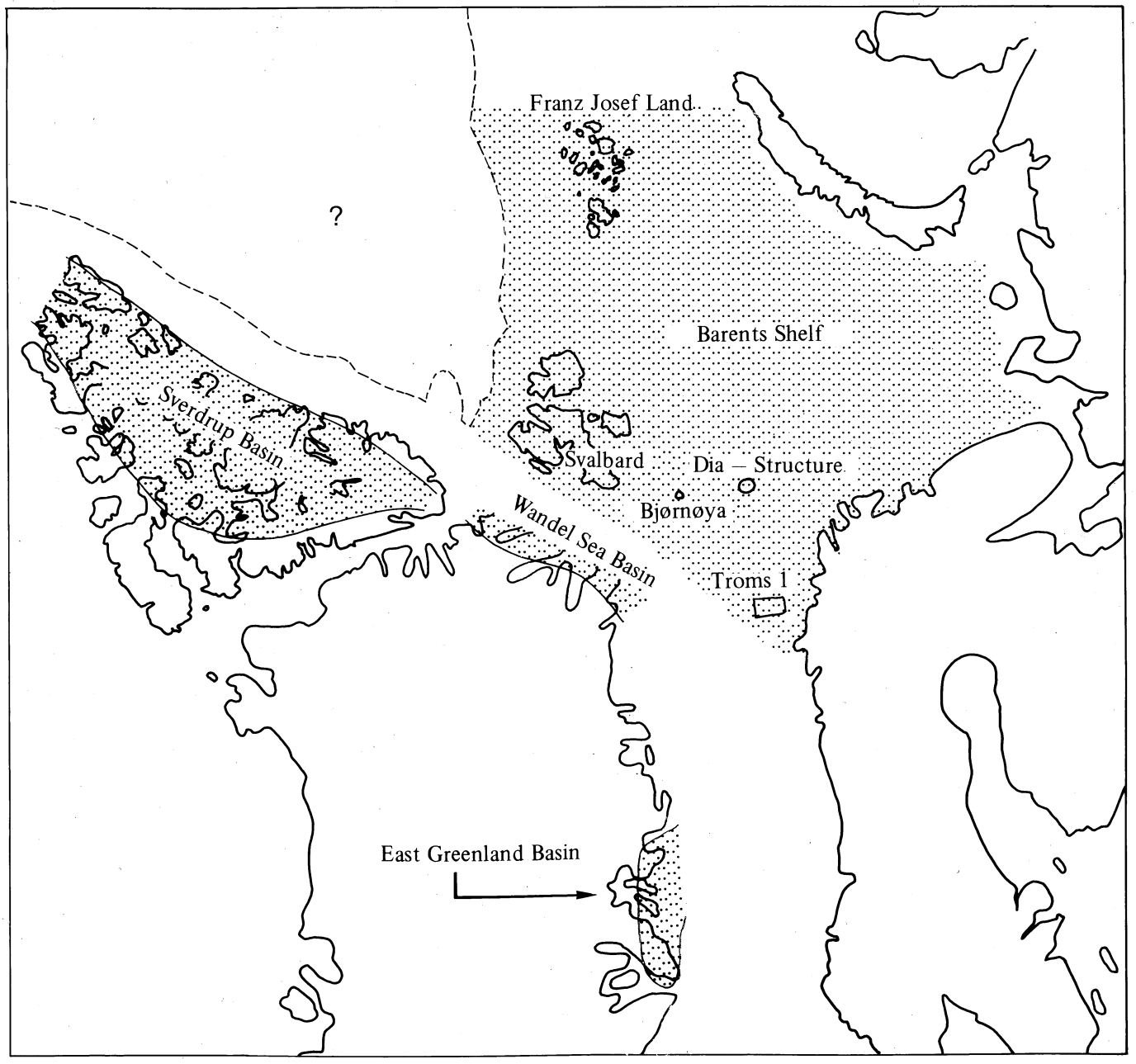
Comparative Organic Geochemistry of Triassic Rocks from the Dia - Structure, Svalbard and surrounding areas.



by
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REPORT

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COMPARATIVE ORGANIC GEOCHEMISTRY OF TRIASSIC ROCKS FROM THE DIA-STRUCTURE, SVALBARD AND SURROUNDING AREAS

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SUMMARY:

The objective of this project was to examine the occurrence and organic geochemistry of the organic-rich Triassic shales of the Dia-structure succession with reference to the occurrence and organic geochemistry of organic-rich Triassic marine shales in adjacent areas of the Arctic. A database comprising IKU data from Svalbard and Dia-structure, together with available published data has been used.

Deposition of organic-rich marine shales during the Triassic was most widespread during middle Triassic times. The most organic-rich shales were deposited during this period. The kerogen present in these organic-rich shales is mainly marine amorphous material and is remarkably consistent in composition throughout the area studied. Deposition of these shales is thought to be concident with the development of upwelling current systems in a shallow epicontinental sea.

Bitumen is generally abundant in these rocks, and a marked lack of compositional variation reflects the relative similarity of the dominant kerogen components in the rocks.

KEY WORDS:	
Organic-rich shales	Dia-structure
Triassic	Svalbard
Organic Geochemistry	Sverdrup Basin

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1. INTRODUCTION

This project was initiated in July-August, 1987 with the objective of investigating the occurrence and organic geochemistry of organic-rich marine shales in the Triassic strata of the Barents Shelf and the surrounding areas. This would allow consideration of the organic-rich shale section sampled during IKU's sampling cruise at Dia-structure in 1986 within a regional context. The region to be studied included, in addition to the Barents Shelf itself, Franz Josef Land, the Canadian Arctic Archipelago and Greenland (Figure 1.1). Although shales of Triassic age are known to occur in northern Alaska and north-western Canada, these areas were not included for detailed study due to time and financial constraints.

The project was intended to examine variations in the distribution and nature of both soluble and insoluble organic matter (kerogen), in the study area. A particular area of interest was to examine the influence of an apparent shift in the geological age of the Triassic shales, from the southern Barents Shelf to the Canadian Arctic Archipelago, on the organic geochemistry of these rocks.

In co-operation with workers at the University of Oslo, personnel at IKU have been involved in the study of the Triassic rocks on Svalbard since 1977. The original IKU-UiO team consisted of Malvin Bjorøy, Atle Mørk, Jorunn Os Vigran, Arne Forsberg, Ragnar Knarud and David Worsley, and the geological information concerning Svalbard in this report is based largely on their work. This geological work was supplemented by a major organic geochemical study carried out at IKU between 1980 and 1982. In conjunction with the abundant data obtained from the IKU Barents Sea Drilling Programme, this has provided a large data base which has duly been used in this study.

For the other areas included in this study, geological and organic geochemical data have been taken from the available literature, with its implied limitations on the type of data available for comparison. Problems with data incompatibility was particularly noted with respect to data published by Soviet sources. This incompatibility is due to the different analytical techniques and reporting methods used by Soviet workers, and somewhat restricted the use of such data for meaningful comparisons. In addition, only the most cursory organic geochemical data has been published by workers in Greenland, and the identification of organic-rich rocks in this area is largely based on geological evidence.

Ideally, in the future, the establishment of an Arctic organic geochemical database should be considered, using a standard set of analytical and reporting methods.Analysis of material from the Triassic successions of Canada and Greenland was prevented by the impossibility of obtaining suitable material within the timespan of this study.

Some additional analyses were carried out on selected samples from Svalbard and the Dia-structure, including microscopic description and bulk (Rock-Eval) pyrolysis of kerogen concentrates. The aim of these analyses was to provide a fuller kerogen description for comparison of Dia-structure succession with that on Svalbard, especially with respect to visual description of the kerogen in the Dia-structure succession.

This report provides a review of the geology and organic geochemistry of the Triassic succession in the Barents Shelf and surrounding areas, and examines the controls on the distribution of organic matter in the Triassic strata.

ACKNOWLEDGEMENTS

Atle Mørk is acknowledged for discussions during the course of the project, and for review of this text. Morten Smelror carried out the description of the kerogen in transmitted light. Sølvi Stene, Torun Vinge and Leif Husvik carried out the kerogen preparation and pyrolysis analyses. Ingrid Waldemarsen and Jan Johansen drafted illustrations and Anne Larsen assisted with preparation of the report. Jorunn Os Vigran and Liv Schou are acknowledged for comments on previous work done at IKU.

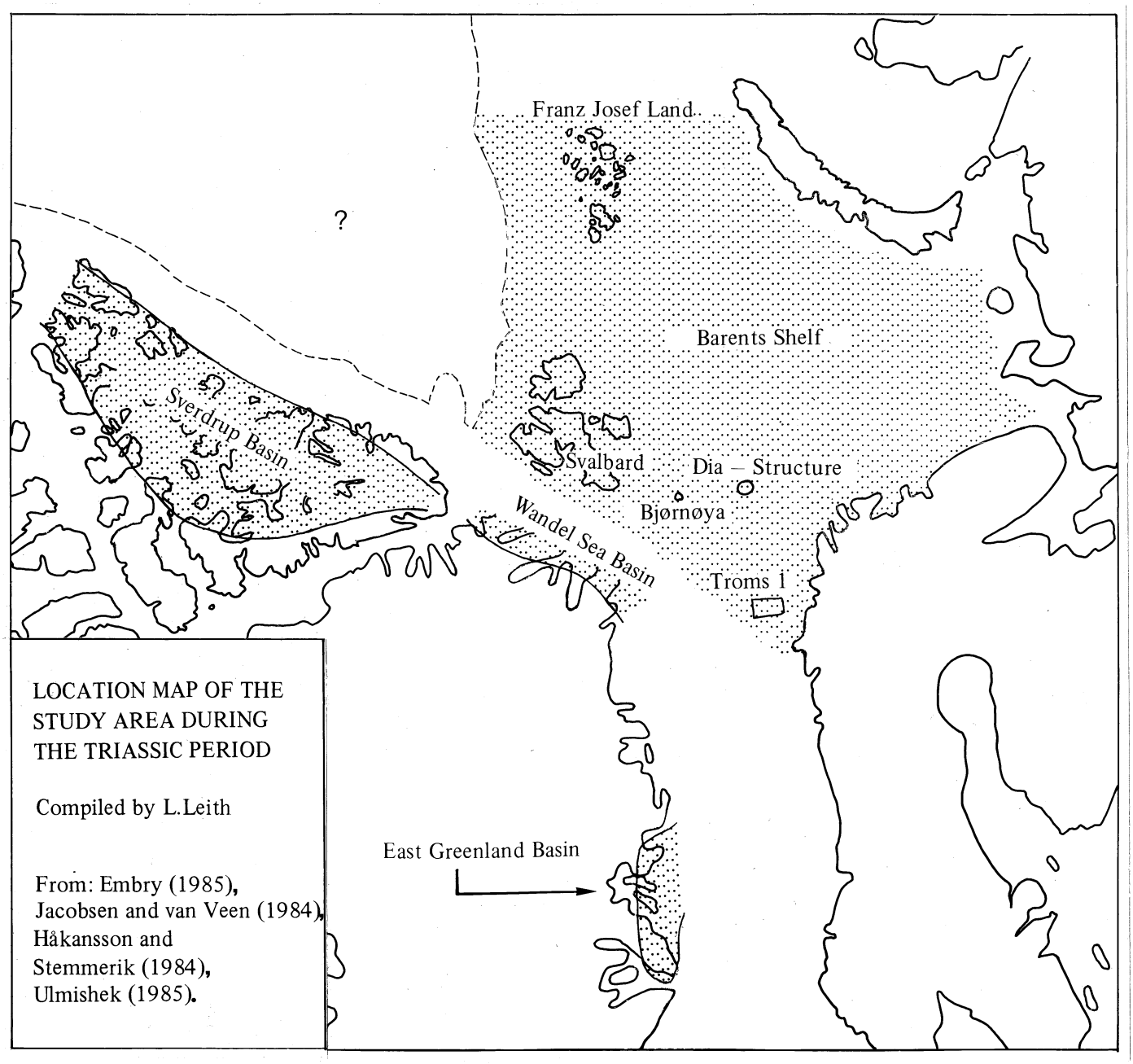

Franz Josef Land
?
Barents Shelf
Sverdrup Basin
Svalbard
Dia – Structure
Bjørnøya
Wandel Sea Basin
Troms 1
East Greenland Basin
LOCATION MAP OF THE STUDY AREA DURING THE TRIASSIC PERIOD
Compiled by L.Leith
From: Embry (1985), Jacobsen and van Veen (1984), Håkansson and Stemmerik (1984), Ulmishek (1985).

Figure 1.1.

2. THE GEOLOGY AND ORGANIC GEOCHEMISTRY OF TRIASSIC STRATA IN THE BARENTS SHELF AND SURROUNDING AREAS

2.1 Triassic Rocks of the Sverdrup Basin

The Sverdrup Basin is a roughly NE-SW trending, elongated, structural depression stretching from Ellesmere Island in the east to Melville Island in the west, in the Canadian Arctic Islands Province. The basin itself is ca. 1300km by 400km, and contains up to 13000m of sediments of Mississippian to Pliocene age, of which ca. 3000m are thought to have been deposited during the Triassic (Embry 1984).

Balkwill and Fox (1982) classified the Sverdrup Basin as an episutural basin (after the nomenclature of Bally and Snelson 1980), superimposed on a deformed, interior area of the Ellesmerian Orogenic Belt. Balkwill et al (1983) consider the basin to have developed by graben formation related to post-orogenic thermal contraction and subsidence following the Franklinian Orogeny.

During the Mesozoic, the Sverdrup Basin was part of a broad epicontinental seaway which faced the Pacific Ocean, stretching from Alaska to the Barents Sea area. Sediment was supplied from cratonic areas of North America, Greenland, Scandinavia, the Ural Mountains and eastern Siberia (Embry 1985).

The basin developed as a gently, but continuously subsiding area throughout the upper Palaeozoic and Mesozoic, although with varying rates of subsidence related to crustal/lithospheric stability (Sweeney 1977; Balkwill and Fox 1982). Balkwill (1978) suggests that the sediment sources the the south and east of the Sverdrup Basin were generated by epeirogenic uplift in the absence of early Mesozoic tectonic activity.

Stratigraphy:

The 3000m of Triassic strata in the Sverdrup basin represent relatively uninterrupted sedimentation from Griesbachian to Rhaetian times (Figures 2.1.1 and 2.1.2).

The Bjorne Formation consists of quartzose, cross-bedded sandstones lying disconformably on red-weathering beds of Permian age (Tozer and Thorsteinsson 1973). Conglomeratic intervals are described from extreme marginal

areas (Figure 2.1.3). Mildly positive areas to the north, east and south are thought to be the main source of the sedimentary rocks in this formation. The latter two areas represent the most important source areas and lie within the Devonian foldbelts of the adjacent Franklinian miogeosyncline (Sweeney 1977; Balkwill 1978: Embry 1985).

These sediments are thought to have been deposited during Griesbachian to Spathian times under non-marine or marine shelf conditions, following an early Triassic transgression which left the area near-emergent (Balkwill et al 1983). Embry (in press) recognised two transgressive-regressive cycles of Griesbachian-Dienerian age and Smithian-Spathian age. The occurrence of beds assigned to the Bjorne Formation is restricted to the margins of the Sverdrup Basin.

The grey to green, pro-delta shales and siltstones of the Blind Fiord Formation represent the basinal time-equivalent succession of the arenaceous rocks of the Bjorne Formation (Figure 2.1.3: Tozer and Thorsteinsson 1973). The depo-centre for these sediments is thought to have been close to the current location of Axel Heiberg Island.

The rocks of the Blind Fiord Formation are thought to represent deep shelf deposition (Tozer and Thorsteinsson 1973; Embry 1985). Shelf conditions persisted in the depo-centre during a period of maximum regression during late Spathian times. At this time, progradation of the Bjorne Formation sediments extended north- and northwest-wards to a line from King Mackenzie Island through Lougheed Island to the southern edge of Cornwall Island and the eastern margin of Ellesmere Island (Balkwill and Fox 1982; Embry 1985).

SCHEI POINT GROUP

This unit was elevated to group status by Embry (1984). Prior to this, the Schei Point Formation was described by Tozer (1963) and Tozer and Thorsteinsson (1973) as a succession of grey to brown weathering, calcareous siltstone and fine-grained sandstone of Anisian to Karnian age, in which five members were recognised: the Lower Shale, Lower Calcareous, Middle Shale, Upper Calcareous and Upper Shale Members. Only the three shale members were recognised in the time-equivalent, basinal Blaa Mountain Formation. In this review, the later nomenclature of Embry (1984) will be used.

Embry (1984) recognised five formations in the Schei Point Group comprising the Murray Harbour Formation, Roche Point Formation, Hoyle Bay Formation,

Pat Bay Formation and Barrow Formation (Figure 2.1.1a). The last formation is assigned a Norian age. These formations are roughly equivalent to the five members recognised by Tozer and Thorsteinsson (1973).

(The BLAA MOUNTAIN GROUP is a basinal, time-equivalent of the Schei Point Group (Figure 2.1.4) and consists of the Murray Harbour, Hoyle Bay and Barrow Formations as described above. As such, the stratigraphy of this group is discussed with that of the Schei Point Group.)

The lower boundary of the Murray Harbour Formation is represented by dark shales which overlie sandstones of the Bjorne Formation. The Murray Harbour Formation consists of a coarsening-upwards sequence from dark grey shales to grey, calcareous siltstones with thin interbeds of thin calcareous sandstone. These rocks may be grey, green or red-weathering at the extreme margins of the basin. This formation is overstepped by younger units of the Schei Point Group at the basin margins, but reaches a thickness of around 640 m near the basin depo-centre.

The upper boundary of this formation is represented by a transition to the sandstones or bioclastic limestones of the overlying Roche Point Formation at the basin margins. Towards the main basin depo-centre, the siltstones of the Murray Harbour Formation are directly overlain by the dark grey shales of the Hoyle Bay Formation.

The rocks of the Murray Harbour Formation are thought to be of Anisian-Ladinian age, and an outer shelf or shelf slope depositional environment is postulated.

The arenaceous/carbonate rocks of the Roche Point Formation can be recognised over much of the western margin and along the southern and eastern rims of the basin, thinning basinwards from a maximum thickness of around 250 m.

