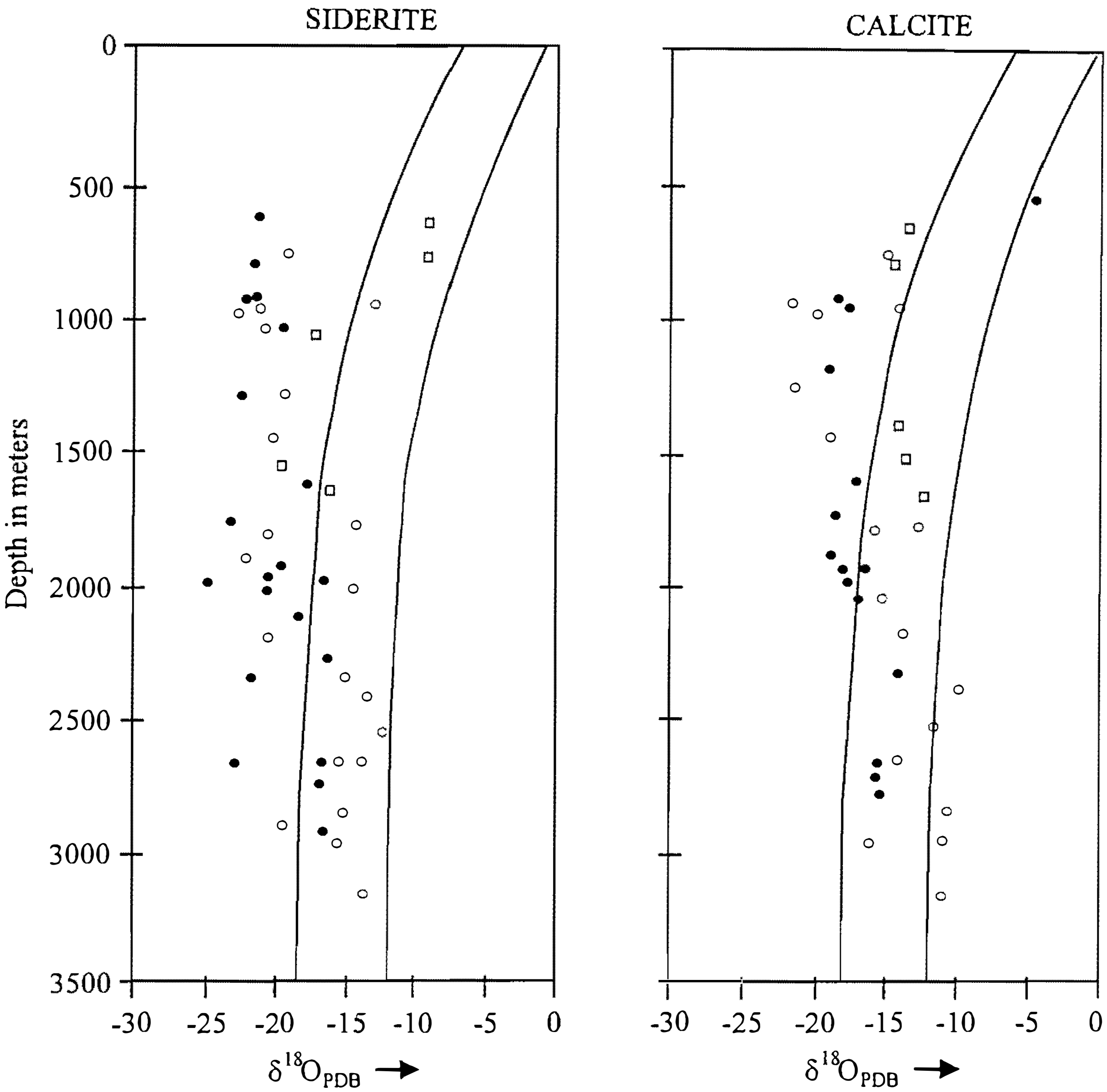

Fig. 11.The stratigraphical variation in the $\delta^{18}O$ values in siderite and calcite from the the wells studied. The parallell lines mark the boundaries of possible formation water composition, and consequently the area of expected, normal burial diagenesis. ● Samples from Graham Bell Island. ○ Samples from Hayes Island. □ Samples from Alexandra Island.

After burial the sediments were suffering diagenetic reactions (Fig. 12) in addition to series of magmatic intrusions from Triassic to at least Albian times (Amundsen et al.1998). The magmatic reactions, hornfelisation and contact metamorphism are not discussed in this study, which focusses on the diagenetic reactions of the sedimentary units.

In the Triassic setting of the "paleo Barents Sea", the relatively warm/humid climate (paleoposition 45-65°N, Dypvik et al. 1998) and well developed vegetation resulted in significant weathering/alteration of minerals, especially the vulnerable biotite. The formation of partly amorphous Ti-O phases were probably related to this early alteration phase. Such diagenetic formation of leucoxene, and later transformation to possibly anatas and brookite (during late diagenesis, epigenesis) explain the higher amounts of such Ti-minerals in the younger, more terrestrial facies. The authigenesis of leucoxene probably took place during the decomposition of plant remains in an acid pedogenetic environment, during both weathering and early diagenetic phases (leucoxene). Rentgarten (1955) and Logvinenko (1956) described in detail authigenic formation of leucoxene, anatase and brookite in sandstones. Pcelina (1960) recorded similar formations in the Jurassic and Cretaceous coal-bearing deposits from Lena Basin (Russia) and distinguished the direct connection between the presence of these minerals and high contents of biotite and plant detritus.

Framboidal pyrite, probably of both early and late diagenetic origin have also been recognized in the samples. The close association between pyrite enrichments and the dark organic and clay-rich sediments in Alexandra Island Well core, shows its possible early diagenetic facies related bacterial/algal origin. Parts of well developed cubic to octahedral pyrite crystals may be results of later diagenetic transformations. Siderite may also commonly, in other areas, show an early diagenetic, terrestrial origin. The siderite found in the Franz Josef Land cores, however, has a different origin. It has a fine grained texture, resembling a possible facies related bacterial/algal origin, but shows stable isotope values indicating marine originated carbon and formation temperatures above 70°C, i.e. burial down to probably more than 3 km. These contrasting evidences can be interpreted to show an original terrestrial to shallow marine biologically formed siderite, that later was transformed to its present isotopic composition leaving the textural appearance unchanged. Minor isotopic anomalies may show, as for the calcites, a weak local relation towards magmatic controlled processes.

The samples are generally very poor in both diagenetic quartz and feldspar, which probably both had a relative late diagenetic origin (Fig. 12), at least with a possible pressure solution associated sourcing for parts of the quartz. This is visulized in the modestly increasing amounts of quartz overgrowth down-well. As also commonly found in other areas, a phase of diagenetic chlorite was precipitated before the quartz overgrowth, as seen by delicate rosettes of chlorite appearing between the quartz overgrowth and the original grain.

The minor amounts of K-feldspar present, show modestly decreasing concentrations downcore, partly followed by increasing amounts of possibly albittized feldspar. The decrease in potash feldspar is, however, also associated with an increase in kaolinite and quartz, making the following relation possible:

K-feldspar ---->kaolinite + $H_4 SiO_4$ + K^+
Albite ----> kaolinite + $H_4 SiO_4$ + Na^+

This mechanism can be the result of fresh water flushing of shallow marine beds or possibly also related to the breaks in sedimentation as indicated by both sedimentological and organic geochemical studies. In the Alexandra Island well a post Olenekian/pre Anisian erosional episode is indicated, while a post Anisian break is present in the Hayes Island cores. Presently no ties between these and any of the diagenetic phases are evident.

The sparitic to poikilotopic calcite cements form the most important and extensive diagenetic phase in the studied cores (Fig. 12). Texturally it surrounds and postdates all other diagenetic minerals. The late calcite formation is naturally reflected in its sparitic to poikilotopic appearance as well as in the oxygen isotopic composition, showing precipitation temperatures close to 100°C. The carbon isotope studies indicate a formation from dissolution of original marine skeletal particles, only with a minor contribution from magmatically supplied CO_2 or thermally driven decarboxylation reactions. The calcite precipitation took place when buried to about the present depths, as is also supported by the maturation values of the organic matter (T_{max}).

CONCLUSION

The Triassic sediments of Franz Josef Land were probably derived from northerly to easterly situated source areas. Relative short transportation, together with moderate alteration and sorting, took place before the final deposition of the various units. The sediments typically show a minor content of rock fragments, but are rather immature being relatively enriched in feldspar, at least in the samples from Graham Bell and Hayes islands. This mirrors their more proximal position in relation to the source area. The Graham Bell samples typically have the highest amounts of rock fragments and feldspar, in the coarsest textures present in the wells studied.

After deposition the sediments were buried to a level about 1 km deeper than today`s position (based on the Rock Eval analyses), a succession probably later removed by ?Cretaceous/Tertiary uplift and erosion. An overall erosion of at least 500 m of post-Triassic beds took place. The burial history throughout the Triassic varies and erosional

DIAGENETIC EVENTS		
PHASE	EARLY ⟶	LATE
QUARTZ	PRECIPITATION	PRESSURE SOLUTION
FELDSPAR	DISSOLUTION PRECIPITATION ALBITIZATION	? DISSOLUTION
CHERT	? DISSOLUTION	
KAOLINITE	PRECIPITATION	? DISSOLUTION
CHLORITE	PRECIPITATION	
ILLITE		? ILLITIZATION
MICA	? DISSOLUTION	? DISSOLUTION
PYRITE	PRECIPITATION	PRECIPITATION
CALCITE	PRECIPITATION	PRECIPITATION RECRYST. FILLING OF FRACT.
SIDERITE		PRECIP./RECRYST.

Fig. 12. The main diagenetic events detected in the Triassic of Franz Josef Land.

breaks are found in the Alexandra Island well (between Olenekian and Anisian) and Hayes Island well (post Anisian, pre Ladinian). So far these breaks, however, do not seem to have any detectable diagenetic effects, except in the organic maturation patterns. A high local thermal impact from the magmatic activity is evident in both the composition of organic matter and in the hornfelsisation.

In Late Jurassic/Early Cretaceous times magmatic activity happened in the Franz Josef Land region. During the period the sediments were baked, the organic matter fried and carbonates precipitated and/or recrystallized. It seems possible that the magmatic activity formed the heat source for the liberation of carbondioxide from the organic rich units. The cracks and joints formed during intrusion may at some point have functioned as important transport avenues for (?)hydrothermal fluids. The joints were at a later stage closed by precipitation from the same solutions. The influence of intrusion is chemically clearly seen in the alteration of organic matter, where it can be traced for several meters in the sedimentary sequences. In contrast the metamorphic changes are seen in the physical properties of the sediments only a few metres from the various intrusions.

Several authigenic phases have been observed in the Triassic successions (Fig. 12), with siderite and calcite as the most common ones; both with late, but different diagenetic origin. The oxygen isotope analyses clearly display their late diagenetic, possible organic origin, indicating formation as an indirect effect of the basaltic intrusion activity, either by precipitation or recrystallisation of carbonate material.

In addition tiny amounts of early diagenetic quartz, feldspar and kaolinite are also found. A few occurrences of early diagenetic chlorite, originally probably chamosite or bertierine, occur too. The early diagenetic kaolinite may have been formed as results of feldspar alteration. Increasing amounts of kaolinite combined with increasing degrees of feldspar disolution are seen downhole, indicating possible mutual relations.

The siderite and most of the calcite are morphologically seen to surround and consequently succeed all other authigenic phases. This is also supported by the isotopic analyses showing a late time of formation.

Since the degree of cementation in the Franz Josef Land cores studied is well developed, however, with an evident lack of stylolitization and serious quartz cementation, it seems reasonable to suggest that the cores have not suffered burial much deeper than the present depth. The samples have modest porosities (0-11.8%), due to extensive carbonate cementation, their clay content and their high amounts of feldspar and rock fragments. Being controlled by late diagenetic mechanisms the existence of available porespace even at a late phase of burial, may in other places of the region have left porosity available for migrating hydrocarbons.

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7. GEOCHEMISTRY AND PETROGENETIC SIGNIFICANCE OF MESOZOIC MAGMATISM ON FRANZ JOSEF LAND, NORTHEASTERN BARENTS SEA

BY H. AMUNDSEN[1], A. EVDOKIMOV[2], V.D. DIBNER[2] & A. ANDRESEN[3]:

ABSTRACT

In an attempt to decipher the origin and petrotectonic significance of Early Cretaceous volcanism on Franz Josef Land, 18 basalt samples collected from two sections (Mable Island and Hooker Island) have been analyzed for their major- and trace element composition. 16 of these samples were also analyzed for their $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios. The major element data classify the basalts as subalkaline tholeiites. Nd-epsilon values between +4 and +6 indicate a mantle source for the basalts. The $^{87}Sr/^{86}Sr$ ratios, however, varies between values close to the mantle array (0.703) and up to crustal values (0.706) and suggest some crustal contamination. The data, taken together, suggests that the Franz Josef Land lavas were derived by melting of an originally depleted mantle source which at a later stage incorporated some seawater during or after emplacement.

The large volumes of basaltic volcanism combined with a predominance of northwest-striking dolerite dikes (c.80% of all dikes) suggest that the Createceous magmatism on Franz Josef Land was related to an aborted NW trending rift. It is further speculated that this failed rift was associated with a tripple junction located northwest of the archipelago during the Mesozoic, and that the other two rifts developed into the rifted margin bordering the Lomonosov Ridge towards the Canada Basin.

INTRODUCTION

Evolution of the deep Arctic basins, particularly the Canada Basin floored by oceanic crust, is poorly constrained due to limited geophysical and geological information Lawver et al. (1990). Large volumes of Mesozoic magmatic rocks that may hold important information regarding the tectonic evolution of the Canada and Eurasia Basins are however present in the sedimentary sequences making up the continental shelf surrounding the basins. Mesozoic magmatic rocks are known from the Arctic Canada Islands (Balkwill 1978; Embry 1991), Svalbard (Steel & Worsley 1984), Kong Karls Land (Smith et al. 1976), Franz Josef Land (Bailey & Brooks 1988 and references therein). Permo-Triassic flood basalts are also known from northern Sibiria (Sharma et al. 1991) (Fig. 1). The exact age and geochemical character of these magmatic rocks are however variably well known and need to be studied before reliable correlations and reconstructions can be made. To characterize the magmatism on Franz Josef Land, more than 100 samples of sills, dikes and flows, collected by Russian expeditions to the archipelago between 1950 and 1980, are currently being analysed for this purpose. The the aim of this paper is to present some preliminary new major and trace element data, including REE data, and Sr and Nd isotopic data on basaltic rocks from Mabel and Hooker Islands (Fig. 2), and to discuss the petrogenetic significance of these

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geochemical data. Additional data from the other islands, including some $^{40}Ar/^{39}Ar$ ages, will be published in a forthcomming issue of Polar Research.

GEOLOGICAL SETTING

Franz Josef Land is a group of islands located at the northern edge of the Barents Sea continental shelf (Fig. 1). The shelf is tilted gently southwards so that Franz Josef Land is located, like Svalbard, on the shallow uptilted northern edge of the shelf. The Barents Sea shelf is bordered to the north by a rifted margin and the Nansen and Amundsen Basins, separated by the Nansen Ridge (Eldholm et al. 1990). Ocean floor spreading along the Nansen Ridge, starting in Early Tertiary (?) time, led to separation of the Lomonosov Ridge from the Barents Sea shelf (Jokat et al. 1992).

The Barents Sea shelf has been a stable epicontinental platform since the Late Paleozoic and through the Mesozoic (Steel & Worsely 1984). On a pre-rift reconstruction this stable platform can be traced from Arctic Canada (Sverdrup Basin) through Svalbard (Embry 1991), Kong Karls Land and Franz Josef Land to the Arctic Urals, the lower Yenisei and the islands of the Kara Sea (Nalivkin 1973). A major magmatic event with eruption and intrusion of large volumes of tholeiitic magmas in Late Jurassic and Early Cretaceous times is recognized in Svalbard, Kong Karls Land, and Franz Josef Land. This magmatic event appears to coincide with a broad northerly uplift of the Barents Sea platform as inferred from sediment transport patterns (Dibner et al. 1962; Steel & Worsley 1984). A second period of regional uplift is recorded in Svalbard in the Late Cretaceous, inferred to be related to a hot spot below the Yermak plateau (Eldholm et al. 1990).

The Franz Josef Land archipelago is separated from northeastern Siberia by a major embayment in the shelf edge, interpreted as a sedimentary basin joining southwards with the Pechora Basin. Bailey & Brooks (1988), who analysed the major and trace element composition of five basalt samples from Northbrook Island (Cape Flores) and one basalt sample from George Island (Cape Forbes) in their study, speculated that this embayment was controlled by a ?Cretaceous rift. In this paper we present additional major and trace element analyses together with some preliminary Sr and Nd isotope data from a separate suite of basalt samples in an attempt to understand the source and tectonic significance of Mesozoic magmatism on Franz Josef Land.

GEOLOGY OF FRANZ JOSEF LAND

Extensive glacial cover on many of the islands limits the surface exposure on Franz Josef Land. Much of the stratigraphic and depositional evolution of the region is thus based on data from three bore holes, drilled on the Hayes, Severnaya and Nagurskaya Islands (Fig 2), respectively, and limited surface exposure.