In the western Sverdrup Basin, the Roche Point Formation is represented by a series of very fine- to medium-grained sandstones and bioclastic packstones with minor shale/siltstone interbeds in which four members are recognised (i.e. in ascending order: Eldridge Bay Member (sandstone), Cape Caledonia Member (shale-sandstone), Chads Point Member (sandstone) and Gore Point Member (limestone). In the eastern Sverdrup Basin, the Roche Point Formation is represented by an undivided series of interbedded and burrowed, very fine- to coarse-grained sandstones and arenaceous, bioclastic

limestones. Vari-coloured shales and siltstones occur along the south-eastern margin of the basin.

These rocks are thought to be of Ladinian-Karnian age, representing deposition in a shallow marine shelf environment, probably below normal wave-base. The upper boundary of this formation is placed at the top of the uppermost limestone or sandstone unit, above which are the shales or siltstones of the overlying Hoyle Bay Formation.

The Hoyle Bay Formation occurs over the whole extent of the Schei Point and Blaa Mountain Groups, reaching a maximum thickness of around 1300 m towards the basin centre.

The rocks of the Hoyle Bay Formation consist of a coarsening-upwards series of shales, siltstones and silty limestones, siltstone being the dominant lithology. In the western Sverdrup basin, the Hoyle Bay Formation is divided into the Eden Bay Member, which is characterised by the presence of numerous limestones with bituminous shale interbeds, and an upper Cape Richards Member. In the eastern Sverdrup Basin, the Hoyle Bay Formation is undivided and consists of shales and calcareous siltstones, with arenaceous, bioclastic limestone and sandstone interbeds along the basin margins.

The rocks of the Hoyle Bay Formation are thought to be of Karnian age, and to represent deposition in an outer shelf or shelf slope environment. The rocks of this formation have generally conformable boundaries with the sandstones of the underlying Roche Point Formation and the base of the first sandstone unit of the overlying Pat Bay Formation. Towards the basin centre, the Hoyle Bay Formation is conformably underlain by the uppermost siltstones of the Murray Harbour Formation, and overlain by the first shale unit of the Barrow Formation.

The rocks of the Pat Bay Formation occur over much of the western Sverdrup Basin, thinning southwards from a maximum thickness of around 260 m. The Pat Bay Formation thins basinwards from a maximum thickness of 20 m along the margins of the eastern Sverdrup Basin.

The Pat Bay Formation is represented by a coarsening-upwards sequence of fine- to very fine-grained calcareous sandstones with thin siltstone interbeds. The sandstones are often massive and highly burrowed.

These arenaceous rocks are considered to have been deposited during Karnian times in a near-shore marine environment. The boundaries of the Pat Bay Formation are conformable, the upper boundary being placed at the top of the uppermost sandstone unit.

The Barrow Formation is recognised over the whole areal extent of the Schei Point and Blaa Mountain Groups. This formation shows a basinward increase in thickness, reaching a maximum thickness of around 1000m near the basin depo-centre.

The rocks of the Barrow Formation consist of a series of grey, silty shales and siltstones with very fine-grained sandstone interbeds. The sandstone beds commonly show parallel and ripple cross-lamination, together with common burrowing. Sandstone interbeds are more common towards the top of the formation.

The Barrow Formation generally has conformable boundaries with the underlying and overlying units, the uppermost boundary being taken at the first thick sandstone unit. Exceptions occur on northeastern Ellesmere Island, where rocks of the Barrow Formation overstep rocks of the Pat Bay Formation, and at the western basin margin, where the Barrow Formation is unconformably overlain by sandstones of the Grosvenor Island Formation.

The rocks of the Barrow Formation have been assigned a Norian age and are thought to represent prodelta and offshore marine shelf deposits.

The Heiberg Formation/Group (Figure 2.1.5) is accorded group status in the western Sverdrup Basin, and formation status in the central and eastern Sverdrup Basin (Embry, 1983). For the purposes of this review, this unit will be referred to as the Heiberg Formation, in accordance with the earlier usage of Tozer and Thorsteinsson (1973). The subdivisions of this unit will not be discussed in any depth. The rocks of the Heiberg Formation are thought to have been deposited during late Norian to Pliensbachian times, thereby falling only partially within the scope of this review.

The rocks of the lower part of the Heiberg Formation consist of a series of carbonaceous sandstones with marine interbeds of probable Norian age. Deposition during Rhaetian to Pliensbachian times is represented by a mainly terrestrial assemblage of sandstones, coals and root-beds. The deltaic strata of the Heiberg Formation reach a maximum thickness of around 2500 m in the eastern and central Sverdrup Basin. Embry (in press) recognises 5

transgressive-regressive cycles in the Heiberg Formation of Norian, Rhaetian, Hettangian, Sinemurian and Pliensbachian age. Sediment source areas are thought to have lain to the east and south of the central Sverdrup Basin.

Depositional History:

Deposition of lower Triassic rocks began in Griesbachian times, following a depositional hiatus during late Permian times (Tozer and Thorsteinsson 1973). A lack of evidence for erosion suggests that this hiatus was merely non-depositional. The main sediment source areas during the Triassic development of the Sverdrup Basin lay to the south and east of the basin, although there is some evidence of an intermittent minor northern source, possibly related to the northwest basin rim (Tozer and Thorsteinsson 1973; Sweeney 1977; Balkwill 1978).

Depositional style from Griesbachian to Norian times was rather constant, with deep marine shelf or slope conditions dominating towards the basin centre. Balkwill (1978) has postulated turbidite deposition in some of the basinal sediments. Delta-plain/front and shallow marine shelf conditions persisted in the western part of the basin and around the basin margins throughout most of this period, extending basinwards on a few occasions.

During the early Triassic, the deltaic sediments of the Bjorne Formation developed from two centres to the east and southwest of the basin (Embry 1985). Balkwill and Fox (1982) describe a dominant delta centre in the western Sverdrup Basin which prograded along the basin axis (Figure 2.1.6). These sediments filled the western basin area almost to the rim of the deep-water depo-centre.

This early Triassic deltaic phase was replaced by an extension of basinal conditions towards the basin margins following a significant early Anisian transgression event. The shallow marine sandstones of the Roche Point and Pat Bay Formations represent the only significant development of coarse clastic sediments during the middle Triassic.

Tozer and Thorsteinsson (1973) indicate that there is no evidence that the northwest basin rim constituted a significant barrier during the Triassic. However, Balkwill (1978) reports the intermittent occurrence of sediments suggestive of shoal conditions in the area of the rim during Dienerian and Karnian times. Meneley et al (1975) suggest that the prominence of the

northwest rim during the Mesozoic may reflect relatively greater subsidence in the Sverdrup Basin.

Balkwill (1978) estimates a sediment accumulation rate of ca. 100 m/Ma for the Griesbachian-Norian succession. A reduced accumulation rate of ca. 50-60 m/Ma is estimated for the fluvio-deltaic sediments which accumulated during Norian to Pliensbachian times. The progradation of the fluvio-deltaic sediments of the Heiberg Formation suggests a relative decrease in subsidence rate during Norian to Pliensbachian times (Sweeney 1977; Balkwill and Fox 1982).

The large deltaic wedge represented by the rocks of the Heiberg Formation prograded northwestwards from the southeast margin of the basin (Figure 2.1.7), eventually infilling the east-central Sverdrup Basin. Marine shelf conditions persisted in the western Sverdrup Basin where the sediment input was lower (Embry 1985). Shoreline/shelf deposits were developed along the northwest and southwest margins of the basin as a result of westwards deltaic progradation into parts of the western Sverdrup Basin. By Rhaetian times, delta-plain and shoreface conditions had become established over most of the Sverdrup Basin (Balkwill 1978). Marine conditions did not become widely re-established until early Jurassic times.

Balkwill et al (1983) and Embry (in press) indicate a latitude of 40°-45° N for the Sverdrup Basin during the early Triassic, followed by a general northwards drift during the Triassic. The nature of the Triassic rocks (i.e. red-beds, limestones) suggest a hot, seasonally dry climate during the early Triassic. Evidence for the development of a more humid temperate climate during the Triassic is suggested by the absence of red beds after Anisian times and limestones after Karnian times. The occurrence of coals and root-beds in rocks of Rhaetian age is thought to reflect the establishment of more humid conditions at this time.

Occurrence of Oil and Gas:

Since the start of hydrocarbon exploration during the sixties, hydrocarbon reserves of ca. 18 billion bbl of oil and 4.2 trillion cubic metres of gas have been estimated for the Sverdrup Basin (Stuart-Smith and Wennekers 1977). The main hydrocarbon reservoirs occur in sandstones of the upper Jurassic Awingak Formation and the Norian-Pliensbachian Heiberg Formation (Embry 1985). Minor shows have been reported from Triassic and lower Cretaceous strata (Rayer 1981). At present, anticlinal and combined anticlinal-

stratigraphic features are the most productive trap types (Rayer 1981).

The main hydrocarbon source rocks are thought to be the Triassic shales of the Murray harbour and Pat Bay Formations (Powell 1978; Embry 1985; Brooks et al in press). Stuart-Smith and Wennekers (1977) classify the Sverdrup basin as being mainly a gas province on account of the high maturity levels encountered in the basin. Snowdon and Roy (1975) showed a relationship between the occurrence of oil and gas fields and the local thermal maturity of the rocks. The major gas fields tend to be located towards the centre of the basin, while oil fields tend to be located in the less thermally mature areas towards the basin margins (Figure 2.1.8).

Organic Geochemistry:

Snowdon and Roy (1975) considered the thermal maturation of the Mesozoic sediments in the Sverdrup Basin using cuttings gas data. They indicated that oil window maturities occur at depths of between 6500 ft and 11000 ft maximum burial. Independent vitrinite reflectance data confirm the upper depth. In areas of the basin which have experienced uplift, the base of the oil window may be encountered at significantly shallower depths than indicated above.

Based on these data, Snowdon and Roy (1975) produced tentative reconstructed organic metamorphic facies maps for the base Triassic and base Jurassic in the Sverdrup Basin (Figure 2.1.9), which were later modified by Powell (1978). These maps indicated that the Palaeozoic rocks are mostly thermally post-mature, except in the most marginal areas of the basin. The occurrence of post-mature Triassic rocks is restricted to the main Triassic depo-centre around western Axel Heiberg Island, Amund Ringnes Island and Ellef Ringnes Island. Thermally mature areas occur in a wide belt around the depo-centre and immature areas occur in a narrow belt on the east, south and west margins of the basin.

A more comprehensive organic geochemical study by Powell (1978), considers both the kerogen and extractable organic matter present in the Triassic rocks (Table 2.1.1). These data are mainly concerned with the western and central portions of the basin, and data are lacking for the depo-centre. In addition, consideration of the Schei Point and Blaa Mountain Groups is hindered by inconsistency in litho-stratigraphic nomenclature.

The sandstones, siltstones and shales of the Bjorne and Blind Fiord Forma-

tions appear to be rather uniformly organic-lean, with average organic carbon contents of around 0.3 wt%. The shales of the Schei Point/Blaa Mountain Groups are more organic-rich, with average TOC contents of 1.9 wt% and 1.4 wt%, respectively. Some particularly organic-rich intervals occur in the shales of the Schei Point Group, reaching TOC values of between 5 wt% and 10 wt% (Powell 1978; Brooks et al in press). These organic-rich intervals probably represent the dark shales of the Hoyle Bay and Murray Harbour Formations described by Embry (1984). Brooks et al (in press) indicate that the shales of the Barrow Formation contain a negligible amount of organic matter.

The highest organic richnesses are reported from immature to moderately mature bituminous shales from the western Sverdrup Basin. Brooks et al (in press) report Rock-Eval hydrogen indices of in excess of 600 mg/g TOC in these rocks. Siltstones of the Schei Point Group also proved to be fairly organic-rich, with an average TOC content of 1.4 wt%. Kerogen data from shales and siltstones of the Schei Point Group (Table 2.1.2) indicate that amorphous and herbaceous material account for 75-90 % of the kerogen. Sandstone and carbonate samples are mostly less organic-rich, and the kerogen contains a higher proportion of woody/coaly material (i.e. ca. 40 %).

The overlying Heiberg Formation consists mostly of shallow marine sandstones and delta-top sediments which include coals and carbonaceous shales. High organic richnesses of up to 14 wt% TOC are associated with these carbonaceous rocks. However, these rocks occur only as interbeds, and the sandstones and siltstones which account for most of this unit are less organic-rich with TOC contents of between 0.5 wt% and 1.5 wt%. Higher TOC contents from these less organic-rich lithologies probably reflect the influence of caved or interbedded carbonaceous rocks. Woody and herbaceous material account for 85-90 % of the kerogen present in rocks of the Heiberg Formation. This is only to be expected from the generally terrestrial/shallow marine nature of the sediments.

Powell (1978) reports that the highest concentrations of extractable organic matter (i.e. 75 to 160 mg/g TOC) occur in the sediments of the Schei Point Group and, to a lesser extent, in the shales of the Blaa Mountain Group (i.e. ca. 60 mg/g TOC). Hydrocarbons typically account for around 50 % of the EOM. Concentrations of 40-60 mg/g TOC are reported are reported from rocks of the Heiberg Formation. The lowest EOM concentrations are reported from arenaceous rocks of the early Triassic Bjorne and Blind Fiord Formations (i.e. 23-46 mg/g TOC).

Gas chromatographic data (Figure 2.1.10) presented by Powell (1978) indicate similarities in composition between the hydrocarbons recovered from rocks of the Bjorne/ Blind Fiord Formations and the Schei Point/Blaa Mountain Groups. With the exception of an immature bituminous shale sample from the westernmost Sverdrup Basin, the gas chromatograms show unimodal n-alkane distributions with maxima around nC17. The pristane peak may be prominent in some samples. Pristane/phytane ratio vary from 1.3 to 2.1, most values lying being between 1.6 and 1.8 (Table 2.1.2). There is no noticeable odd- or even-carbon number predominance, even in samples from rocks estimated to be marginally mature by Powell (1978).

In contrast, although the EOM from the Heiberg Formation also shows a unimodal n-alkane distribution with a maximum around nC17, there is a noticeable odd-carbon number predominance in some samples, and pristane/ phytane ratios tend to be greater than 2 (i.e. 2.0-2.8). One of these samples shows some similarity with EOM from the lower to middle Triassic rocks.

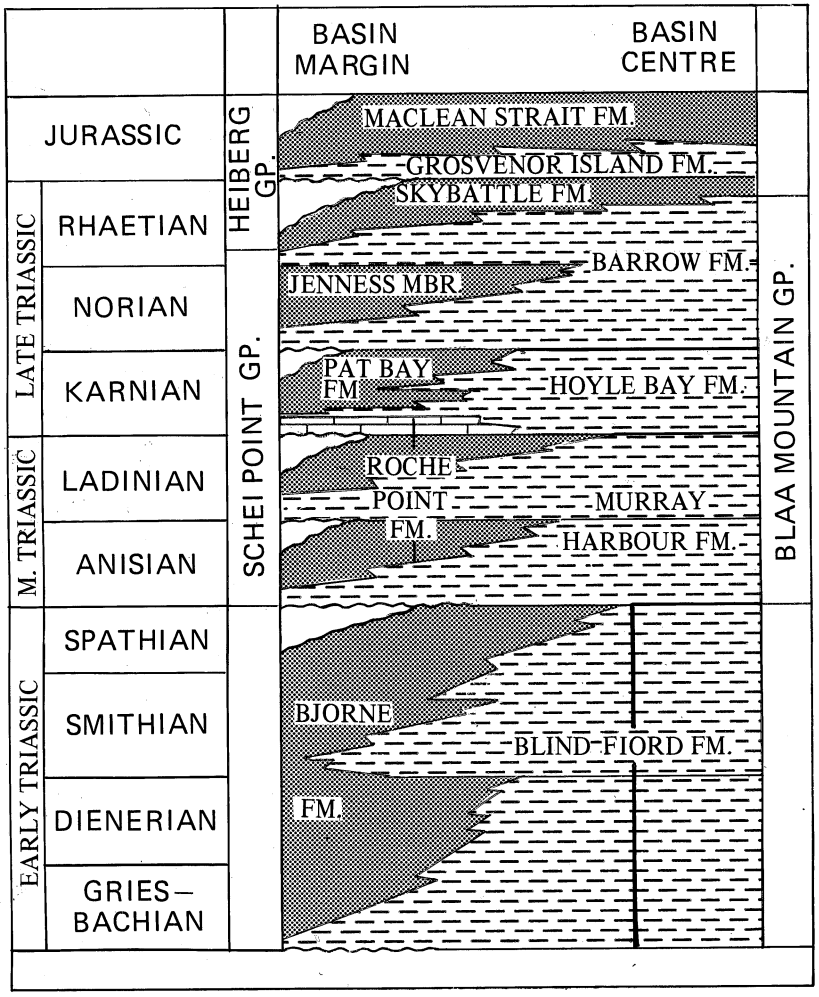
Brooks et al (in press) obtained a correlation between extracts from organic-rich shales of the Hoyle Bay and Murray Harbour Formations and discovered oils from the Sverdrup Basin. GC-MS data for these extracts and oils show development of the normal 17α(H)21β(H)-hopane series, together with an extensive development of C_{20}-C_{30} tricyclic diterpane peaks. The latter feature was interpreted to indicate a microbial/bacterial origin for the organic matter. The m/z 217 mass fragmentograms of the extracts and oils showed development of both regular and rearranged steranes. The regular sterane peaks were dominated by the C_{29} ethyl cholestane peak and, in addition C_{30} sterane isomer peaks were commonly observed. These two features were interpreted to indicate a contribution from marine algal organic matter.

Powell (1978) suggests that hydrocarbon generation in the Sverdrup Basin most likely began in early Cretaceous times, maximum hydrocarbon generation being reached in the basin depo-centre just prior to the beginning of the late Cretaceous/early Tertiary Eurekan Orogeny.

In conclusion, organic geochemical data indicate the occurrence of organic-rich shales and siltstones in the Hoyle Bay and Murray Harbour Formations of the Schei Point and Blaa Mountain Groups. The organic matter in these shales is thought to consist largely of algal/liptinitic material deposited under anoxic/dysoxic conditions. The areal extent of these organic-rich

shales varies throughout the basin at different stratigraphic levels.