The geology of Franz Josef Land has been summarized in several publications by Dibner and coworkers (Dibner 1970; Dibner & Sedova 1959; Dibner & Shulgina 1960; Dibner et al.1962) and by Churkin et al. (1981) and the reader is referred to these publications for detailed information on the history of geological exploration, stratigraphy and paleogeography of the region. Only the main features from these publications are presented here. New detailed information on the stratigraphy and depositional environment of the Triassic succession has recently been presented by Dypvik et al. (1998).

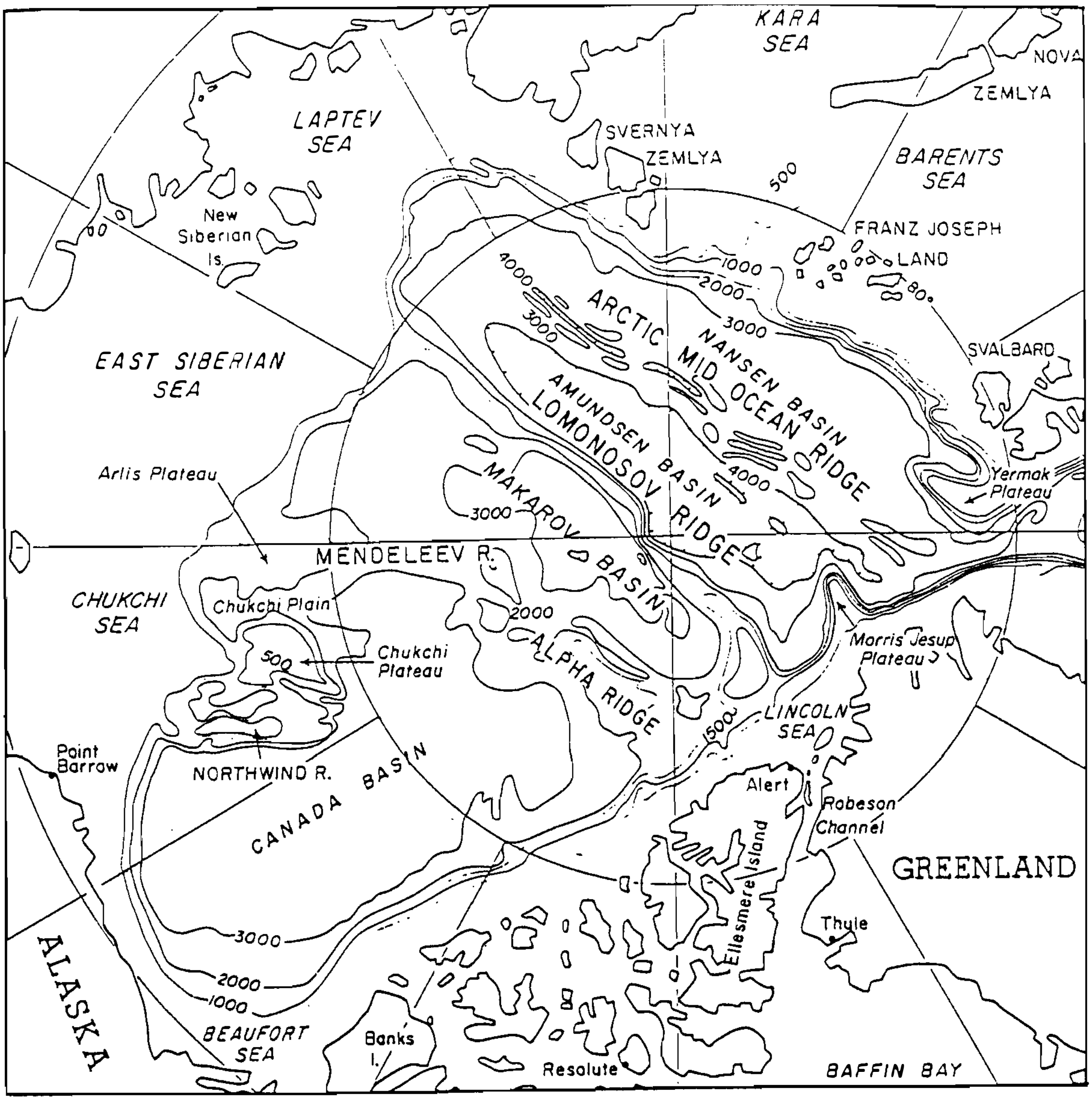


Fig.1. Simplified map of the Barents Sea and Arctic Basins showing the location of the main structural features and volcanic provinces and discussed in the text.

The Upper Paleozoic and Mesozoic platform rocks making up Franz Josef Land overlie a folded and metamorphic upper Proterozoic basement (Tarakhovskiy et al. 1983) recorded in the Alexandra Island well (Fig. 2). No basement was drilled in the other two 2-3000 m deep wells. The archipelago is dominated by Mesozoic strata intruded by dolerite dikes and sills, but Carboniferous shale and coal beds have been recorded on Alexandra Island (Fig. 2) and appear also to be present in the section from Hooker Island (Figs. 2 and 3). A major hiatus separates the Carboniferous beds from overlying, northwest dipping Upper Triassic and Jurassic strata on Hooker Island. The Jurassic strata are unconformably capped by Lower Cretaceous basalts and interbedded sandstone and carbonaceous shale with lenses of coal (Fig 3). A Hauterivian to Albian age is indicated for the strata interbedded with the volcanic flows analysed in this study.

Dikes of dolerite and gabbro-dolerite are common on Franz Josef Land; forming linear ridges easily recognized on aerial photographes. These vertically to steeply dipping dikes show two prominent trends. The majority of mapped dikes (80%) has a northwestlerly trend, whereas 10% of the recorded dikes trend northeasterly. The remaining 10% of the

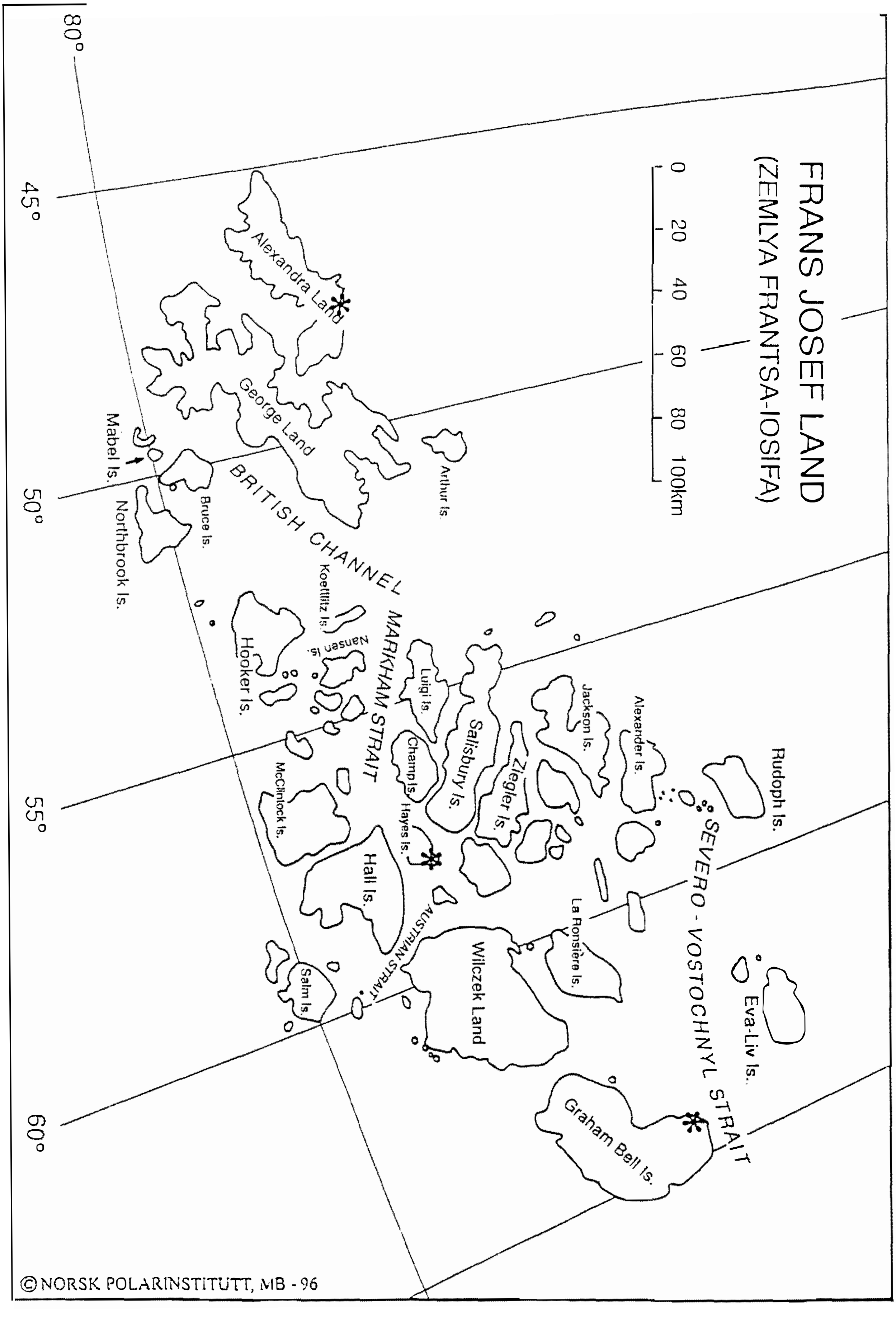


Fig. 2. Map of Franz Josef Land archipelago showing the location of the Hooker and Mabel Islands where the analyzed samples were collected. Stars mark the position of the three deep wells drilled on Franz Josef Land.

dikes trend west-northwesterly, north-south and east-northeasterly. Dikes with a northeasterly trend appear to be the most laterally extensive dikes; for example the Diagonalnya Dike has been traced for more than 100 km across the Graham Bell, Wilcsek Land, Hayes and Yuzhny Komsomolsky islands. Ditmar et al. (1981) concluded that the northwesterly trending dikes are post-Early Cretaceous in age and the youngest dike swarm, based on truncation of Cenomanian sandstones on Hoffman Island (Fig.2).

Effusive bodies, represented by basalt sheets, tuff breccia of pyroclastic rocks, and numerous lava flows, occupy vast areas in the central and western parts of Franz Josef Land. Field relationships suggest they are the results of repeated volcanic activity along linear magma chambers. Since the region is dominated by northwesterly trending dikes cutting across Lower Cretaceous sedimentary-volcanic sequences it seems reasonable to interpret the dikes as feeders for the basalt sheets.

MATERIAL

The eighteen samples analysed in this study were collected in two sections on Mabel and Hooker Islands respectyively, and include both flows and ?pyroclastic deposits (Fig. 3). The samples from Hooker Island were collected from three distinct flows separated by thin siltstone beds. The Mable Island samples represent most likely six or more separate flows. Sediments interbedded with the basaltic flows indicate a Cretaceous age for the volcanism. The exact stratigraphic position of the analysed samples are given in Fig. 3.

ANALYTICAL METHODS

The major and some trace element concentrations in the samples were determined by X-ray fluorecence using a Philips PW 1400 spectrometer and Philips PW 1732/10 generator at the University of Tromsø. Major element composition was determined on glass tablets (duplicates) composed of $Li_2B_4O_7$ and rock powder (8:1). Trace elements (see Table 1) were determined on pressed tablets of rock powder. A detailed description of procedures used during preparation and analyses is available on request.

Additional trace elements, including REE, were determined by NAA at the Mineralogical-Geological Museum, University of Oslo. The relatively short life-time (n, gamma)-isotopes of the elements Ho, Sm, Lu, U (Np-239), As, Sb, Br, W, Rb, Ga, Na, K and La were detected two to four days after irridation using epithermal INAA. The sample detector distance was decreased due to the lower decay activity. The elements Sm, Ti, Yb, Ba, U, Th, Hf, Ce, Ni (Co-58), Tb, Sc, Rb, Fe, Zn, Co, Eu and La were measured two weeks after irridation. Ce, Ti, Lu, Cr, Hf, Cs, Fe, Tb, Sc, Eu, Co and Ta were determined from samples irridated by the thermal INAA-technique. The isotopes of Sm, U, (Np), Br, Co and Fe were also detected in at least two peaks at different activation levels of each run. The elements Ce, Ti, Cr, Hf, Cs, Fe, Tb, Sc, Co, and Ta were thus determined by both epithermal and thermal techniques.

Two or three international standard samples were included in each run. All samples were calibrated to the BCR-1 standard (Govindaraju 1989) values. The calculated and literature values of the standard G-2 (granite) and PCC (peridotite) are compared for control. Each run included two samples with five repeated measurements to calculate the precision levels for each element. The precision is given as the standard diviation (one sigma of the mean five values). For elements analysed in several peaks and runs the standard deviation and weighted averages represent data from two (combination of thermal and epithermal detection) up to 20 values. Each detected peak is individually

Table 1. Major and trace element composition of basaltic flows from Hooker and Mable Islands, Franz Josef Land. Samples 12-1-1 and 23-2 to 23-9 are from Mabel Island, the rest from Hooker Island. Their exact stratigraphic positions are given in Fig. 3.

Unit	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.
Smp.	12-1-1	23-2	23-4	23-5	23-6	23-7	23-8	23-9	67-1
Lith.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.
SIO2	48.66	49.64	47.29	49.69	47.81	47.89	47.72	49.86	48.95
TIO2	1.44	1.97	1.92	2.01	1.72	1.83	1.69	2.98	1.82
AL2O3	14.61	15.44	14.46	14.84	14.81	14.53	14.17	11.42	14.41
FEO	10.67	11.89	12.28	11.90	12.19	12.38	11.78	16.46	11.60
MNO	0.16	0.18	0.21	0.21	0.23	0.24	0.29	0.26	0.21
MGO	6.47	4.79	6.03	4.71	6.08	6.17	5.41	4.36	6.32
CAO	11.26	10.65	10.27	10.82	11.16	11.62	11.84	8.48	11.15
NA2O	2.08	2.31	2.06	2.37	2.15	2.09	2.25	2.67	2.25
K2O	0.23	0.41	0.11	0.37	0.13	0.11	0.18	0.53	0.25
P2O5	0.13	0.21	0.18	0.21	0.15	0.19	0.19	0.31	0.19
Sum	96.90	98.81	96.17	98.45	97.78	98.43	96.83	99.16	98.44
Mg/(Mg+Fe)	51.9	41.8	46.7	41.4	47.1	47.0	45.0	32.1	49.3
Cs	<0.1	0.23	0.06	0.08	0.46	0.10	0.03	0.14	0.37
Rb	6	12	1.35	9.30	3.59	1.72	1.49	9.82	7.67
Ba	104	146	113	146	155	157	240	254	169
Sr	244	234	264	216	230	232	204	180	182
Br	0.03	0.11	0.14	<0.1	0.17	<0.1	0.13	0.25	0.12
Th	1.13	1.31	0.79	1.03	0.93	1.12	1.89	1.82	1.39
U	0.84	1.22	0.69	0.95	0.04	1.10	0.93	1.51	0.04
Ta	0.34	0.75	0.92	0.51	0.51	0.72	0.51	0.81	0.55
Nb	<1.5	9	3	6	8	11	7	16	7
La	7.81	8.40	7.75	11.20	8.73	11.02	11.41	17.13	10.14
Ce	15	21	15	18	18	22	25	35	21
Nd	na	na	13.44	17.27	12.96	14.80	15.50	24.52	14.77
Sm	na	4.57	3.87	4.91	3.76	4.14	4.18	6.97	4.22
Eu	1.20	1.61	1.69	1.65	1.36	1.52	1.24	2.21	1.34
Tb	0.69	0.89	0.74	0.89	0.85	0.92	0.96	1.42	0.90
Ho	0.54	0.91	0.78	1.10	1.02	0.72	1.05	1.30	1.20
Yb	1.91	2.75	1.87	2.65	2.73	2.76	2.93	4.16	2.64
Lu	0.51	0.35	0.18	0.23	0.36	0.37	0.35	0.61	0.33
Hf	2.10	2.93	2.51	3.22	2.69	3.21	2.94	4.66	2.88
Zr	91	124	118	152	118	123	127	223	114
Y	21	32	27	34	28	29	29	57	29
Sc	35	36	34	40	41	42	41	40	39
V	364	420	455	358	423	421	385	674	400
Cr	192	214	140	150	148	178	148	76	291
Ni	67	53	60	56	70	61	64	27	80
Co	41	43	40	35	44	47	46	42	45
Zn	100	104	73	80	103	103	120	107	107
W	0.74	0.64	1.18	0.57	0.71	0.10	0.57	0.56	0.66
Ga	11	16	9	13	19	22	48	21	27
As	0.72	1.21	0.24	0.64	0.33	0.77	0.23	0.64	0.55
Sb	0.62	0.21	0.04	0.12	0.00	0.09	0.07	0.12	0.10
Au (ppb)	0.64	0.70	1.12	2.22	0.18	0.78	2.33	0.43	1.53