The discovered oils of the Sverdrup Basin are indicated as being derived from hydrogen-rich debris in the organic-rich shales mentioned above. Maturation data suggest that the kerogen in the shales of the Blaa Mountain Group are often thermally post-mature. Snowdon and Roy (1975) and Brooks et al (in press) showed a correspondence between the occurrence of gas and oil fields, and the thermal maturity of the Triassic succession.



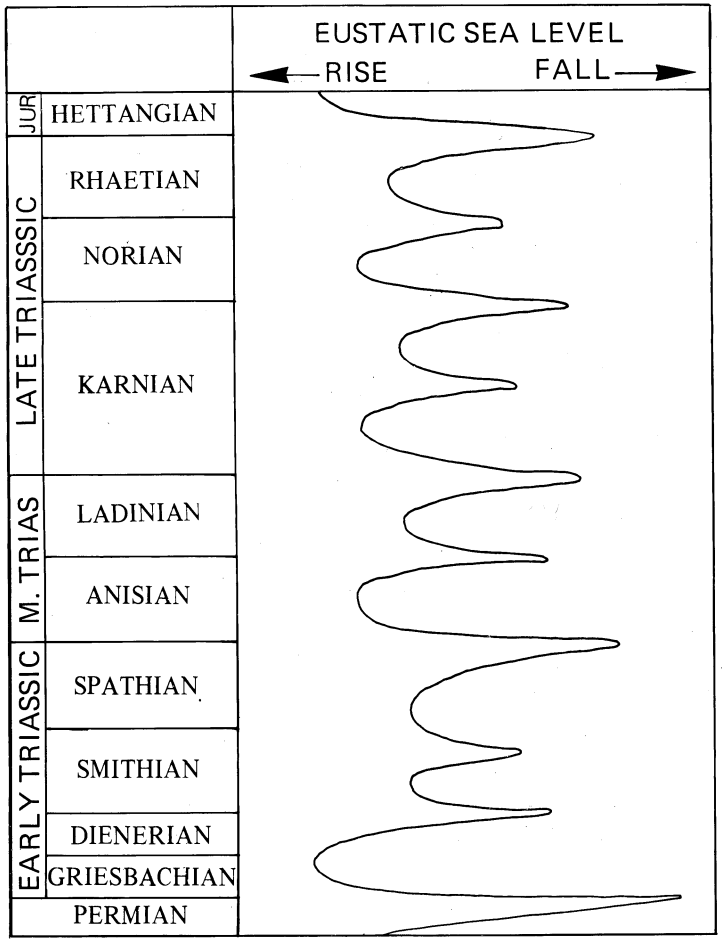


Figure 2.1.1. Triassic Stratigraphy and Eustatic Sea-level Curves for the Sverdrup Basin (After Embry in press).

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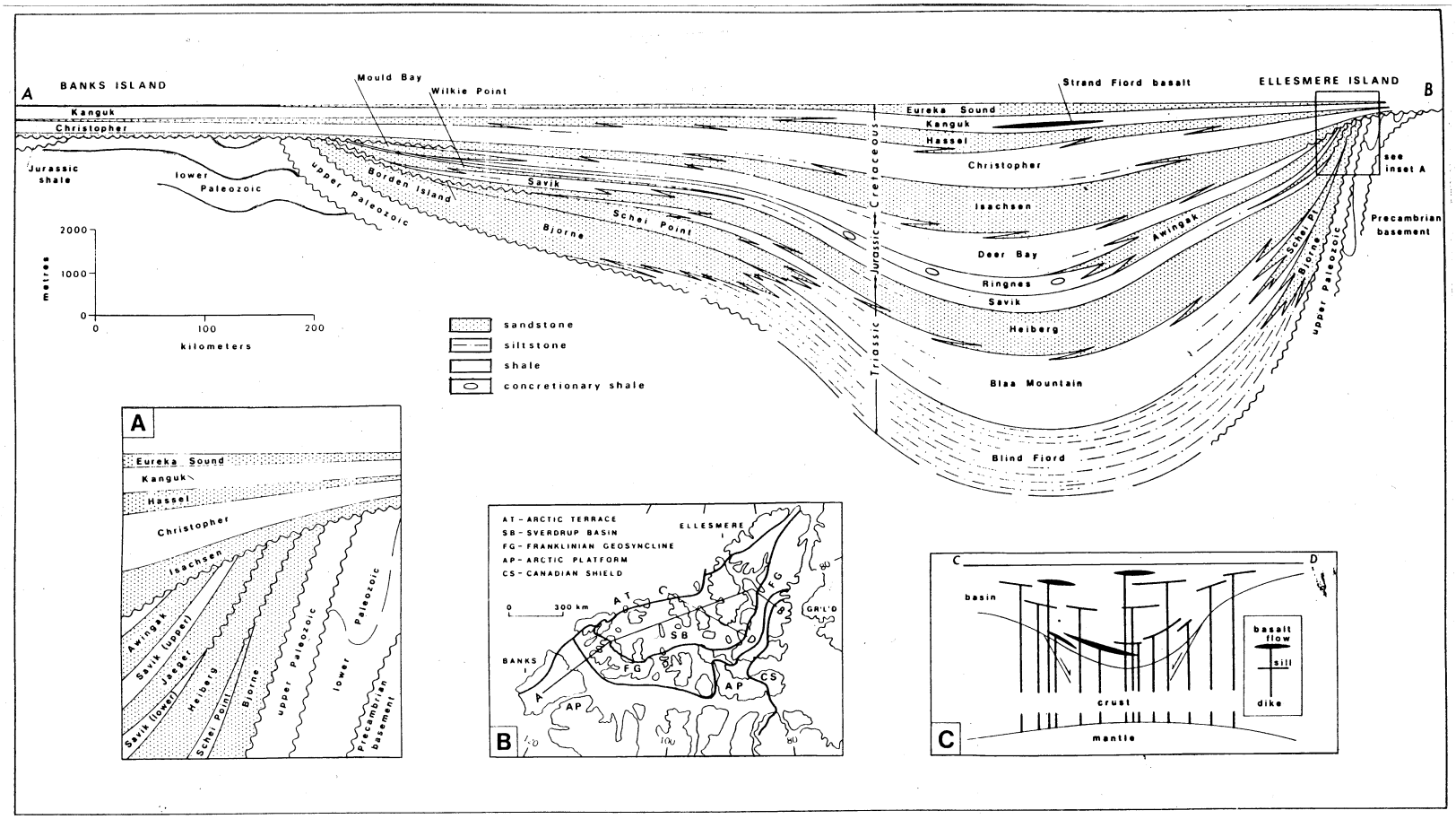

Figure 2.1.2. Schematic stratigraphic cross-section of Mesozoic strata across the Canadian Arctic Archipelago. Inset A: detailed stratigraphic relationships on Ellesmere Island; Inset B: cross-section location map; Inset C: Schematic crustal cross-section across the Sverdrup Basin (Balkwill et al 1983).

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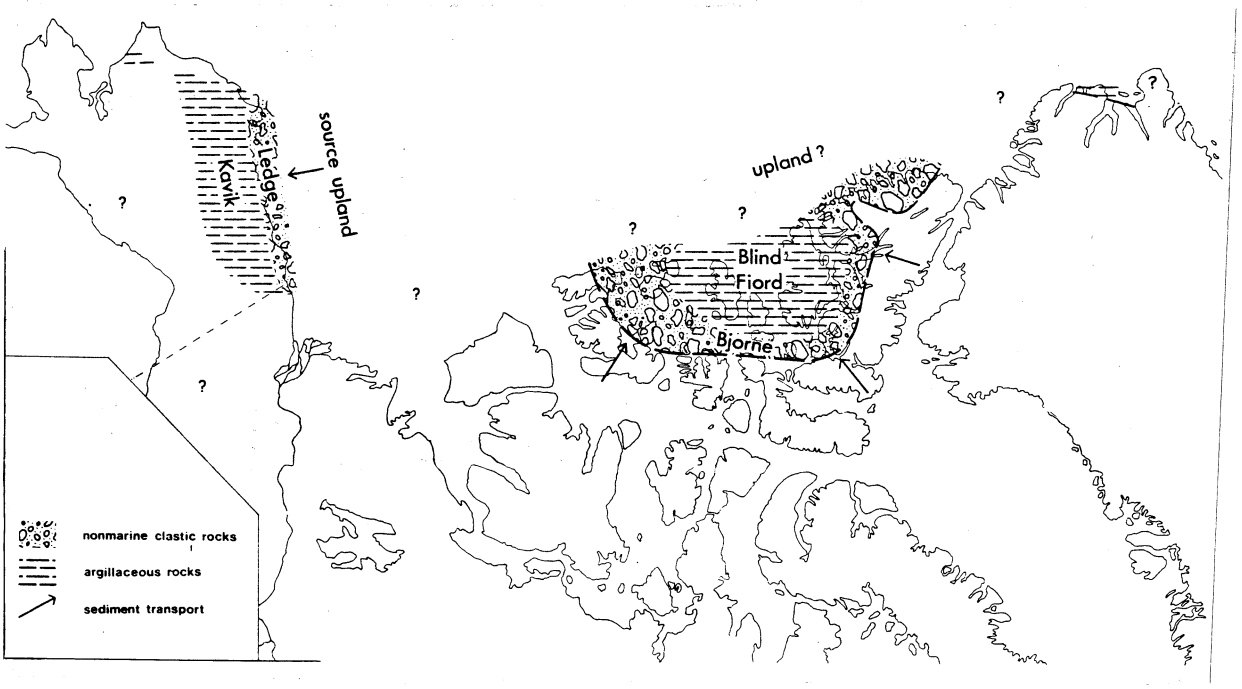

Figure 2.1.3. Lower Triassic (Smithian) facies distribution map (Balkwill et al 1983).

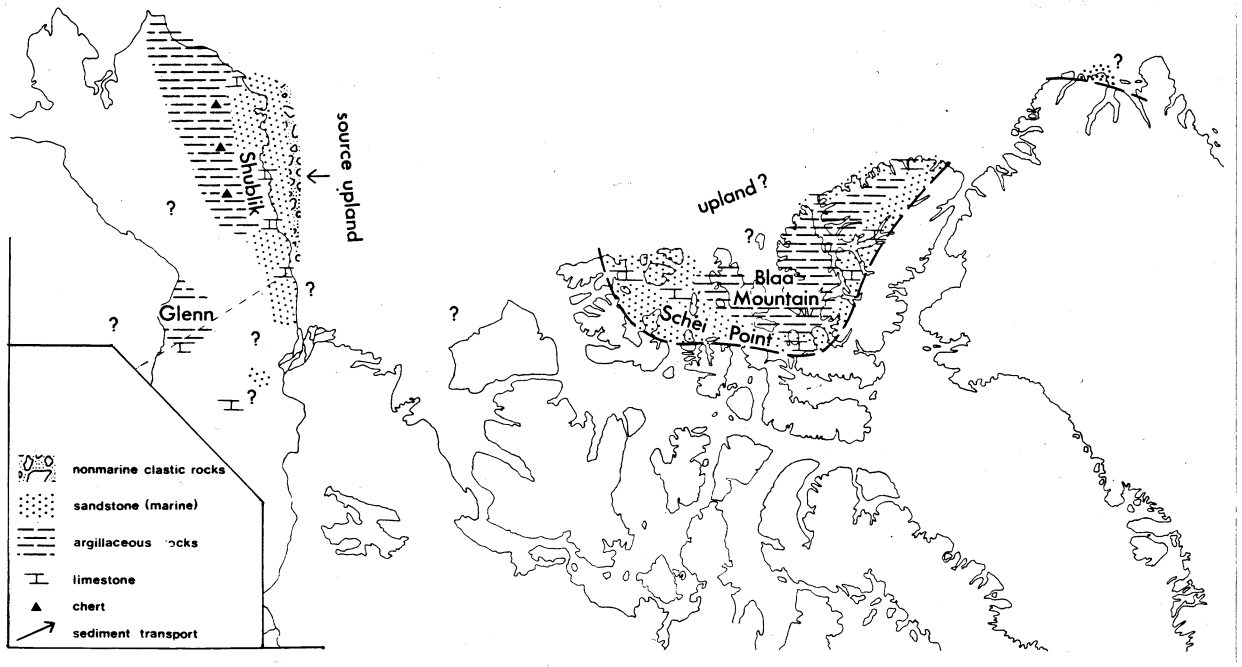

Figure 2.1.4. Upper Triassic (Karnian) facies distribution map (Balkwill et al 1983).

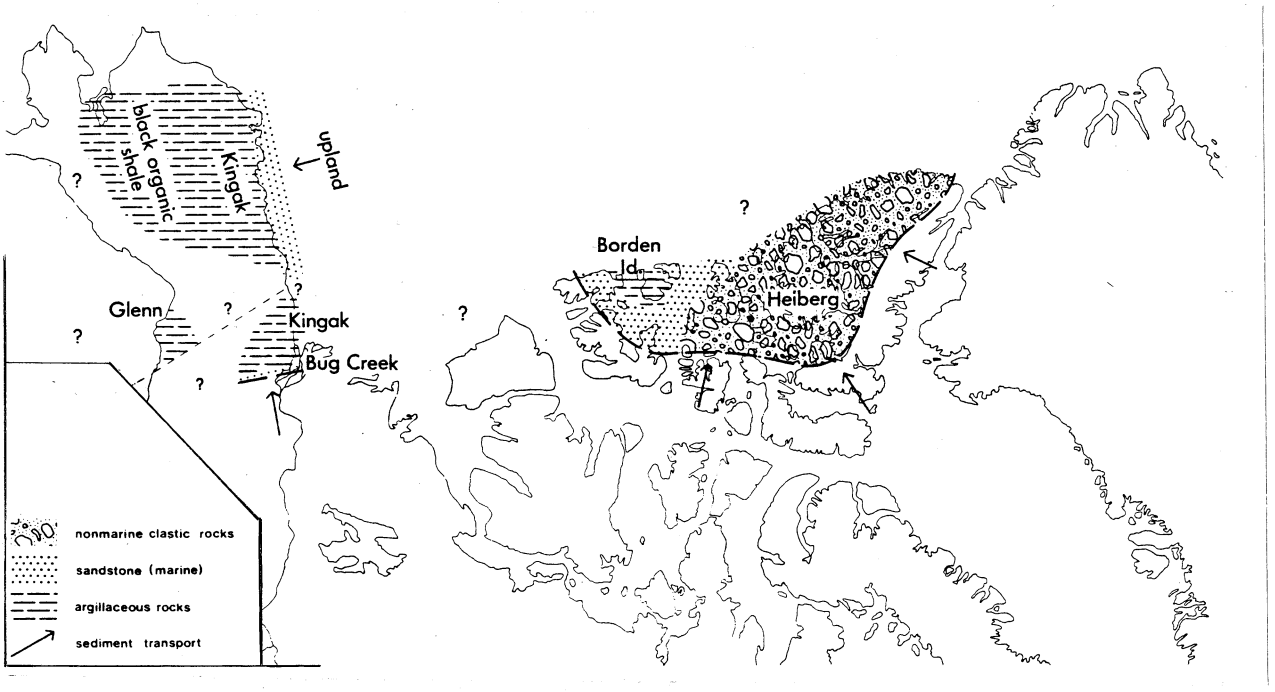

Figure 2.1.5. Lower Jurassic (upper Sinemurian) facies distribution map (Balkwill et al 1983).

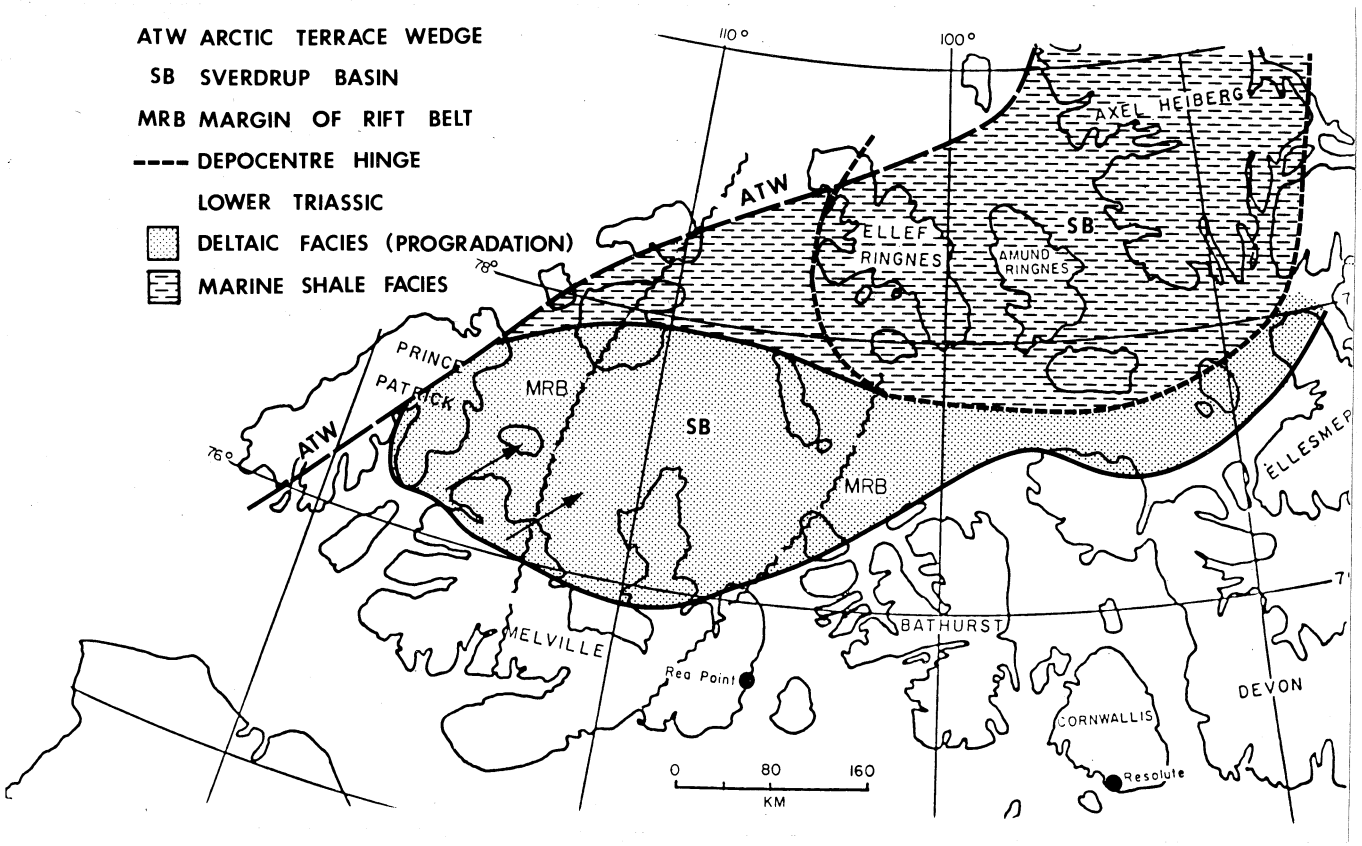

Figure 2.1.6. Lower Triassic facies distribution map, showing deltaic progradation from western Sverdrup Basin (Balkwill and Fox 1982).

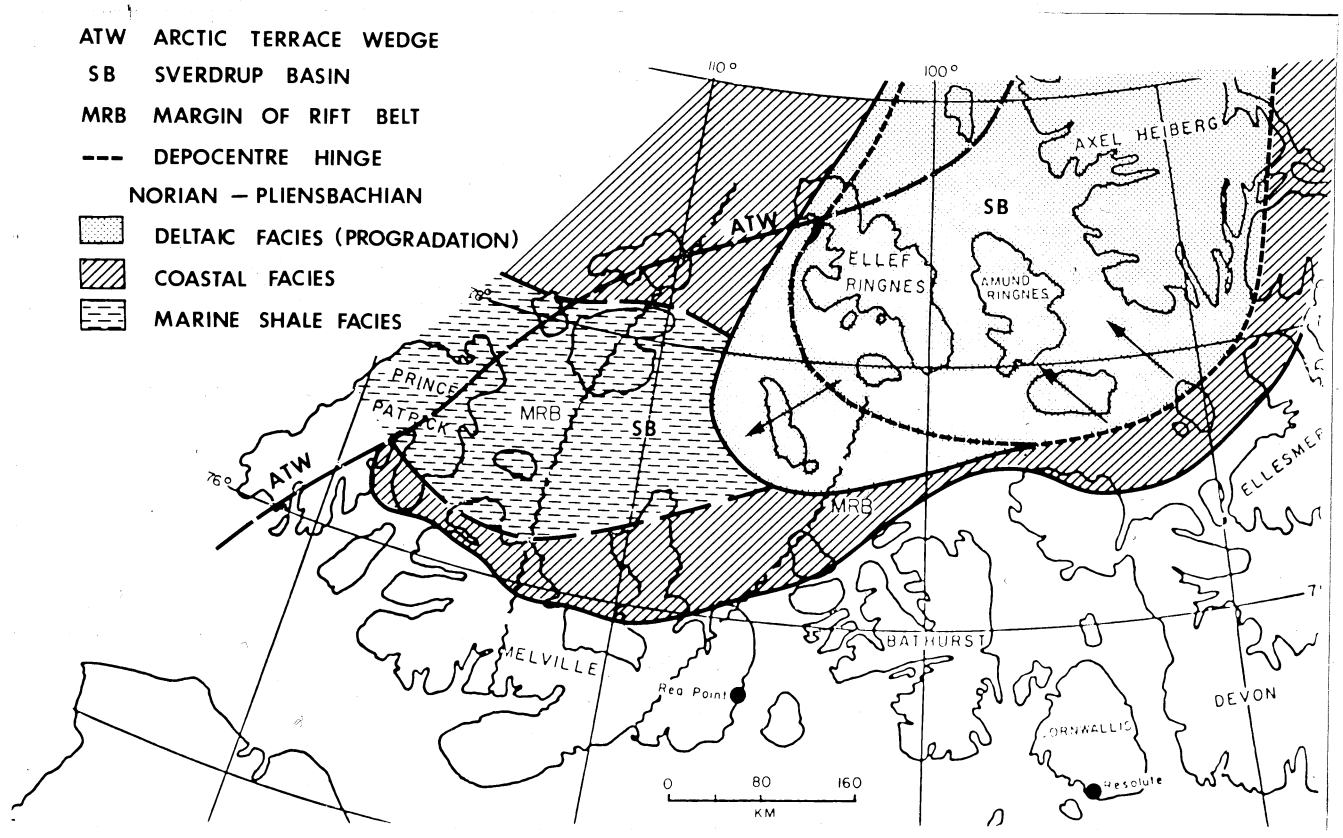

Figure 2.1.7. Upper Triassic-Lower Jurassic facies distribution map, showing deltaic progradation in western Sverdrup Basin (Balkwill and Fox 1982).

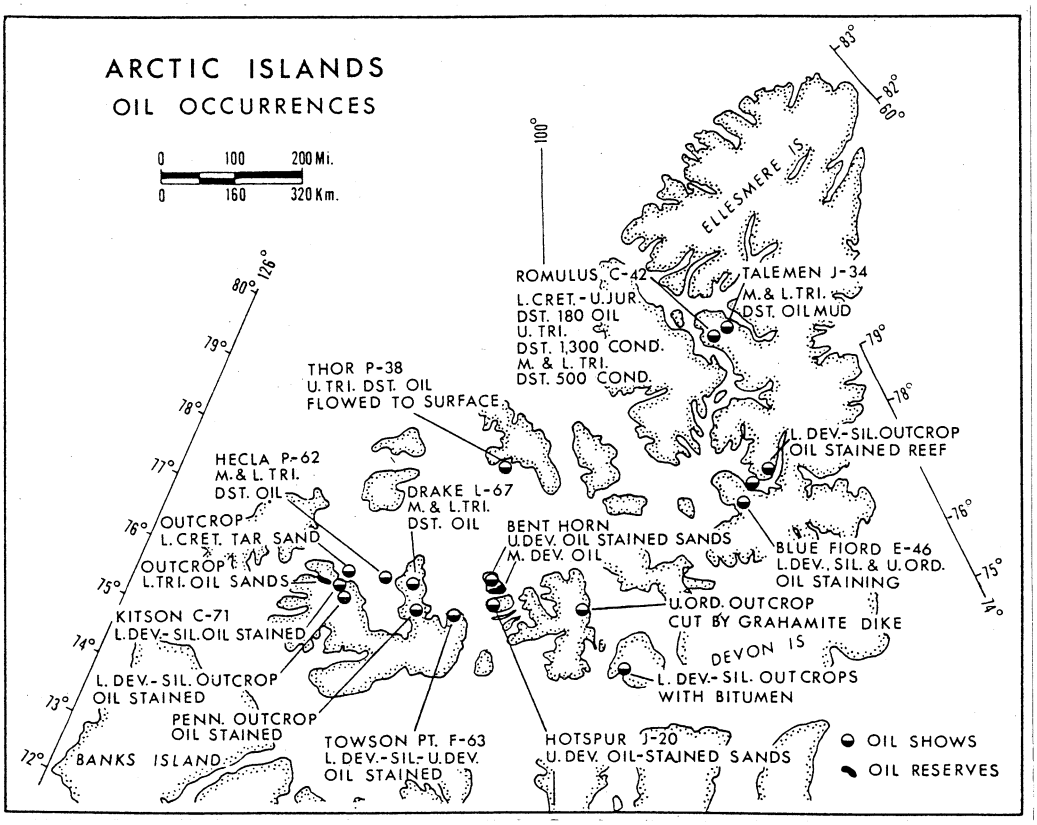

Figure 2.1.8a. Oil occurrences in the Canadian Arctic Islands (Rayer 1981).

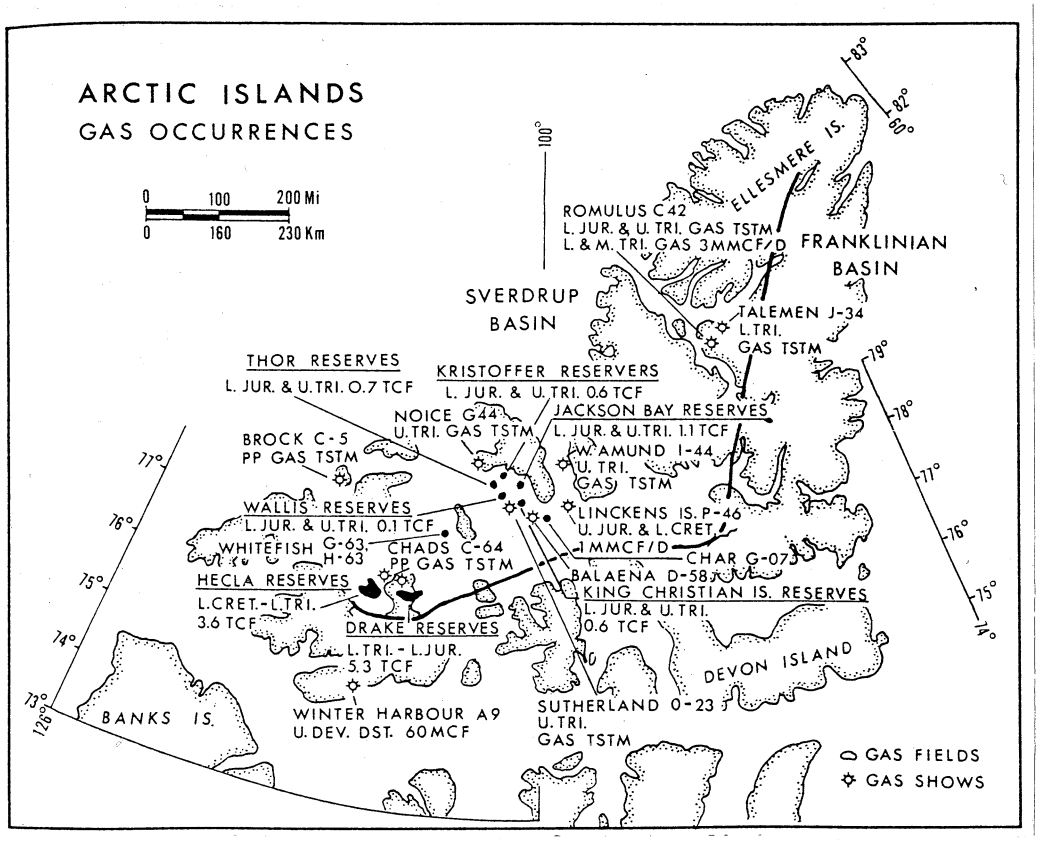

Figure 2.1.8b. Gas occurrences in the Canadian Arctic Islands (Rayer 1981).

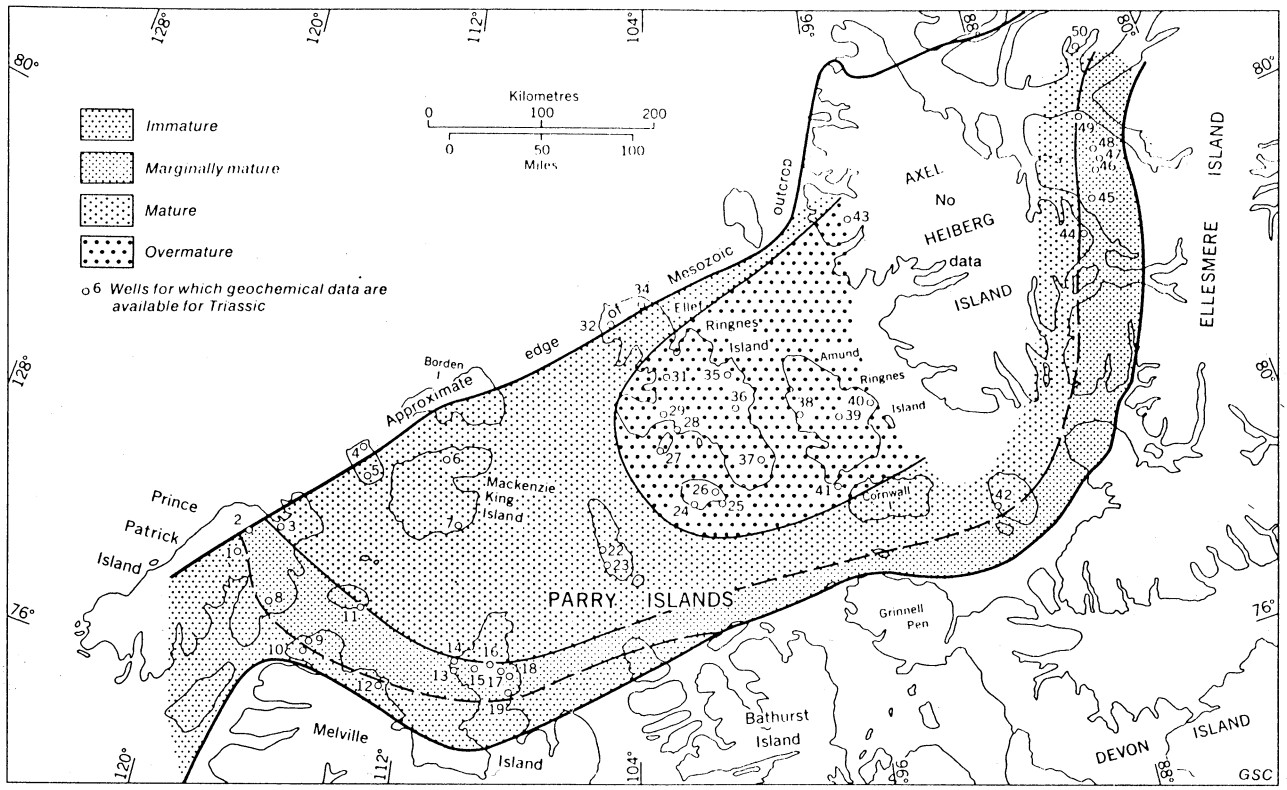

Figure 2.1.9a. Organic metamorphic facies map for base Triassic (Powell 1978).

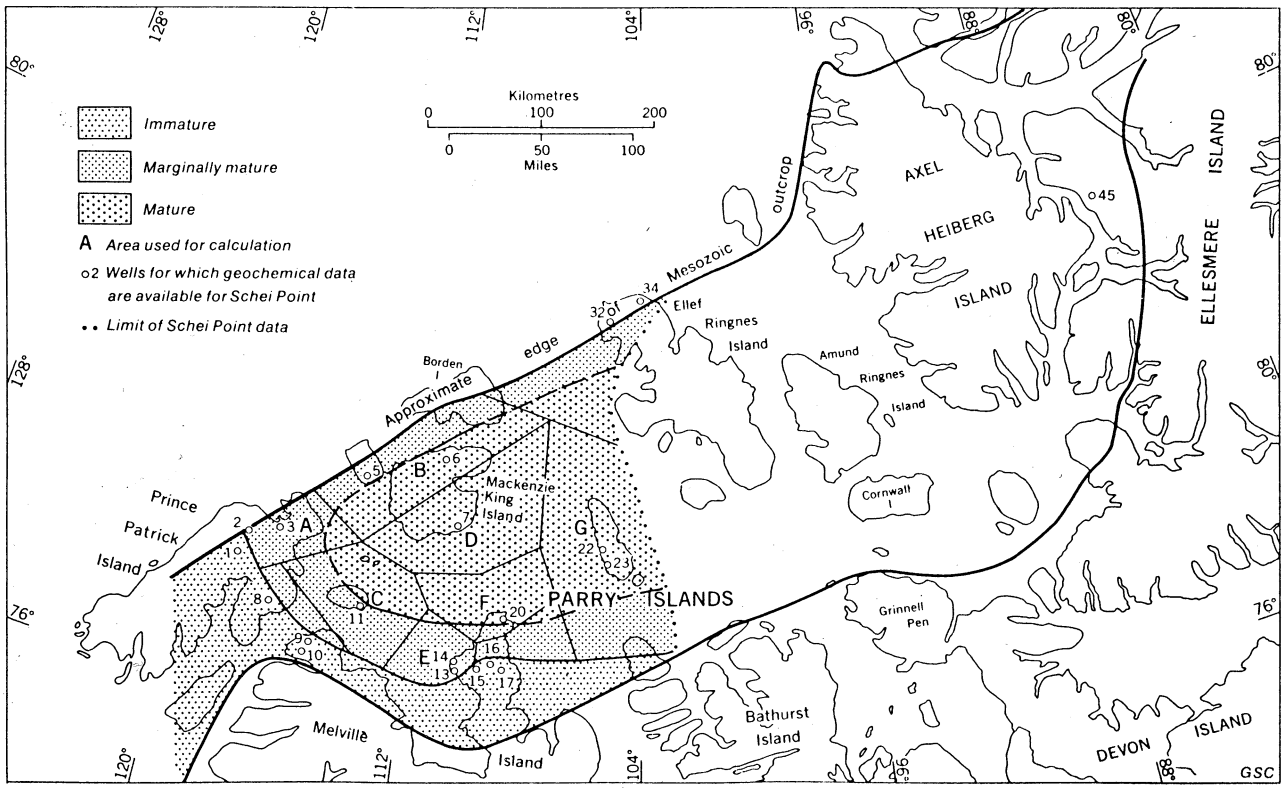

Figure 2.1.9b. Organic metamorphic facies map for the Schei Point Group (Powell 1978).