E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	E. CRET.	TRIAS.	TRIAS.
69-2	69-3	69-4	69-5	69-7	69-8	69-9	69-10	70-4	71-2	20-6
VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	VOLC.	SED.	SED.
44.48	47.15	47.58	47.05	49.62	49.06	46.97	47.88	49.01	30.46	59.61
1.82	1.73	1.77	1.79	1.59	2.13	1.58	1.67	1.81	0.58	0.27
17.72	13.94	14.78	14.74	14.93	12.91	14.31	14.29	14.94	7.62	3.38
10.68	12.00	10.96	12.00	10.84	12.47	11.03	10.60	11.53	4.00	4.54
0.12	0.18	0.23	0.19	0.21	0.26	0.22	0.27	0.21	0.51	0.42
3.89	6.31	6.66	6.21	6.39	6.36	7.29	6.93	5.88	1.08	2.26
10.57	11.36	11.65	10.33	11.71	10.93	10.21	8.61	11.36	26.82	13.59
2.54	2.22	2.03	2.56	2.41	2.41	2.17	2.46	2.19	0.08	0.32
0.09	0.08	0.09	0.19	0.15	0.18	0.08	1.12	0.18	0.72	0.79
0.18	0.18	0.17	0.17	0.14	0.21	0.15	0.15	0.17	0.04	0.02
93.28	96.48	97.14	96.56	99.19	98.31	95.24	95.16	98.56	71.91	85.20
39.4	48.4	52.0	48.0	51.2	47.6	54.1	53.8	47.6	32.5	47.0
0.03	0.17	0.00	0.32	0.14	0.11	0.24	0.37	0.34	3.40	0.23
0.75	1.74	1.09	6.05	3.45	5.40	0.90	74.07	82.14	45.30	19.15
146	108	115	187	124	150	167	773	146	183	215
207	191	196	224	194	183	190	182	195	108	208
nd	<0.1	0.08	0.13	0.04	0.18	0.08	0.26	0.04	2.06	0.17
1.17	0.79	1.21	1.16	1.07	1.56	1.06	1.10	1.20	4.17	1.94
0.05	0.78	0.81	0.72	1.04	0.04	0.65	1.25	1.10	0.60	0.38
0.75	0.70	0.56	0.41	0.67	0.61	0.42	0.38	0.66	0.51	1.08
8	7	9	7	<1.5	6	7	4	6	8	3
nd	9.24	8.26	7.92	8.90	11.40	8.20	9.10	8.62	18.50	8.25
18	17	22	16	18	24	16	21	20	31	17
13.73	14.34	13.85	13.84	11.22	15.15	11.22	13.73	14.44	12.53	9.16
3.94	3.97	4.08	3.99	3.70	4.25	3.65	3.94	4.11	2.14	1.72
1.31	1.32	1.55	1.43	1.42	1.90	1.25	1.63	1.68	0.47	0.59
0.70	0.68	0.81	0.79	0.87	1.05	0.75	0.83	0.87	0.29	0.31
0.69	0.60	1.10	0.79	0.70	1.35	0.98	0.95	0.77	0.59	0.33
2.43	1.89	2.72	2.62	2.38	3.22	2.22	2.35	2.72	1.34	1.06
0.26	0.25	0.30	0.29	0.25	0.39	0.27	0.36	0.20	0.19	0.22
2.88	2.40	2.85	2.57	2.66	3.56	2.41	2.36	3.12	2.80	3.32
125	111	122	121	87	132	97	109	107	119	154
28	28	28	29	21	34	25	28	33	12	10
38	38	41	35	40	46	32	40	39	6	7
448	398	400	401	370	480	359	379	393	80	60
270	201	325	226	286	246	226	320	260	72	229
110	85	91	72	88	60	83	81	81	18	15
20	39	45	39	44	45	40	42	43	7	7
95	75	106	87	84	111	101	99	91	64	80
nd	0.25	0.99	0.38	0.09	0.89	0.82	0.06	0.66	1.61	1.29
nd	17	42	7	6	23	36	24	14	22	12
0.35	0.57	0.79	0.39	0.33	1.92	0.23	0.27	6.34	0.48	1.49
0.05	0.05	0.02	0.11	0.06	0.14	0.06	0.07	0.35	0.07	0.30
nd	1.37	1.65	0.07	1.09	3.09	13.13	1.09	1.03	1.23	0.88

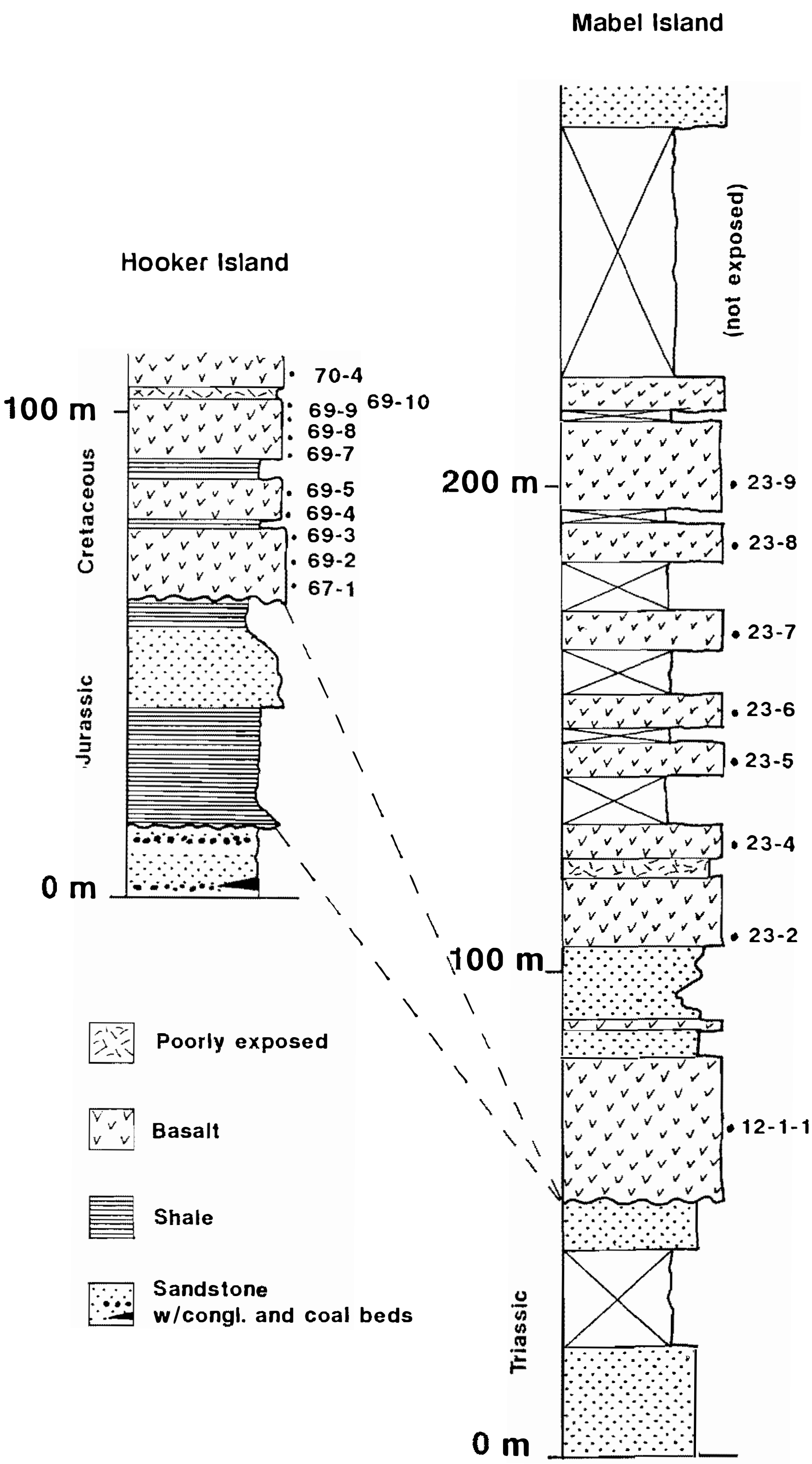


Fig. 3. Measured sections from Hooker and Mabel Islands, showing depositional ages for sediments and stratigraphic position of the analysed basalt samples.