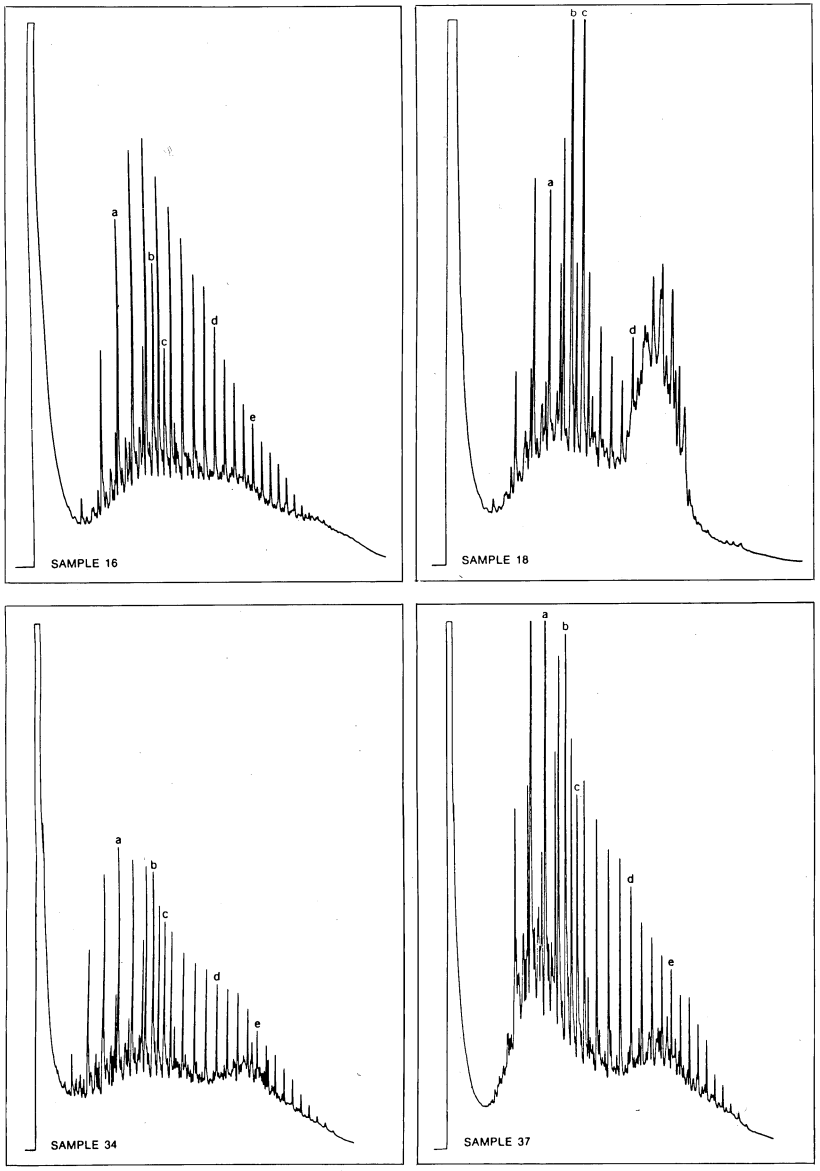

Figure 2.1.10a. Gas chromatograms of saturated hydrocarbons in rocks of the Schei Point Group (Powell 1978).

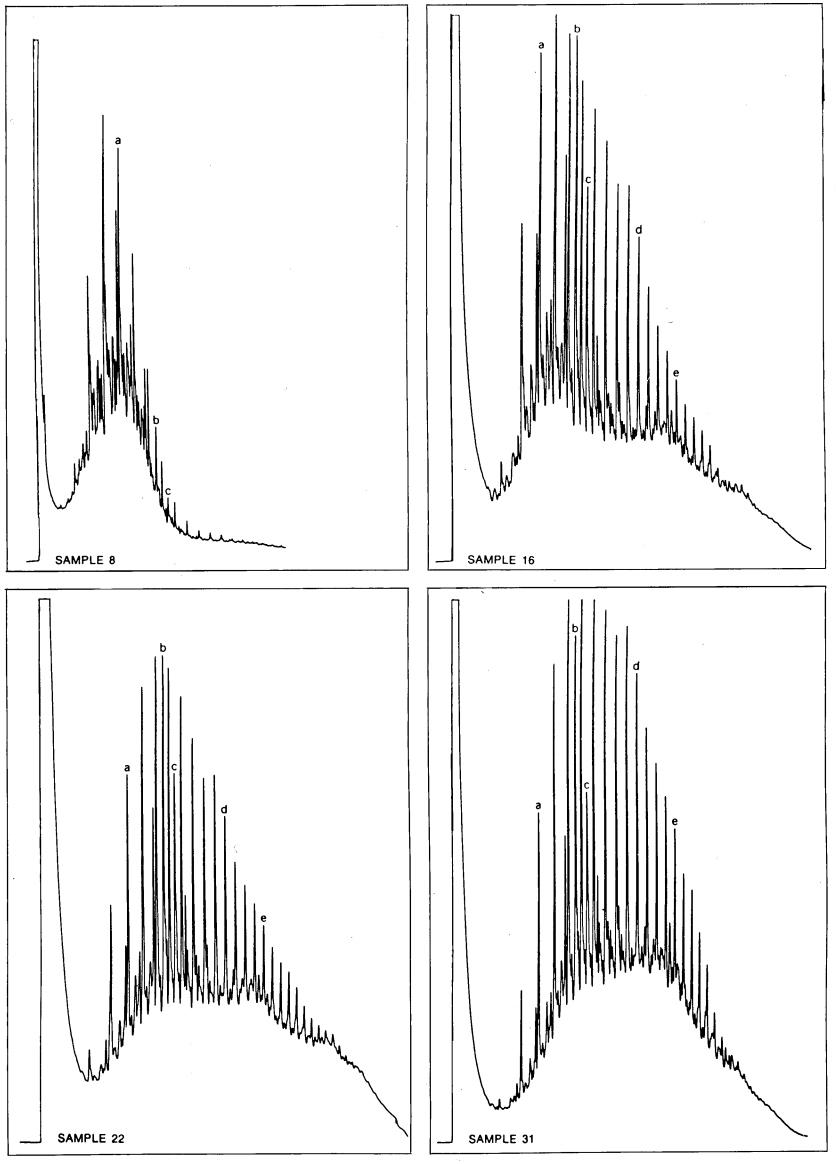

Figure 2.1.10b. Gas chromatograms of saturated hydrocarbons in rocks of the Blaa Mountain Group (Powell 1978).

(Gas chromatogram identifications given overleaf).

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Key to Saturated Hydrocarbon Gas Chromatograms from the Schei Point and Blaa Mountain Groups

Sample 16 (Schei Point Gp.): Fosheim N-27, Ellef Ringnes Island.
Siltstone/Shale/Limestone, 640-649 m.
Pristane/phytane ratio=1.9.
(Thermally mature).

Sample 18 (Schei Point Gp.): Intrepid H-49, Prince Patrick Island.
Bituminous shale, 820-829 m.
(Thermally immature).

Sample 34 (Schei Point Gp.): Satellite F-68, Prince Patrick Island.
Shale/Limestone, 868 m.
Pristane/phytane ratio = 1.4.
(Marginally mature).

Sample 37 (Schei Point Gp.): Skybattle Bay C-15, Lougheed Island.
Siltstone, 2838-2847 m.
Pristane/phytane ratio = 1.6.
(Thermally mature).

Sample 8 (Blaa Mountain Gp.): Kristoffer B-06, Ellef Ringnes Island.
Shale/siltstone. 2042 m.
(Mature-Postmature).

Sample 16 (Blaa Mountain Gp.): Neil 0-15, Ellesmere Island.
Shale, 1082-1097 m.
Pristane/phytane = 1.7.
(Mature-Postmature).

Sample 22 (Blaa Mountain Gp.): Sutherland 0-23, S. Ellef Ringnes Island.
Siltstone, 2131-2140 m.
Pristane/phytane ratio = 1.7.
(Thermally mature).

Sample 31 (Blaa Mountain Gp.): Romulus C-42, Ellesmere Island.
Igneous-affected shale, 2499-2515 m.
Pristane/phytane ratio = 2.1.
(Marginally mature?).

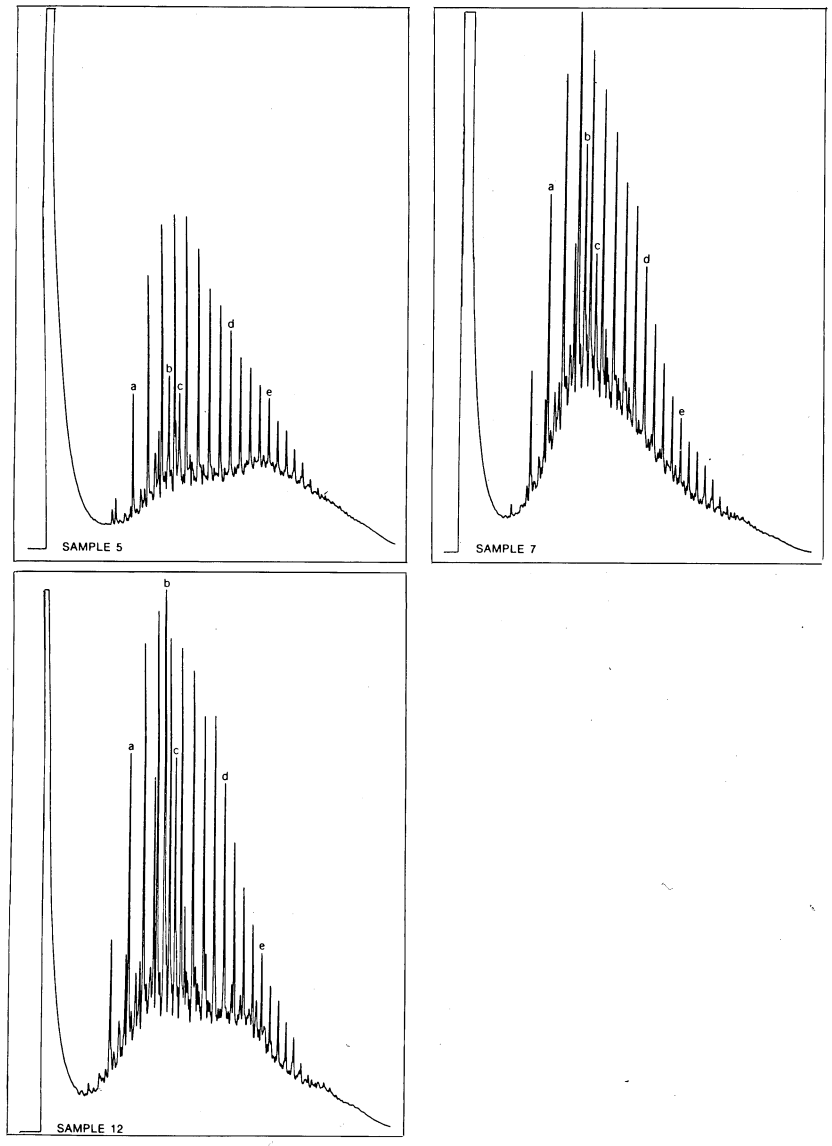

Figure 2.1.10c. Gas chromatograms of saturated hydrocarbons in rocks of the Blind Fiord/Bjorne Formation (Powell 1978).

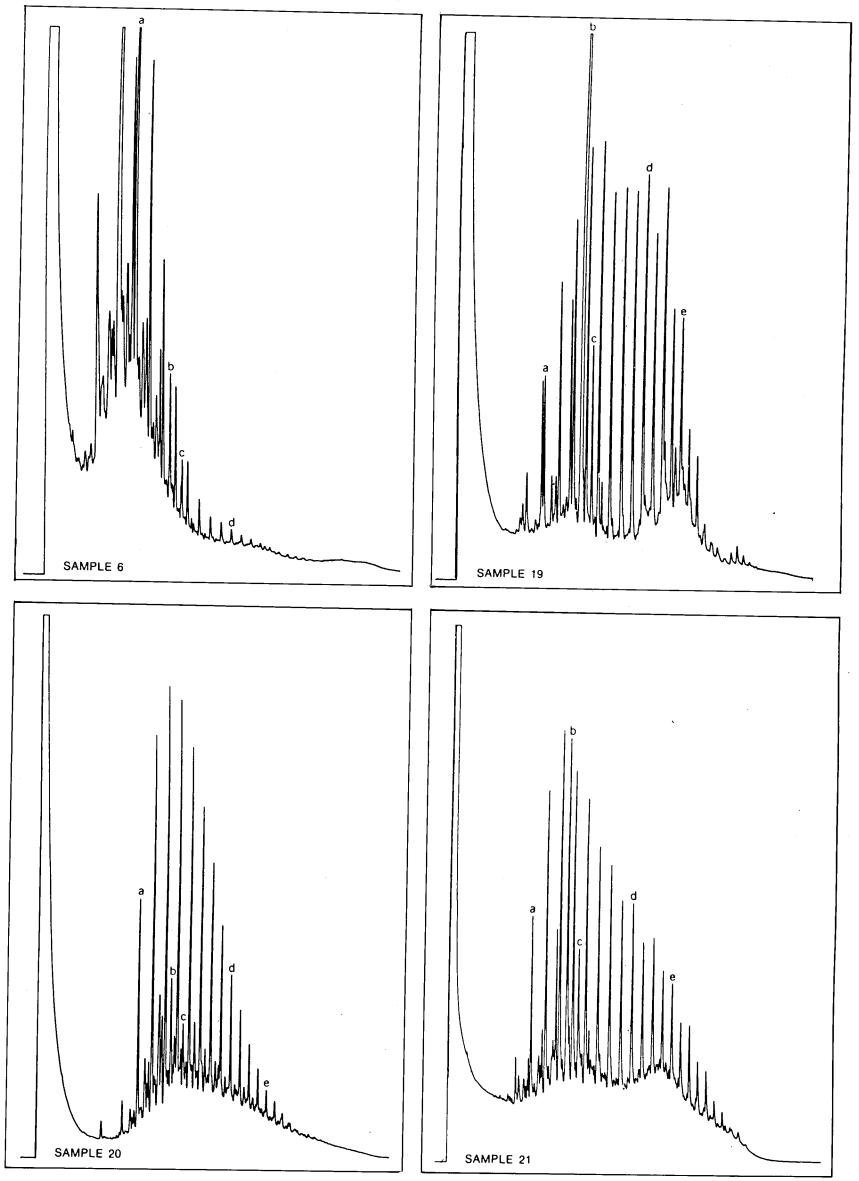

Figure 2.1.10d. Gas chromatograms of saturated hydrocarbons in rocks of the Heiberg Formation/Group (Powell 1978).

(Gas chromatogram identifications given overleaf).

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Key to Saturated Hydrocarbon Gas Chromatograms from the Bjorne Formations and the Heiberg/Borden Island Formations

Sample 5 (Bjorne Fm.) : Neil O-15, Ellesmere Island.
Sandstone/siltstone, 1372-1387 m.
Pristane/phytane ratio = 1.3.
(Mature-Postmature).

Sample 7 (Bjorne Fm.) : Romulus C-42, Ellesmere Island.
Sandstone, 3658-3673 m.
Pristane/phytane ratio = 2.0.
(Thermally mature).

Sample 12 (Bjorne Fm.) : Taleman J-34, Ellesmere Island.
Sandstone, 2957-2972 m.
Pristane/phytane ratio = 1.8.
(Marginally Mature?).

Sample 6 (Heiberg Fm.) : Helicopter J-12, Ellef Ringnes Island.
Carbonaceous siltstone, 3749 m.
Pristane/phytane ratio = 2.3.
(Mature-Postmature).

Sample 19 (Heiberg Fm.) : May Point H-02, Ellesmere Island.
Shale/siltstone, 2743-2758 m.
(Thermally immature).

Sample 20 (Heiberg Fm.) : Mid-Fiord J-53, Ellesmere Island.
Siltstone (Igneous-affected?), 1829-1838 m.
Pristane/phytane ratio = 2.0.
(Thermally immature).

Sample 21 (Borden Island Fm.): North Sabine H-49, Melville Island.
Siltstone/sandstone, 3048-3063 m.
Pristane/phytane ratio = 2.7.
(Thermally mature).

TABLE 2.1.1

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR THE TRIASSIC SUCCESSION IN THE SVERDRUP BASIN

UNIT NAME	LITHOLOGY	TOC (wt%)	EXTRACTABLE ORGANIC MATTER Concentration (mg/g TOC)	HC (%)	PrPh
Heiberg Fm.	Shale**	4.8	56.8	36.3	2.5
	Siltstone+	0.7	42.1	48.6	2.5
	Sandstone°	1.5	60.6	38.9	2.5
Blaa Mountain Gp.	Shale*	1.1	61.2	57.6	1.8
Schei Point Gp	Shale	1.9	76.9	49.8	1.6
	Siltstone	1.4	103.4	51.0	1.6
	Sandstone	0.5	75.6	45.5	1.6
	Carbonate	1.0	162.8	47.0	1.6
Bjorne Fm	Sst/Silt/Sh	0.3	45.8	47.8	1.7
Blind Fiord Fm	Silt/Sh	0.3	23.0	20.9	na

Sh = Shale; Silt = Siltstone; Sst = Sandstone.
** = includes coaly and carbonaceous shales; ° = includes coal/carbonaceous shale fragments; * = Included possible heat-affected shales and a series of organic-lean samples from King Christian Island.

TABLE 2.1.2. KEROGEN COMPOSITION AND MATURITY VARIATION*
(Triassic Succession of the Sverdrup Basin)

UNIT NAME	LOCATION (Island Name)	DEPTH (m)	MAIN LITH	% KEROGEN COMPOSITION AM	HE	WO/CO	MATURITY LEVEL
Heiberg Fm.	Ellef Ringnes	2377	Shale	20	50	30	marginal
	King Christian	853	Shale	--	70	30	marginal
	King Christian	1085	Sst.	--	50	50	marginal
	Melville	3063	Silts.	15	60	25	mature
Schei Point Fm.	Brock	91	Shale	80	20	--	marginal
	?Hazen Strait?	1609	Shale	80	10	10	marginal
	Prince Patrick	1076	Shale	40	35	25	immature
	Melville	3216	Sst.	40	20	40	mature
	Melville	3551	Shale	5	65	30	mature
	Melville	775	Shale	20	10	70	immature
	Lougheed	2847	Silts.	40	50	10	mature

(* - Data taken from Powell (1978))

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

2.2 The Triassic Succession of Central-East Greenland

Extensive outcrops of Mesozoic and Tertiary age rocks occur in a north - south belt from Scoresby Sund in the south to Germainia Land, 800 km to the north. This belt reaches a maximum width of 140 km in Jameson Land and narrows northwards. The occurrence of Triassic rocks (ca. 1200 m) is concentrated in the southern 300 km of the belt, between Scoresby Sund and Kap Stosch (Figure 2.2.1).