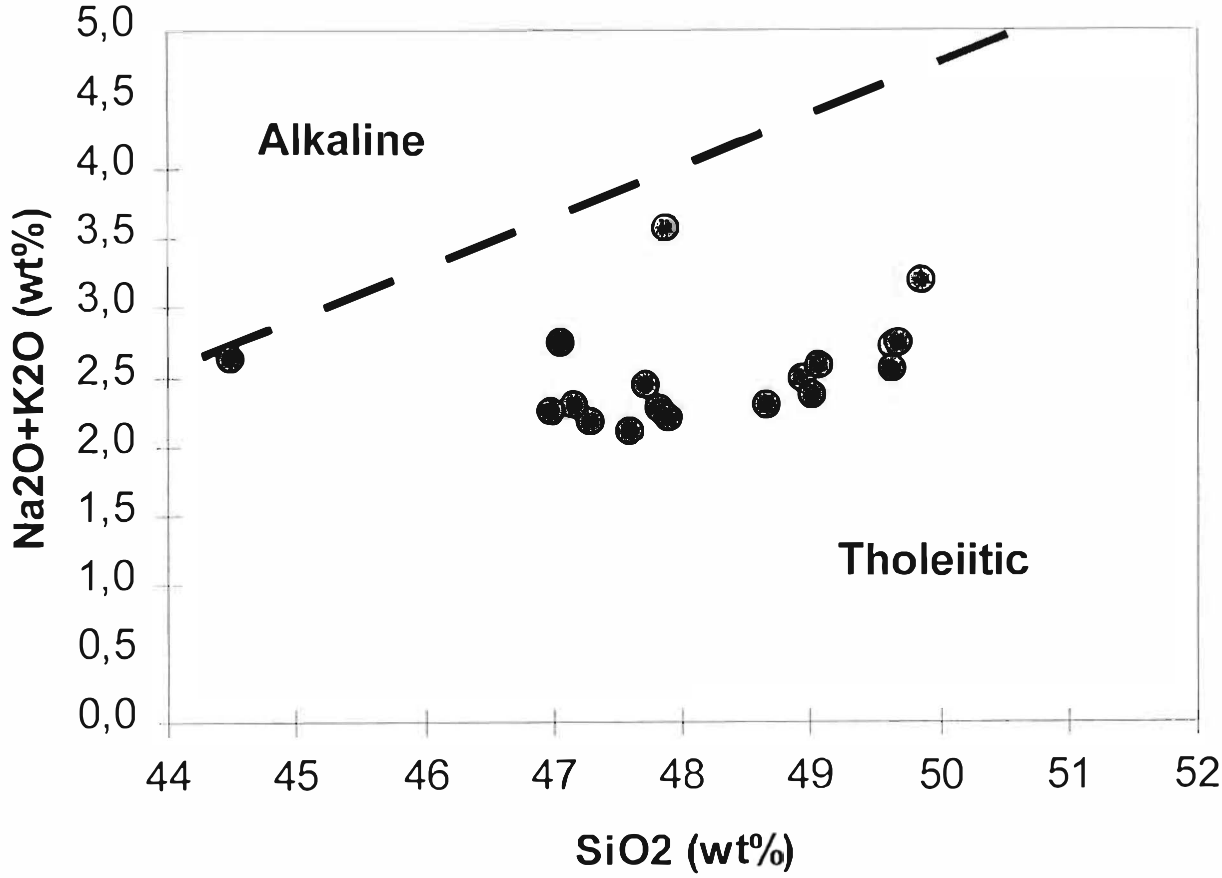


Fig. 4. Alkali-Silika diagram showing composition of the analyzed Franz Josef Land volcanic flows.

compared to get the best representative values. The background values are detected by running the Al-sample. In the case of Ga the activity from the Al-foil represents 30-50% of total radiation. Corrections of the foil activity are also made for Ti, Cr, and Ni.Sr- and Nd-isotopes were determined by mass spectrometry (VG 354 Micromass) at the Mineralogical-Geological Museum, University of Oslo. The analytical procedures are described in detail by Jacobsen & Heier (1978) and Sundvoll et al. (1992).

RESULTS

Major and trace element data

Major and trace element composition of the 18 analysed samples are listed in Table 1. SiO_2 content generally range from 47 to 50 wt %. MgO contents range between 4 and 7 wt % with mg (100xMg/(Mg+Fe)) varying from 32 to 54. TiO_2 content ranges from 1.4 to 3 wt % and Na_2O values are relatively low ranging from 2 to 2.5 wt%. All analysed samples exept one classify as subalkaline tholeiites in a silica versus alkali diagram (Fig. 4).

The obtained trace element data from the analysed samples, normalized to values for primordial mantle, are given in Table 1 and plotted in Fig. 5. From this figure we can observe that the concentrations of Cs, Rb, and K are strongly variable, ranging from 1 to 100 times primordial mantle. Concentrations of U show a bimodal distribution, being either c. 1.5, or 30-60 times the primordial mantle composition. With these exceptions,

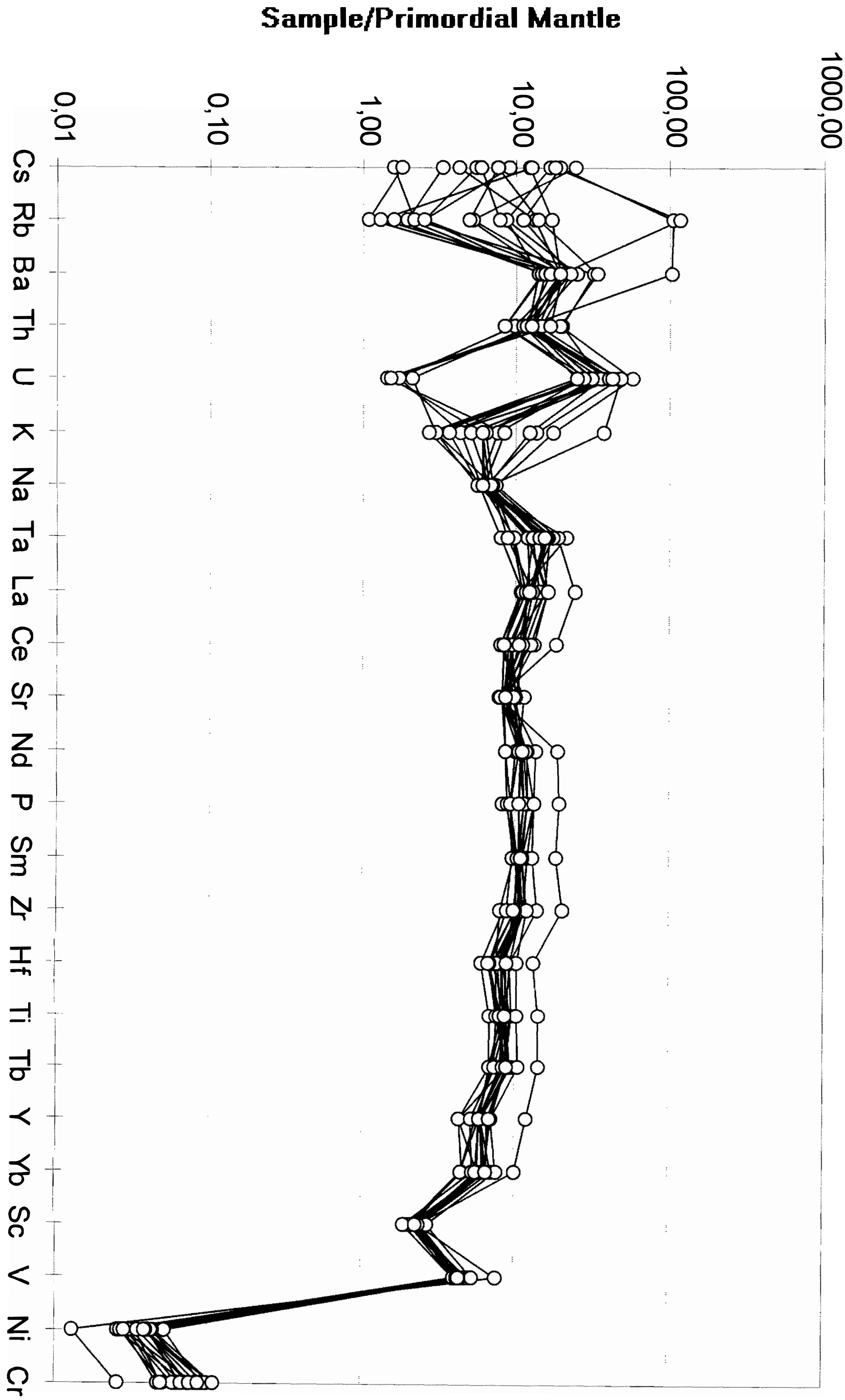
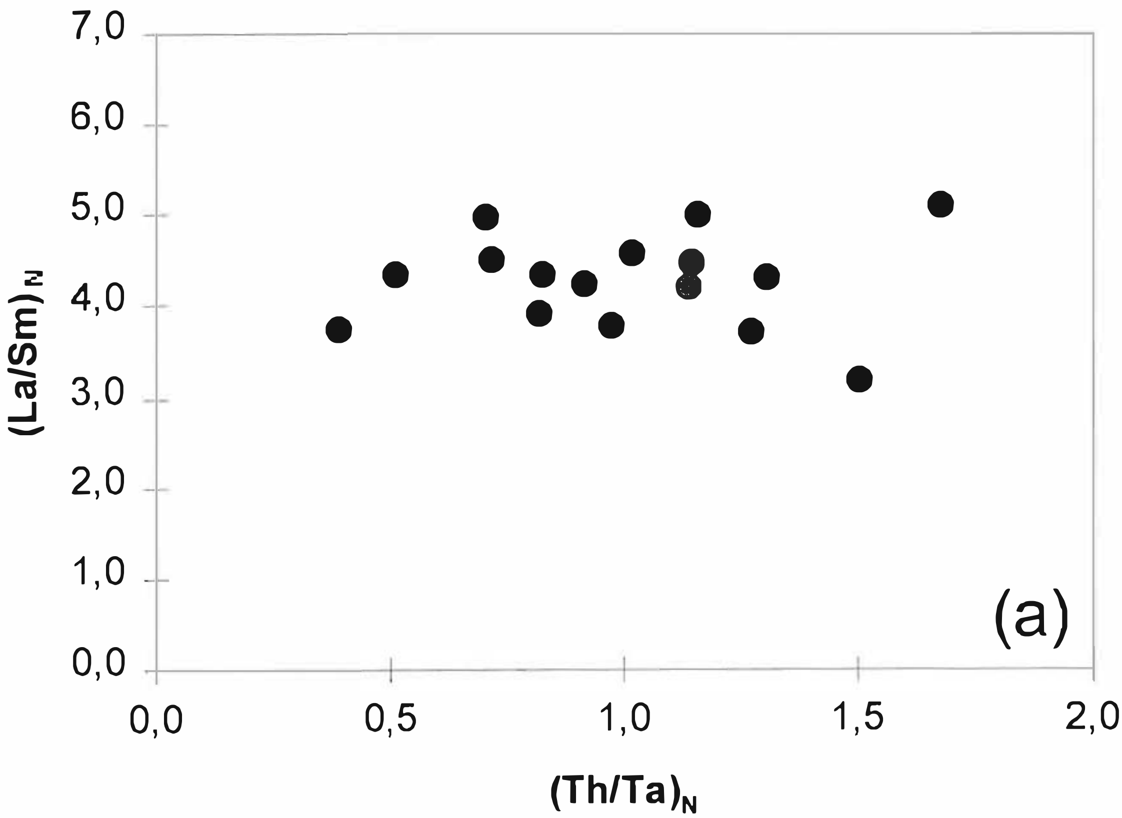