The Triassic rocks were deposited in a north-south orientated, fault-bounded basin (Figure 2.2.2). The western boundary fault is exposed in Jameson Land, where it is known as the Main Fault. The eastern boundary fault is not exposed, but its existence is inferred from the presence of coarse alluvial fan sediments in the early Triassic. At least two northeast-southwest orientated cross-faults have been postulated to exist along the lines of Kong Oscars Fjord and Kejser Franz Josephs Fjord, based on sedimentary evidence.

These faults were active throughout the Mesozoic, and are thought to have been initiated as a result of the incipient breakup of the Laurasian supercontinent, eventually leading to the opening of the North Atlantic Ocean (Clemmenson 1980a). Surlyk (1981), however, connects the development of the Permian - Triassic marine embayment to the post-Caledonian foreland collapse of East Greenland. Clemmensen (1980a & b) and Surlyk (1981) recognise the effects of tectonic activity on Triassic sedimentation in East Greenland.

Two phases of activity (Figure 2.2.3) are recognised on these fault systems during the Triassic; one occurs during the early Triassic (Scythian) and Surlyk (1981) has correlated this with the Hardegsen tectonic phase of North-West Europe (Zeigler 1978); the second major phase of activity occurred in the late Triassic (Rhaetian-Liassic) and Surlyk (1981) has correlated this with the early Kimmerian tectonic phase of North-West Europe (Zeigler 1978).

Stratigraphy:

The litho-stratigraphy of the Triassic rocks of East Greenland was extensively revised by Perch-Nielsen et al (1974) and additional revisions (Figure 2.2.4) were made by Clemmensen (1980b).

The Triassic sequence is represented by the SCORESBY LAND GROUP. This group is divided into the NORDENSKJØLD BJERG SUBGROUP and the KAP BIOT SUBGROUP.

The NORDENSKJØLD BJERG SUBGROUP consists of the Wordie Creek and Pingo Dal Formations, and has been assigned an Early Triassic age by Perch-Nielsen et al (1974).

The Wordie Creek Formation overlies the marine Permian sediments of the Foldvik Creek Formation unconformably in the north and conformably in the south. Birkelund (1976) has suggested the presence of a hiatus between the Foldvik Creek and Wordie Creek Formations, which decreases in prominence from north to south.

The Wordie Creek Formation is comprised of up to 1000m of predominantly marine sediments. Grey shales and subordinate grey or green glauconitic or arkosic sandstones occur in the lower part of the formation. The upper part of the formation is represented by green or variegated marine shales and sandstones showing locally developed mudcracks and current-produced features. Arkose and arkosic conglomerates occur locally along the east and west margins of the basin. Clemmensen (1980b) has subdivided the Wordie Creek Formation into the Svinhufvuds Bjerge Member and the Ødepas Member on Traill Øya.

The overlying Pingo Dal Formation has a transitional boundary with the Wordie Creek Formation, and represents a change to the predominantly continental sediments which dominate the rest of the Triassic succession. This formation is divided into the Rødstaken and Paradigmabjerg Members over much of the Jameson Land basin. The Paradigmabjerg Member is replaced by the Klitdal Member in eastern Jameson Land and Liverpool Land.

The Rødstaken Member is characterised by dark red medium-grained sandstones with some variegated mudstones and sandstones, changing to pebbly sandstones, arkoses and conglomerates in the upper part of the unit. This is overlain by the red, pink or greyish arkoses, sandstones and conglomerates of the Paradigmabjerg Member in the north, northeast and west parts of the basin, and by the pink feldspar-rich, pebbly sandstones and matrix-supported conglomerates of the Klitdal Member along the east border of the Jameson Land basin.

The KAP BIOT SUBGROUP consists of the Gipsdalen and Fleming Fjord Formations. The rocks of these group reflect a period of low clastic input in an

arid environment followed by reactivation of a western sediment source area and increased clastic sedimentation under increasing humid climatic conditions. These rocks vary from Anisian? to early Rhaetian age (Perch-Nielsen et al, 1974).

The Gipsdalen Formation is characterised by gypsiferous sandstones and mudstones, together with a thin layer of dark coloured marine limestones and mudstones. This formation is divided into the Solfaldsdal Member in the east part of the Jameson Land basin (variegated and gypsiferous sandstones and arkoses), and the Kolledalen Member in the northwest part of the Jameson Land basin (yellowish-orange or grey quartz sandstones with common gypsum nodules or cement). The Solfaldsdal Member is of more widespread occurrence in the basin. In the middle of the Solfaldsdal Member, 3-35 m of mostly dark grey or black, occasionally bituminous, mudstones and limestones represent the Gråklint Beds of Clemmenson (1980b). The Gråklint Beds are equivalent to the bituminous Myelina Limestone of Henderson (1976). These bituminous sediments are thought to represent a significant marine incursion of Anisian? age. The Solfaldsdal and Kolledalen Members are overlain by the variegated, gypsum-bearing sandstones and mudstones of the Kap Seaforth Member.

The rocks of the Karnian? to early Rhaetian Fleming Fjord Formation represent a marked change from the rocks of the underlying formations. The lower part of this formation is represented by the cyclically bedded yellow dolostones, green mudstones, flat pebble conglomerates and stromatolitic limestones (Sporfjeld Beds) to grey quartz sandstones and red sandstones and mudstones (Pingo Dal Beds) of the Edderfugledal Member. This member is overlain by the red mudstones and fine-grained sandstones of the Malmros Klint Member. The upper part of the Fleming Fjord Formation is represented by the dominant interbedded red or green mudstones and grey fine to coarse-grained sandstones of the Ørsted Dal Member. The upper part of this member, and the top of the Triassic sequence, consists of the red or variegated mudstone and carbonate rocks of the early Rhaetian age Tait Bjerg Beds.

This Triassic sequence is followed by the grey lacustrine and fluviatile sediments of the late Rhaetian to Liassic Kap Stewart Formation. The presence of a hiatus in sedimentation has been suggested between the Tait Bjerg Beds and the Kap Stewart Formation.

Depositional History:

The shales, siltstones and sandstones of the Wordie Creek Formation were deposited under intertidal to subtidal conditions in a shallow marine embayment with a northwards-tilted palaeoslope (Figure 2.2.4). The embayment is thought to have been open to the north and to have been bounded to the east and west by the newly active boundary faults implied from the presence of reworked Permian material in the lower Triassic rocks. Reef limestones of the Foldvik Creek Formation formed local palaeo-highs in the vicinity of Wegener Halvøy. Teichert and Kummel (1972) suggested a hiatus between the Foldvik Creek and Wordie Creek Formations equivalent to the Dzhulfian stage.

This period of marine deposition coincided with movement on the two boundary fault systems, with a large accompanying clastic input to the basin margins in the form of coarse alluvial fan deposits. This clastic input became of increasing importance towards the upper part of the Wordie Creek Formation. The coastal plain sediments of the Rødstaken Member mark the cessation of marine depositional conditions. The sediments of the Rødstaken Member vary laterally into the alluvial fan and floodplain sediments of the Paradigmabjerg and Klitdal Members (Figure 2.2.5). An arid climate has been suggested for this period based on sedimentological evidence such as the presence of incipient caliche layers and the arkosic nature of the coarse sediments. Clemmensen (1980a) has suggested that Central East Greenland was at a latitude of ca. 15°N at this time.

The Gipsdalen Formation represents a change in sedimentation with a marked reduction in clastic input from the bordering highlands, presumably reflecting the marked erosion of these uplifted margins which occurred during Early Triassic times. The Gipsdalen Formation (Anisian? - Ladinian?) is marked by the widespread deposition of gypsiferous sandstones and mudstones, the former tending to be much finer-grained than those which typified the underlying Pingo Dal Formation. Alluvial fan sediments are replaced throughout most of the basin by aeolian deposits in the northwest and floodplain grading to sabkha and lacustrine sediments elsewhere. A subtropical climate at a latitude of 20-30°N has been suggested.

This arid, sabkha-type deposition was briefly interrupted during the Anisian by a widespread marine transgression in this area. Clemmensen (1980a) has suggested that interaction between the eastern boundary fault system

and the Kong Oscars Fjord Fault System resulted in intermittent subsidence in the Kap Biot area allowing the Boreal Sea to impinge on the terrestrial Jameson Land basin. This Anisian marine transgression resulted in the deposition of the dark coloured, occasionally bituminous limestones and mudstones of the Gråklint Beds. Barrier calcarenites were developed in the Kap Biot area during this time.

Further movement on the eastern uplift closed off the sea, and evaporitic deposition was resumed, to deposit the variegated gypsum-bearing sandstone-mudstone association of the Kap Seaforth Member. At this time, three lacustrine/sabkha sub-basins were developed in the basin and formed seasonal lakes. Clemmensen (1980a) has suggested that alternating NE and SE trade winds had a significant influence on the nature of the sediments of the Kap Seaforth Member.

During the deposition of the overlying Edderfugledal Member of the Fleming Fjord Formation, uplift to the north of the Kong Oscars Fjord Fault resulted in an input of clastic material from this uplift. In addition, two of the small sub-basins merged into a large playa lake with the resulting deposition of the dolostone-mudstone-carbonate rocks of the Sporfjeld Beds. An upwards decrease in the occurrence of gypsum and halite casts in these beds is interpreted to reflect decreasing periods of salinity in the playa lakes (Clemmensen 1980a).

Sporadic uplift to the north resulted in periods of increased clastic input during this period. Otherwise, generally silty/carbonate deposition continued to be prevalent. The salinity of the East Greenland lake appears to have continued to decrease and the lake waters became largely fresh during deposition of the Malmros Klint Member (Clemmensen 1979). Aeolian sandstone deposits in the northwest of the basin show evidence of a dominant NE wind direction, while the decrease in occurrence of red-beds suggests a less arid climate (Figure 2.2.6).

Renewed activity on the western boundary fault system (early Kimmerian phase) resulted in uplift of the western highlands, and an increased clastic input. The eastern boundary was not reactivated, and the lake appears to have moved towards the eastern boundary at this time.

The Ørsted Dal Member represents a marked change in deposition with disappearance of red-beds and deposition of grey clastic sediments and carbonates. The sediments of the Ørsted Dal Member represent floodplain and

braided river channel deposits, the braided river deposits showing a progressive progradation over the floodplain deposits (Clemmensen 1980b). These rivers show evidence of eastwards-flow, grading into finer-grained lacustrine sediments. Periodic rejuvenation of the western source area controlled the input of coarser clastic material. Evidence of minor marine incursions may indicate a northeastern opening to the Boreal sea.

The mainly carbonate deposition typical of the Tait Bjerg Beds marks a change from the predominantly fluviatile deposition of the lower Ørsted Dal Member to more lagoonal conditions, with the greatest degree of subsidence occurring along the eastern boundary of the basin. The Traill Øya area may have been uplifted at this time and the basin appears to have been extended southwards. Clemmensen (1979, 1980a) suggests that the Central East Greenland basin was located at a latitude of approximately 40°N at this time and had a humid, temperate climate.

Perch-Nielsen et al (1974) indicate the occurrence of a depositional hiatus between the Tait Bjerg Beds and the deposition of the tidally-influenced sediments of the Kap Stewart Formation. The faulting in this area had an even more marked influence on the deposition of the Jurassic rocks (Surlyk et al 1981).

Clemmensen et al (1980) noted a number of similarities between the Triassic successions in Central East Greenland, the North Sea and Northwest Scotland. Alluvial red-beds are a feature of the Triassic succession in all three areas, although the aeolian and associated evaporite deposits are best developed in East Greenland. Marine facies are present in all three areas, although the marine carbonates of the Gråklint Beds are only found in Greenland. Tectonic controls on sedimentation were important in all three areas. Jacobsen and van Veen (1984) indicate that only the uppermost Upper Norian-Rhaetian succession at Haltenbanken can be compared lithologically to the equivalent sediments in East Greenland. Otherwise, the Triassic succession at Haltenbanken is more similar to that seen in the North Sea.

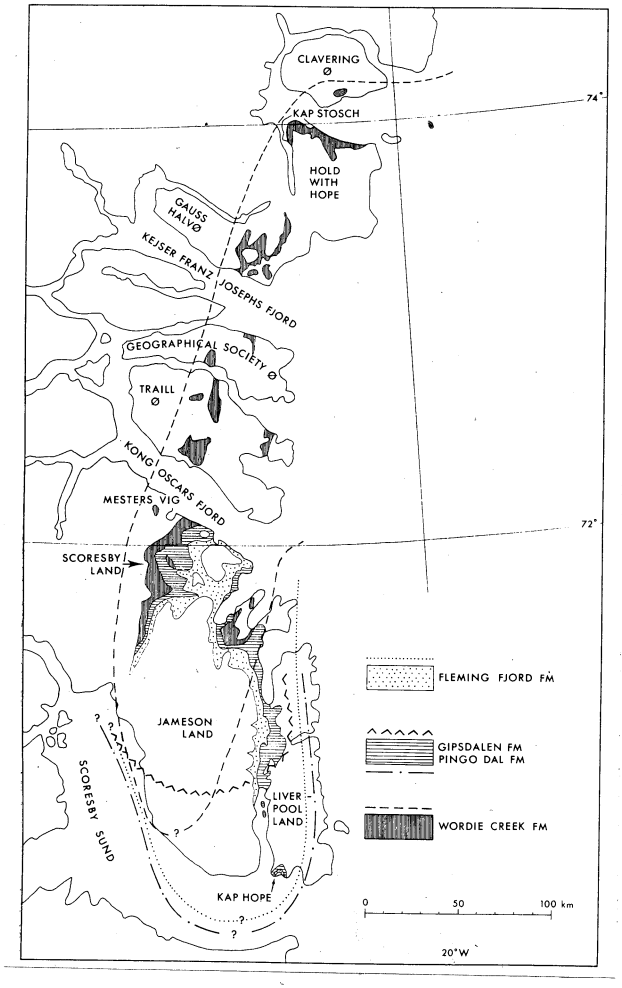

Figure 2.2.1. Distribution of outcropping Triassic sediments and estimated extensions of the Triassic formations (Perch-Nielsen et al 1974).

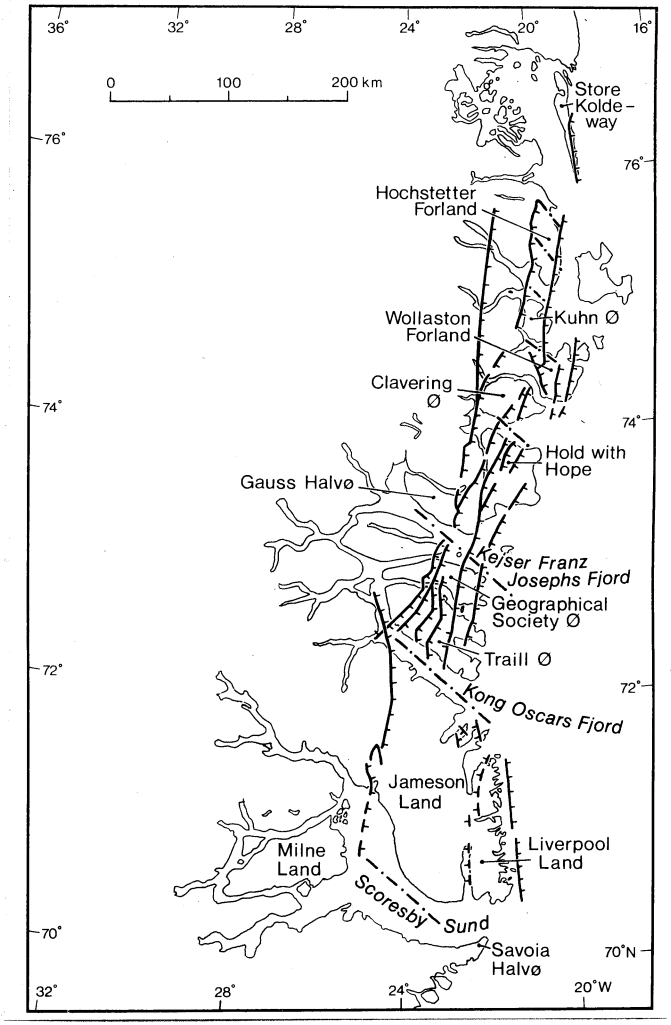

Figure 2.2.2. Major post-Caledonian faults in East Greenland (Surlyk et al 1981).

IKU SINTEF-GRUPPEN

APPROXIMATE AGE	JAMESON LAND AND SCORESBY LAND					TRAILL Ø
	GROUP	SUBGROUP	FORMATION	MEMBER	BEDS	MEMBER
RHAETIAN	Scoresby Land	Kap Biot	Fleming Fjord	Ørsted Dal	*Tait Bjerg	S Ørsted Dal N
NORIAN?						
CARNIAN?				Malmros Klint		S ?Malmros Klint N
LADINIAN?				Edderfugledal	*Pingel Dal *Sporfjeld	Edderfugledal
			▲Gipsdalen	▲Kap Seaforth		Kap Seaforth
ANISIAN?				*Kolle-dalen / ▲Solfalds-dal	*Gråklint	*Vega Sund
U		Nordenskiöld Bjerg	▲Pingo Dal	▲Paradig-mabjerg / Klitdal		Paradigmabjerg
SCYTHIAN				Rødstaken		
L			Wordie Creek			*Ødepas *Svinhufvuds Bjerge

* New unit ▲ Redefined unit ☐ Undivided ||||||| Hiatus

Figure 2.2.3a. Lithostratigraphic subdivision of the Triassic rocks in Jameson Land and Scoresby Land (Clemmensen 1980a).

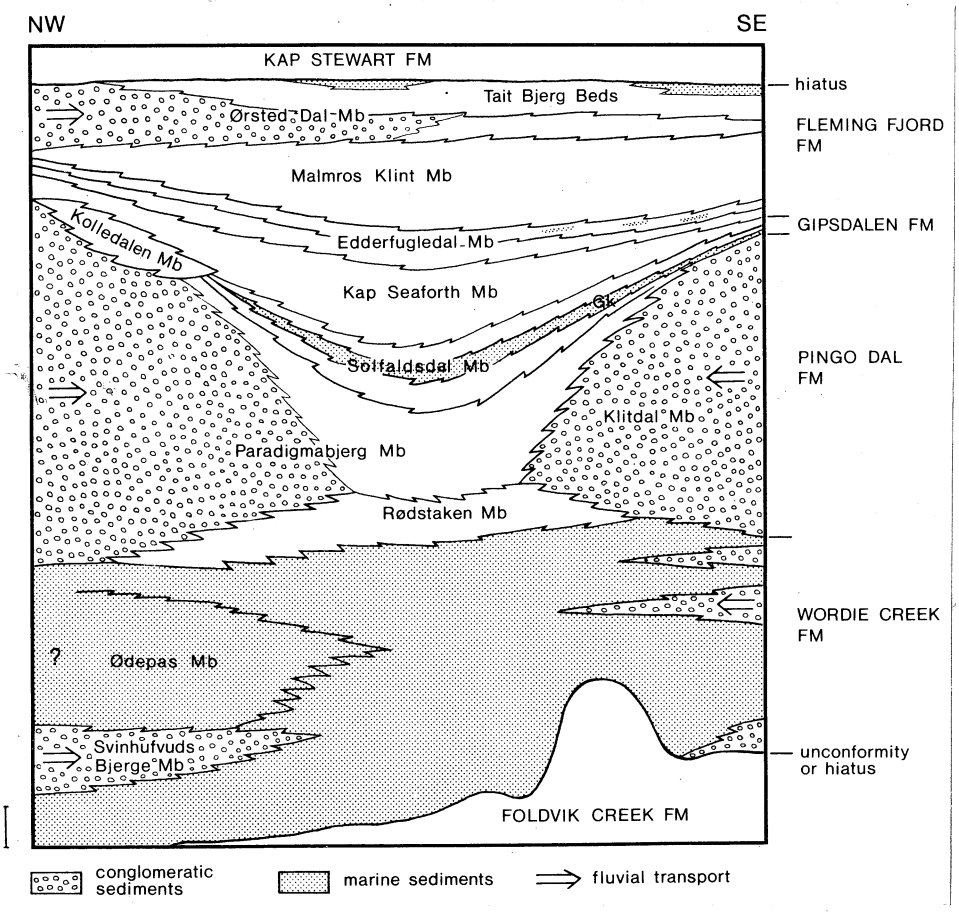

Figure 2.2.3b. Stratigraphic relationship of the Triassic deposits in the Scoresby Land Group (Clemmensen 1980b).

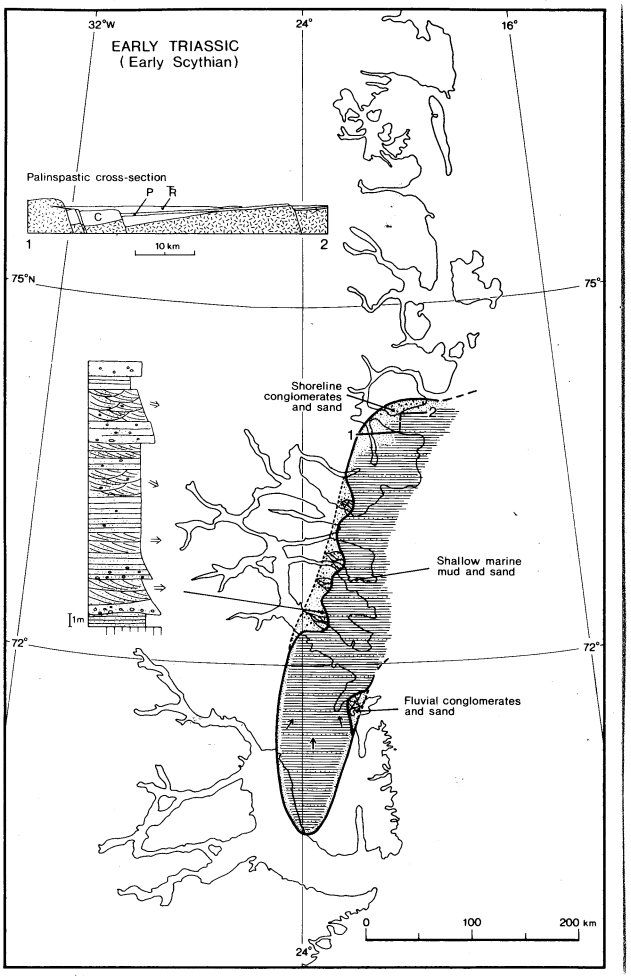

Figure 2.2.4. Early Lower Triassic palaeogeography (Surlyk et al 1981).
(Broken line indicates coastline during maximum transgression).

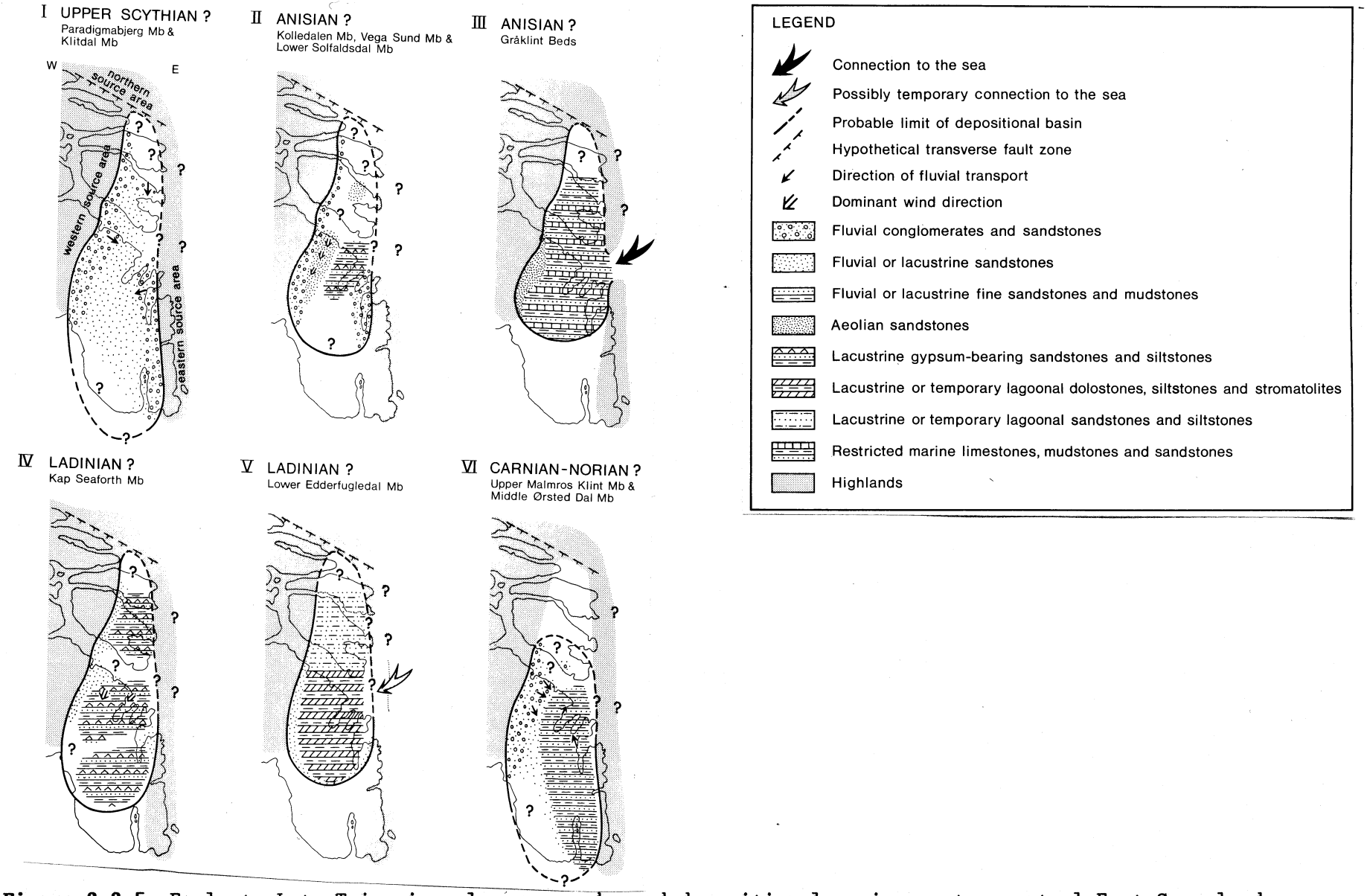

Figure 2.2.5. Early to Late Triassic palaeogeography and depositional environments, central East Greenland (Clemmensen 1980).

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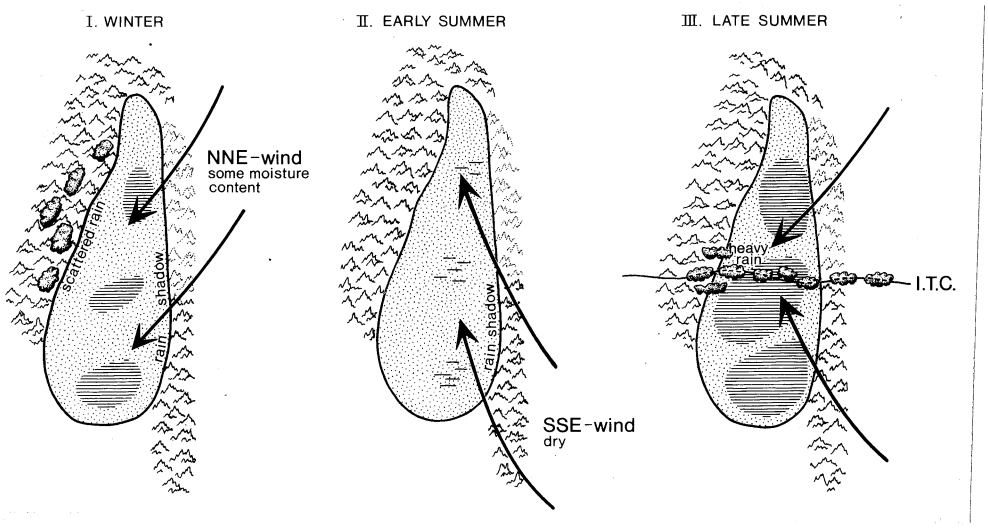

Figure 2.2.6. Suggested palaeogeographic and palaeoclimatic conditions during deposition of the (Anisian-Ladinian) Kap Seaforth Member (Clemmensen 1980a).

2.3 Triassic Succession of Northeastern Greenland: Wandel Sea Basin

Around 7 km of Carboniferous to Tertiary sedimentary rocks are preserved in a 500 km - long coastal belt in northern Greenland. The outcrop of these rocks is rather patchy and discontinuous (Figure 2.3.1).

Triassic rocks in the Wandel Sea Basin are represented by approximately 1 km of marine sediments occurring only in a fault-block area in the Trolle Land area of northeastern Greenland (Figure 2.3.2).

The deposition and preservation of these sediments has been strongly influenced by extensive faulting along the east-west trending Harder Fjord Fault Zone (HFFZ) and northeast-southwest trending Trolle Land Fault Zone (TLFZ) in Peary Land. Sinistral, transpressive strike-slip movement on the HFFZ system resulted in block-faulting along the TLFZ, with vertical movements of up to 1 km? Associated with this phase of activity is localised erosion/preservation of sediments and a slight south-southeast tilting of the fault blocks (Håkansson and Pedersen 1982).

Stratigraphy:

The Triassic rocks form the upper part of the Permo-Triassic Trolle Land Group (Figure 2.3.3). Two formations are recognised in the Triassic succession, representing two coarsening-upwards cycles (Håkansson and Stemmerik 1984).

The Parish Bjerg Formation overlies the marine calcareous shales of the late Permian Midnatfjell Formation with a slight angular unconformity. The lower part of the formation is represented by of 35 m of well-sorted, reddish sandstone with alternating beds of light-coloured, pebbly conglomerate. These lower beds are overlain by ca. 100 m of dark-coloured heterolithic shale and ca. 170 m of fine-grained, well-sorted sandstone with lenses of ferrigenous conglomerate. Shallow marine trace fossils are observed in the upper part of the formation. The age of this formation has not been exactly defined, but an uppermost Permian-Early Triassic age has been suggested (Håkansson 1979).

The Parish Bjerg Formation is overlain by ca. 600m of sandy/silty rocks representing the Dunken Formation. This formation is divided into a lower unit of recessive sandy/silty shale of Early Triassic age, and an upper unit of fine-grained, well-sorted sandstone showing evidence of moderate to

strong bioturbation. This upper unit is thought to be of Anisian age (Håkansson 1979).

Disseminated carbonaceous material, possibly of terrestrial origin is common, especially in the upper part of the formation. The rocks of the Dunken Formation contain shallow marine trace fossils and a sparse marine fauna. The Dunken formation is of more restricted extent than the underlying Parish Bjerg formation.

No further sediments have so far described between the top of the Dunkin Formation and the base of the upper Jurassic Ladegårdsåen Formation. The Parish Bjerg and Dunkin Formations are considered to have been deposited at the same time as the Barentsøya Group of Svalbard. No equivalent to the Kapp Toscana Group has been reported from Northeast Greenland.

Depositional History:

The limited occurrence of the Triassic sediments limits the inferences that can be drawn concerning the depositional history of these rocks. The marine character of these sediments has been outlined above, a generally shallow marine environment being suggested. The coarsening-upwards cycles and the occurrence of possible terrestrial carbonaceous material in the Dunken Formation may indicate proximity to a land area.

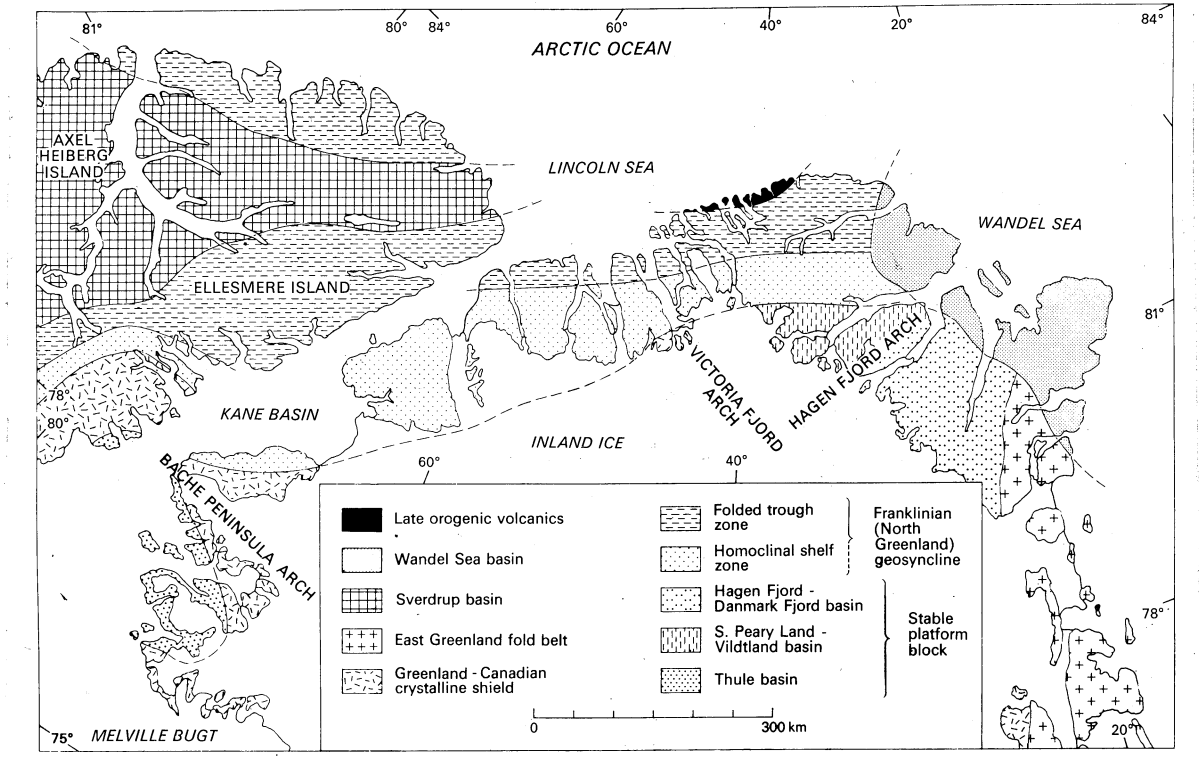

Figure 2.3.1. Map showing main structural-stratigraphic units of northern Greenland and adjacent Arctic Canada (Dawes 1976).

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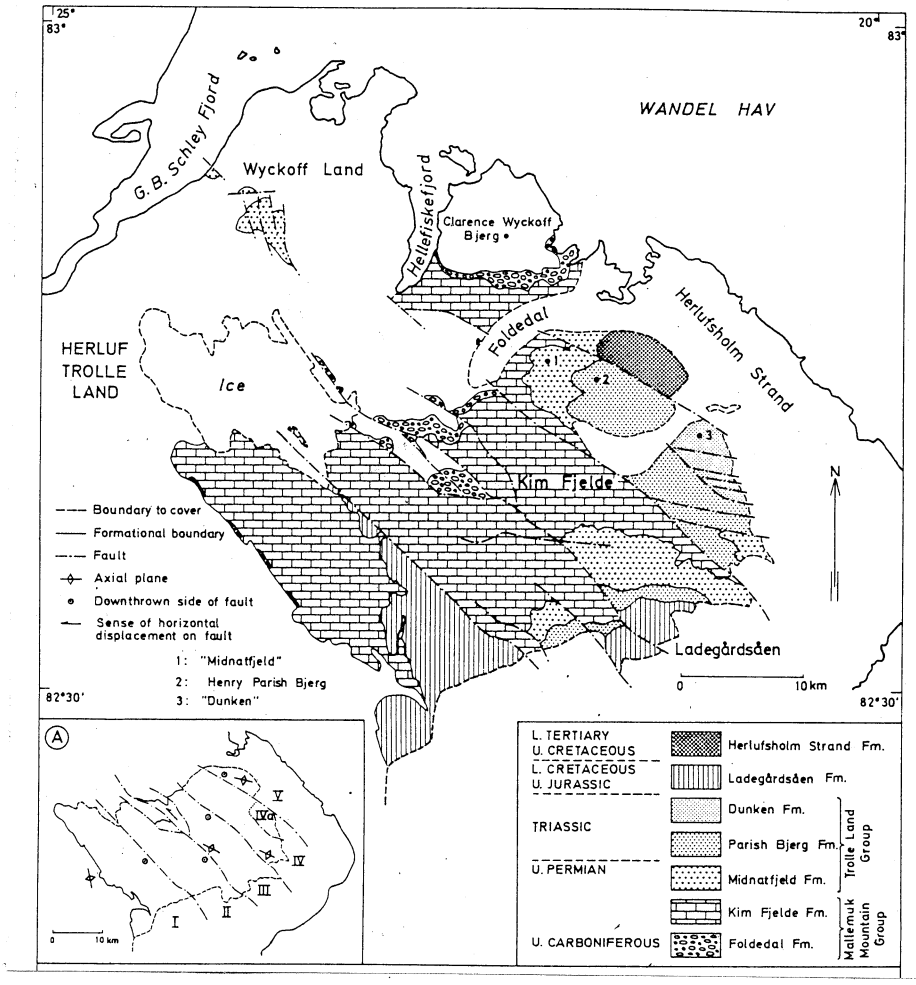

Figure 2.3.2a. Lithostratigraphic map of the Kim Fjelde region of eastern Peary Land, showing occurrence of Triassic strata (Håkansson 1979).