Fig. 5. Spider diagram showing trace element composition of Franz Josef Land volcanics, normalized to values for primordial mantle (from Wood 1979 and Sun 1982).



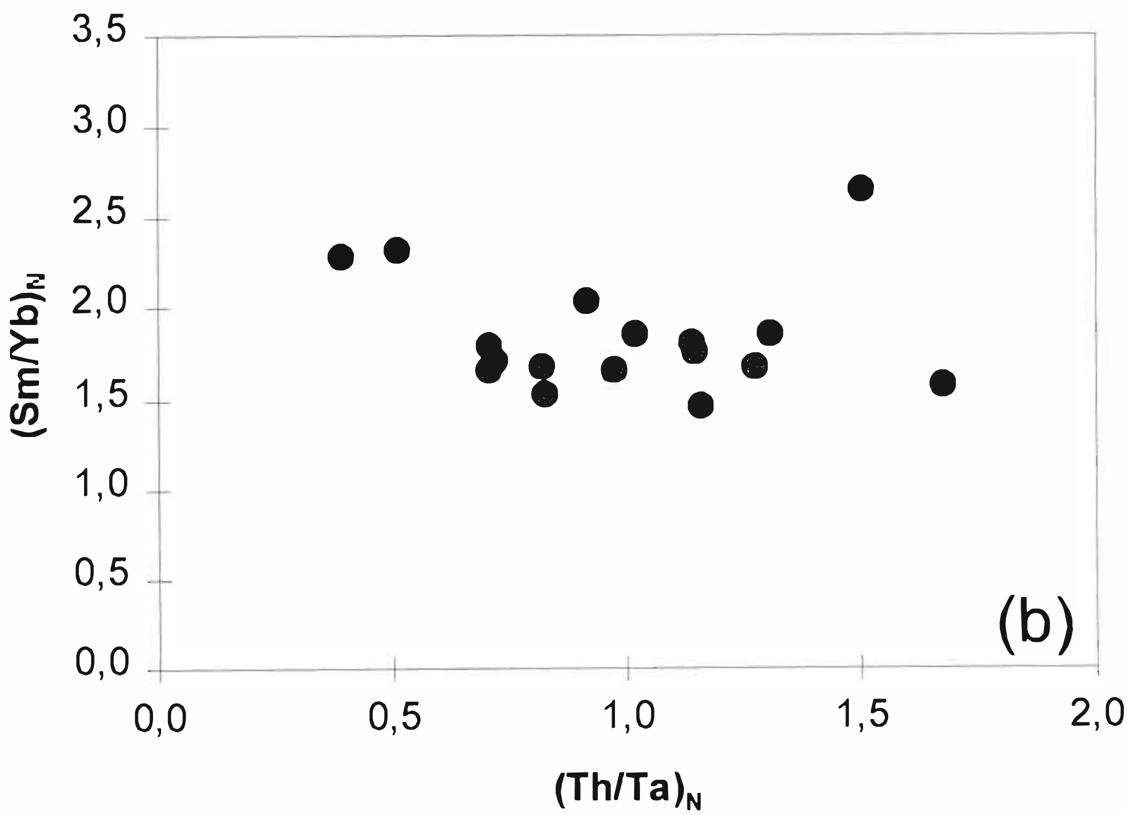


Fig. 6. (La/Sm)N (a) and (Sm/Yb)N (b) plotted against (Th/Ta)N for Franz Josef Land volcanics. Compositional fields for MORB (mid-ocean ridge basalt), OIB (ocean island basalt), and CFB (continental flood basalts) (from Wooden et al. 1993) are shown for comparison.

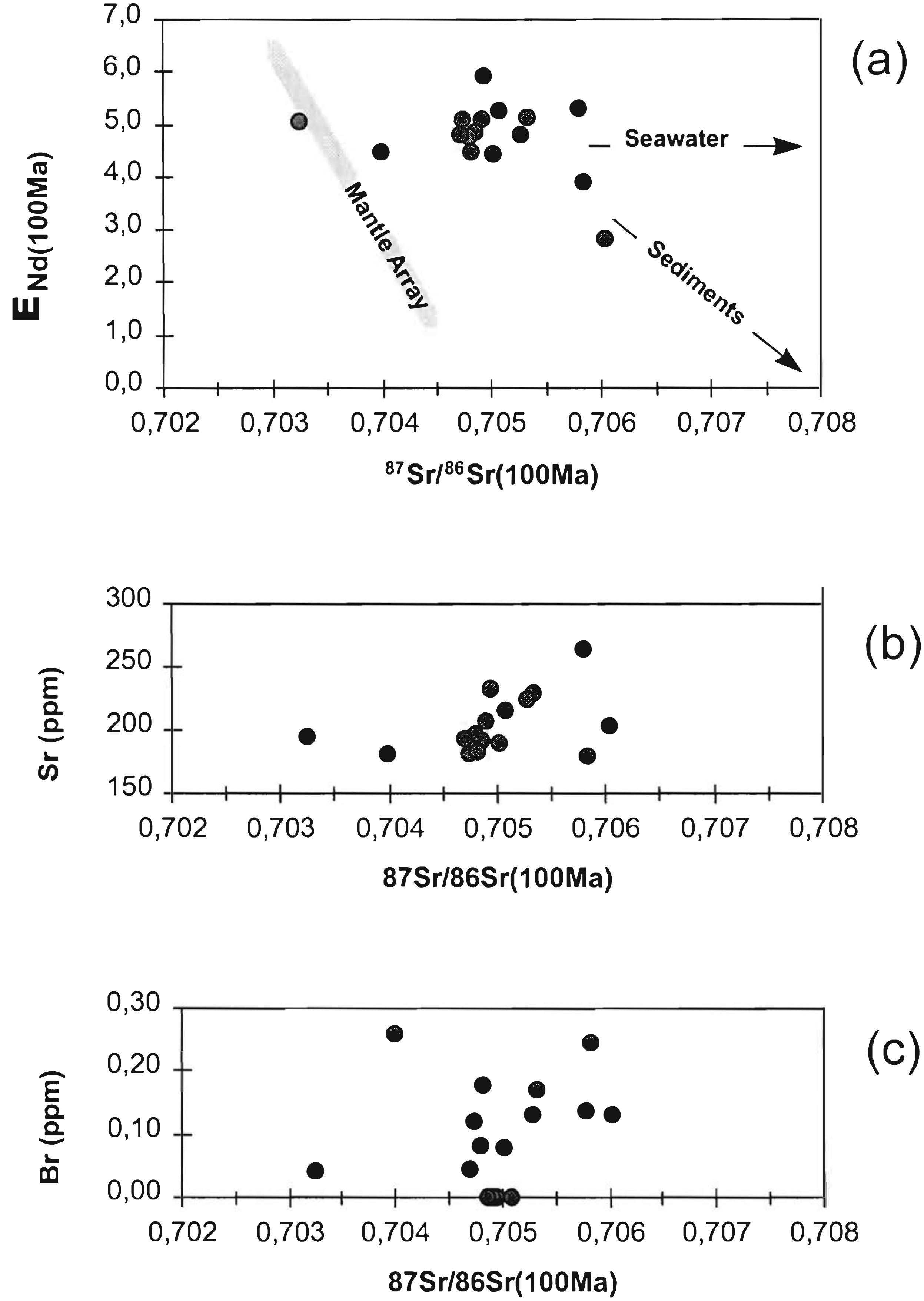


Fig. 7. (a) Epsilon Nd and Sr isotopic composition for Franz Josef Land volcanic rocks recalculated back to 100 Ma. Stipled line denotes mantle array. (b) Relationship between Sr isotopic composition recalculated back to 100 Ma and Sr concentration. (c) Relationship between Sr isotopic composition recalculated back to 100 Ma and Br concentration.

Table 2. Sr and Nd isotope data on basaltic rocks from Hooker and Mable Islands, Franz Josef Land. The stratigraphic positions of the individual samples are given in Fig. 4.

Unit	Smp	Lith	Sm ppm	Nd ppm	147Sm/ 144Nd	143Nd/ 144Nd	2s	(110Ma) EpsNd	Rb	Sr	87Rb/ 86Sr	87Sr/ 86Sr	2s	(110Ma) 87Sr/ 86Sr
E. CRET.	23-4	VOLC	3.87	13.44	0.1754	0.512895	6	5.3	1.35	263.7	0.0148	0.705812	8	0.705789
E. CRET.	23-5	VOLC	4.91	17.27	0.1731	0.512891	5	5.3	9.30	215.6	0.1252	0.705247	5	0.705055
E. CRET.	23-6	VOLC	3.76	12.96	0.1768	0.512887	5	5.1	3.59	229.6	0.0454	0.705392	11	0.705323
E. CRET.	23-7	VOLC	4.14	14.80	0.1705	0.512922	6	5.9	1.72	232.1	0.0215	0.704961	12	0.704928
E. CRET.	23-8	VOLC	4.18	15.50	0.1643	0.512760	7	2.8	3.77	203.8	0.0537	0.706111	19	0.706029
E. CRET.	23-9	VOLC	6.97	24.52	0.1731	0.512821	5	3.9	10.82	179.8	0.1748	0.706074	18	0.705807
E. CRET.	67-1	VOLC	4.22	14.77	0.1741	0.512883	5	5.1	7.51	181.6	0.1201	0.704903	10	0.704719
E. CRET.	69-1	VOLC	3.57	12.28	0.1769	0.512871	11	4.8	0.75	206.9	0.0106	0.705371	4	0.705355
E. CRET.	69-2	VOLC	3.97	14.06	0.1721	0.512882	10	5.1	6.56	975.0	0.0195	0.704934	9	0.704904
E. CRET.	69-3	VOLC	4.08	14.38	0.1725	0.512870	6	4.9	1.74	190.7	0.0266	0.704889	8	0.704848
E. CRET.	69-4	VOLC	3.98	14.07	0.1724	0.512866	8	4.8	1.09	196.2	0.0162	0.704823	11	0.704798
E. CRET.	69-5	VOLC	3.99	13.84	0.1758	0.512870	5	4.8	6.05	223.9	0.0784	0.705384	4	0.705264
E. CRET.	69-7	VOLC	3.71	12.91	0.1751	0.512870	6	4.8	3.45	193.6	0.0518	0.704778	8	0.704699
E. CRET.	69-8	VOLC	5.97	20.58	0.1768	0.512854	12	4.5	5.40	183.3	0.0855	0.704933	7	0.704802
E. CRET.	69-9	VOLC	3.64	12.83	0.1726	0.512848	10	4.4	0.90	189.8	0.0137	0.705036	7	0.705015
E. CRET.	69-10	VOLC	3.94	13.73	0.1745	0.512852	6	4.5	74.07	181.8	1.1835	0.705630	12	0.703819
E. CRET.	70-4	VOLC	4.11	14.44	0.1734	0.512881	6	5.1	82.14	195.4	1.2212	0.704943	12	0.703074
TRIAS	71-2	SED	2.14	12.53	0.1041	0.512099	4	-9.2	45.30	107.7	1.2226	0.712887	13	0.711016
TRIAS	20-6	SED	1.72	8.16	0.1284	0.512430	15	-3.1	19.15	208.2	0.2671	0.708716	10	0.708307

the incompatible elements plotted in Fig. 6, from Th to Tb, all show concentrations around ten times primordial mantle. Interrelationships between REE, Th and Ta concentrations are illustrated in Fig. 6. While normalized values for La/Sm scatter between 4 and 5, similar to ocean island basalts (OIB), are normalized values for Sm/Yb c. 2, comparable to some MORB. Values for (Th/Ta)N vs (La/Sm)N scatter between 0.3 and 1.7. Strongly compatible elements such as Ni and Cr, show concentrations between 0.01 and 0.1 times primordial mantle composition (Fig. 5).

Sr- and Nd-isotope data

Sr and Nd isotopic data from the 16 analysed samples are listed in Table 2, and the data are plotted recalculated back to 100 Ma in Fig. 7a. The bulk of the samples show values for epsilon Nd at 100 Ma scattering between +4 and +6, typical for mantle derived melts. $^{87}Sr/^{86}Sr$ ratios, however, vary from values close to the mantle array (0.703) up to crustal values (0.706). Furthermore, the $^{87}Sr/^{86}Sr$ ratios are positively correlated with Sr and Br concentrations (Fig. 7b).

DISCUSSION

The major element composition of the Franz Josef Land basalts studied here show them to be tholeiitic basalts, similar to previously studied dolerites from the same area (Bailey & Brooks 1988). Despite their position in a continental environment, their trace element signature do not mimic that of continental flood basalts (CFB) (Fig. 6). Rather they seem to have affinities towards ocean island basalts (OIB). The relatively flat trace element patterns illustrated in Fig. 6, with values around ten times primordial mantle composition, mimics the signature of E-type MORB (e.g. Sun & McDonough 1989). Thus the chemical composition of the Franz Josef Land basalts suggests they were derived by melting of an originally depleted mantle source, overprinted by a later enrichment event. A similar conclusion was indicated by Bailey & Brooks (1988) based on their major element data.

The importance of later enrichment processes is substantiated by the Nd and Sr isotopic data. Mantle enrichment processes most commonly involve introduction of Nd with relatively enriched isotopic composition (i.e. low epsilon Nd values)., as well as Sr with high 87/86 ratios. In case of the Franz Josef Land basalts, however, the isotopic compositions illustrated in Fig. 8a show increasing $^{87}Sr/^{86}Sr$ values at near constant epsilon Nd values. Such an isotopic imprint is characteristic of basalts contaminated through interaction with seawater, or interaction of mantle source material mixed with marine sedimentary material. The importance of interaction with marine material is further substantiatied by the positive correlation beteen $^{87}Sr/^{86}Sr$ and both Sr and Br concentrations. Whether this imprint reflects contamination by surrounding Cretaceous sediments during emplacement or later interaction with seawater cannot be discriminated by the data presented here.

POSSIBLE TECTONIC IMPLICATIONS

The high number of post-Early Cretaceous dolerite dikes transecting the islands of Franz Josef Land, most of which trend NW, indicates that this part of the Barents Sea Shelf underwent lithospheric extension in the Cretaceous. It is interesting to notice that the trend of the majority of the dolerite dikes is sub-parallel to the Cenozoic Saint Anna Basin bordering the Franz Josef Land to the east and the Franz-Victoria Basin to the west (Verba et al. 1992). A reasonable interpretation is thus to consider these Cenozoic basins as thermally controlled sag basins, following a phase of early Cretaceous rifting and associated magmatism. The less frequent northeast-trending dikes (c. 10%) are subparallel to the prograde margin separating the Lomonosov ridge from the Canada/Makarov Basin (Fig. 1), indicating that these latter dikes were associated with a SW trending rift which developed into a passive prograde margin in the Late Cretaceous (Jokat et al. 1992). Assuming that the highest frequencey of northwest-southeast trending dikes crossed the Franz Josef Land archipelago we may speculate that a trippel junction was located at the intersection between this dike swarm and the Lomonosov ridge in a pre-drift position in the Cretaceous.

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