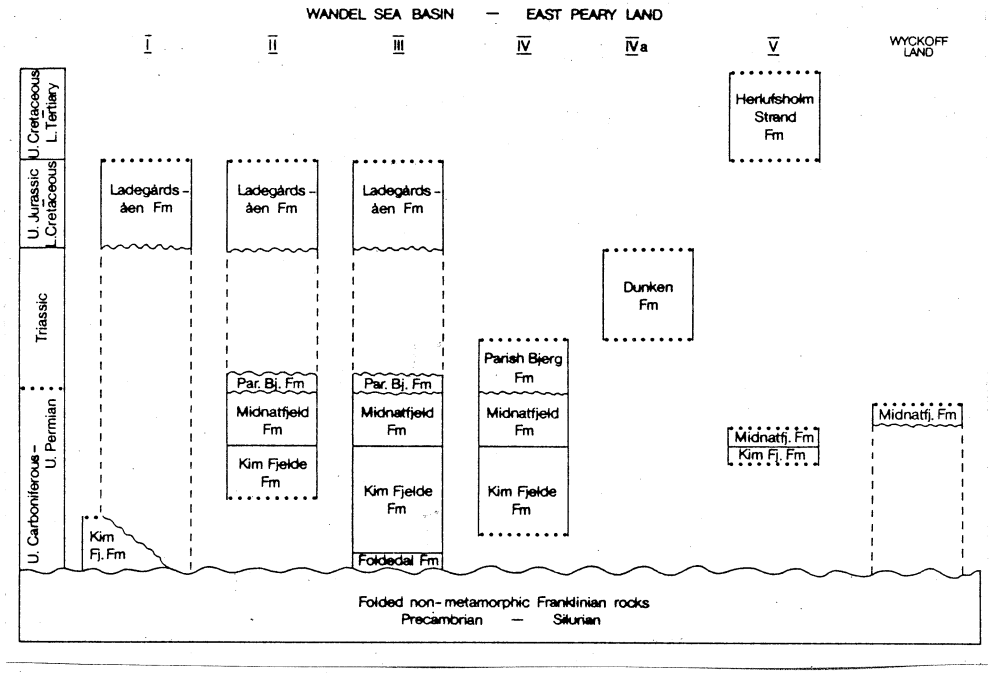

Figure 2.3.2b. Lithostratigraphic composition of the major fault blocks in eastern Peary Land (See inset "A" in Figure 2.3.2a.) (Håkansson 1979).

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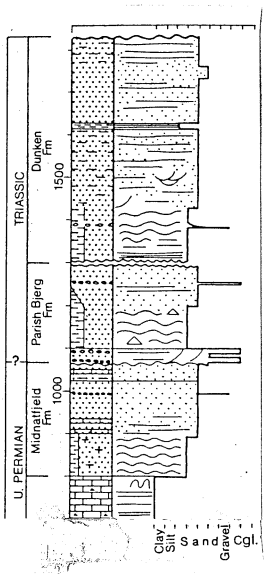

Figure 2.3.3a. Composite lithological sequence for the uppermost Permian and Triassic strata in the northern part of the Wandel Sea Basin (Håkansson 1979).

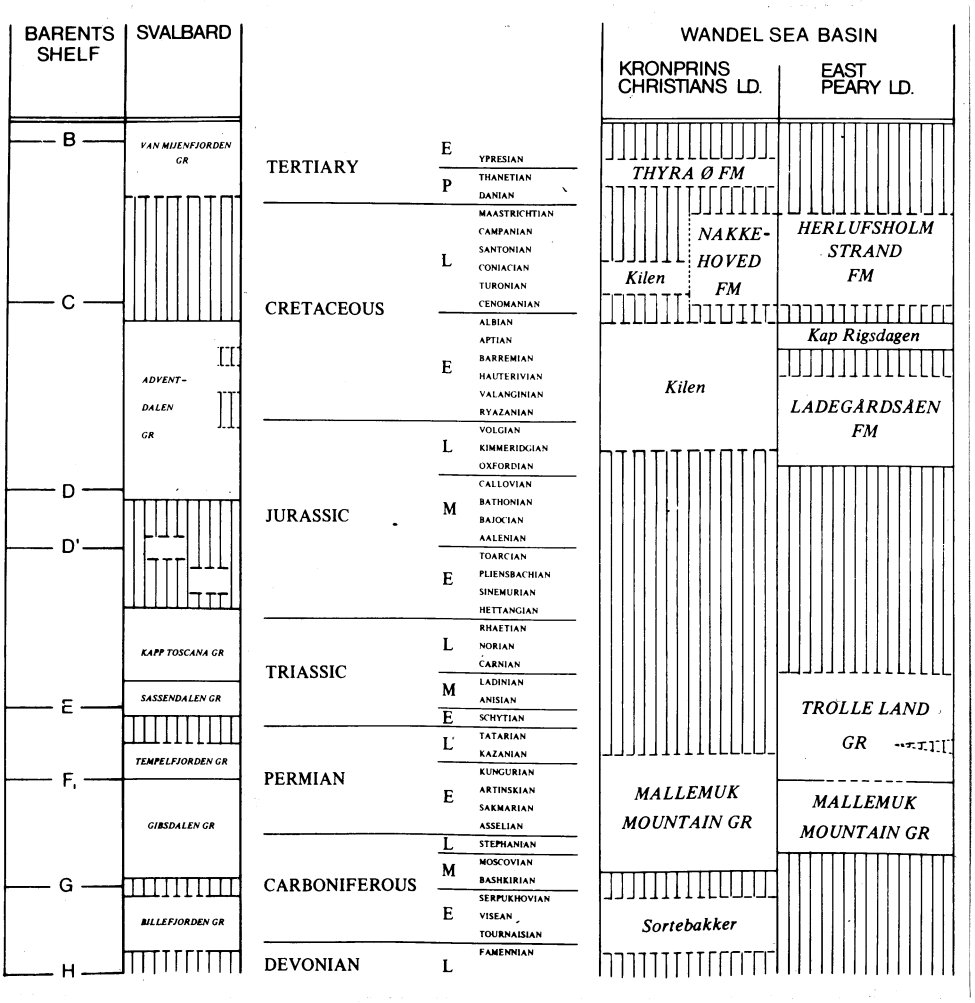

Figure 2.3.3b. Stratigraphy of the Wandel Sea Basin compared to Svalbard and the Barents Shelf (Håkansson and Stemmerik 1984).

2.4 Triassic Succession of the main Svalbard Archipelago

The Svalbard Archipelago lies in the area between 74°N-81°N and 10°E-35°E, and comprises four main islands (Spitsbergen, Nordaustlandet, Barentsøya and Edgeøya), together with a large number of much smaller islands.

Rocks of Triassic age outcrop along a narrow belt running northwards from Sørkapp to Festningen on Isfjorden, and then eastwards along a broader belt to the islands of Barentsøya and Edgeøya (Figure 2.4.1). In addition, rocks of Triassic age are thought to occur to the south below the Tertiary basin of central Spitsbergen. The total Triassic succession reaches a maximum composite thickness of around 1200 m in central Spitsbergen, thinning southwestwards towards the Sørkapp-Hornsund High, and northeastwards towards Barentsøya and Edgeøya.

Mørk et al (1982) recognise three structural terrains in the Triassic succession: 1) gently dipping, occasionally thrusted or faulted beds lying south of Hornsund and west of the Palaeogene West Spitsbergen Fold Belt; 2) highly folded, often thrusted beds lying in the main fold-belt, north of Isfjorden and extending eastwards towards the Pretender Lineament, and; 3) gently dipping or flat-lying sequences to the east of the Pretender Lineament.

Steel and Worsley (1984), indicate that Triassic deposition in Svalbard occurred in a stable platform environment, which was largely unaffected by tectonic or igneous activity until the Jurassic-Cretaceous times. Ulmishek (1985) suggests that, with the exception of the area around the Sørkapp-Hornsund High, the variations in thickness seen in the Triassic rocks reflect variations in sediment supply, rather than the tectonic movement or down-warping across the NW-SE trending lineaments suggested by Mørk et al (1982) and Steel and Worsley (1984).

During the lower and middle Triassic, the major sediment sources appear to have lain mainly to the west of Spitsbergen. An eastern sediment source appears to have become more prominent during the late Triassic with the deposition of the De Geerdalen and Wilhelmøya Formations.

Stratigraphy:

The 250-1200 m thick Triassic succession on Svalbard is subdivided into the Sassendalen Group of Griesbachian to Anisian age, and the Kapp Toscana

Group of Ladinian to Rhaetian age. The divisions reviewed here follow the system of Mørk et al (1982).

SASSENDALEN GROUP

It is intended to consider the western development of the Sassendalen Group first (Figure 2.4.2), followed by the central-eastern development of this group. The thickest developments of this group occur between the western foldbelt and the Pretender lineament (Figure 2.4.3), where three coarsening-upwards cycles can be recognised (Vardebukta, Tvillingodden and Bravaisberget Formations). East of the Pretender Lineament, the sequence is shale-dominated and thins over the Nordenfjorden Block before thickening to >400 m over the Billiefjorden Fault Zone. Other lineaments to the east of this fault zone appear to have been inactive during the deposition of the Sassendalen Group.

The Vardebukta formation is recognised in the western outcrop area of the Sassendalen Group. It is considered to be equivalent to the Deltadalen Member of the Barentsøya Formation in central and eastern Svalbard, and to the lower part of the Kistefjellet Formation in the Sørkapp-Hornsund area. The lowermost rocks of the Vardebukta formation consist of a series of grey, often silty shales which lie conformably on siliciclastic beds of upper Permian age. The succession coarsens-upwards into bedded sandstones which may contain shell fragments, trace fossils and mud-cracks. The rocks of this formation are considered to be of Griesbachian to Dienerian age, reaching a maximum thickness of ca. 290 m at the type locality near Festningen.

The rocks of the Tvillingodden Formation are considered to be equivalent to those of the Sticky Keep Member of the Barentsøya Formation, and to the rocks of the upper part of the Kistefjellet Formation. The dark grey, laminated shales at the base of this formation conformably overlie bioturbated silty shales and siltstones of the Vardebukta Formation. Thin sandstone beds become more abundant up the succession, grading into a upper unit which consists of very finely-grained, thin-bedded sandstones. Evidence of bioturbation becomes more frequent up the formation. The top of the formation is taken at a thick, fossiliferous, sandy limestone horizon.
In more southern outcrops of this formation, more than one coarsening-upwards sequence may be observed, together with a distinctive limestone horizon (Skilsen Bed). The rocks of this formation thin southwards from a maximum thickness of nearly 300 m at Bravaisberget. Ammonite and bivalve data

occurrences suggest a Smithian to Spathian age for the Tvillingodden Formation.

The Bravaisberget Formation is considered to be equivalent to the Botneheia Member of the Barentsøya Formation in central and eastern Svalbard, and to the Verdande Bed of Bjørnøya. In the type section at Bravaisodden, phosphatic shales (Passhatten Member) at the base of the Bravaisberget Formation overlie massive siltstones of the underlying Tvillingodden Formation. The phosphatic shales grade upwards into bioturbated, fine-grained sandstones with calcareous and phosphatic cements (Somovbreen Member). A second coarsening-upwards cycle grades from a more shaley development of rocks into another fine-grained sandstone unit showing low-angle cross-bedding and mega-ripples. In Sørkapp Land, the Karentoppen Member is recognised as a cross-bedded sandstone sequence, which rests on the phosphatic shales of the Passhatten Member and grades upwards into the fine-grained sandstones and siltstones of the Somovbreen Member. South of Bellsund, only one coarsening-upwards sequence can be recognised, the grain-size of the coarsest sequence increasing southwards.

The Bravaisberget Formation is considered to be of early Anisian to late Ladinian age, and thins southwards from a maximum thickness of ca. 200 m at Bravaisodden to ca. 70 m at Kistefjellet in Sørkappland.

The Kistefjellet Formation is a 43 m thick succession of conglomerates, shales and interbedded shale and sandstone beds which directly overlie the Hekla Hoek basement on the Sørkapp-Hornsund High in Sørkappland. This formation is thought to represent a condensed sequence which was deposited from Dienerian to early Anisian times.

The Barentsøya Formation consists of a series of argillaceous sediments of Griesbachian to early Ladinian age which occur in central and eastern Spitsbergen, Edgeøya and Barentsøya. The unit was first defined by Lock et al (1978) on Northeast Barentsøya.

The lowermost member of this formation, the Deltadalen Member, consists of a series of greenish-grey shales and sandstones which overlie glauconitic sandstones of Permian age at the type locality, and which fine upwards into shales with siltstone or fine-grained sandstone interbeds. Limestone concretions and marine fossils are common. This unit is considered to be of Griesbachian to Dienerian age, and thins eastwards and westwards from a maximum thickness of ca. 120 m at the type locality.

The uppermost silty shales and siltstones of the Deltadalen Member are overlain by the laminated, dark grey shales of the overlying Sticky Keep Member. Thin, calcareous siltstone beds also occur in this member, becoming more common towards the top of the formation. Calcareous nodules are common and tend to be concentrated at particular horizons. Bivalve and ammonite fossils occur throughout this unit. This unit is thought to be of Smithian to Spathian age and reaches a maximum development of ca. 120 m at the type locality.

The uppermost, fossiliferous, calcareous siltstone bed of the Sticky Keep Member is overlain by the black, phosphatic shales of the Botneheia Member. This member may be divided into a lower unit consisting of dark phosphatic shales with a few thin calcareous siltstone beds, and an upper unit (Blanknuten Bed) with dark, often calcareous, papery shales and common thin siltstone beds. The uppermost boundary of this member is taken at a siltstone bed rich in phosphatic nodules and trace fossils. The Botneheia Member is considered to be of Anisian to late Ladinian age. The Botneheia Member thins eastwards from a maximum thickness of ca. 170 m at the type locality, to ca. 70-80 m on Edgeøya and Barentsøya.

KAPP TOSCANA GROUP

The Kapp Toscana Group (Figure 2.4.4) can be recognised over most of the area of Mesozoic outcrop in the Svalbard Archipelago, although the sequence is not always complete.

The dark, phosphatic shales of the Sassendalen Group are overlain by grey silty shales and siltstone laminae with siderite nodules of the Tchermaksfjellet Formation. There is an increase in the abundance of siltstone laminae, and an accompanying decrease in the occurrence of siderite nodules, towards the top of this formation. The Tschermaksfjellet Formation is uniformly developed throughout central and eastern Svalbard, but is not developed in parts of the western Triassic outcrop area where rocks of the De Geerdalen Formation may directly overlie rocks of the Bravaisberget Formation.

The rocks of the Tschermaksfjellet Formation are thought to be of late Ladinian to late Karnian age at the type locality, where a thickness of ca. 40 m is developed.

The silty mudstones and shales of the Austjøkelen Formation occur over the Sørkapp-Hornsund High and are considered to be laterally equivalent to the shales of the Tschermaksfjellet Formation. The rocks of this formation thin southwards over the Sørkapp-Hornsund High from ca. 30 m to 12 m.

The base of the De Geerdalen Formation is taken at the first hard sandstone bed in the Kapp Toscana Group and often shows a gradational boundary with the uppermost silty beds of the Tschermaksfjellet Formation. The rocks of the De Geerdalen Formation consist of a series of coarsening-upwards shales and fine-grained sandstones. The relative proportion of sandstone in the succession increases both to the northeast and southwest. The rocks of the De Geerdalen Formation are considered to be of late Karnian to Norian/ Rhaetian age, and thin from a maximum thickness of over 400 m on Barentsøya and Edgeøya, to less than 30 m over the Sørkapp-Hornsund High. In central and eastern Spitsbergen, this formation has a rather uniform development of ca. 300 m.

The Wilhelmøya Formation is the uppermost formation of the Kapp Toscana Group and consists of a simple coarsening-upwards sequence from a sideritic claystone to a mature, quartzitic sandstone. Lag conglomerates are common. The upper and lower boundaries of this formation are marked by phosphatic conglomerates at most localities. The upper phosphatic conglomerate is referred to as the Brentskardhaugen Bed and contains a distinctive Toarcian fauna. The rocks of the Wilhelmøya Formation thin westwards from a maximum thickness of ca. 120 m at the type locality, to less than 50 m west of the Billiefjorden Fault Zone. The rocks of this formation are considered to be of Norian/Rhaetian to Bathonian age.

In the western Triassic outcrop area, the Wilhelmøya Formation is represented by the Knorringfjellet Member in the outer Isfjorden area, and by the Smalegga Member in Sørkappland. The shales, siltstones and carbonates of the Knorringfjellet Member grade southwards into the mainly bioturbated sandstone of the Smalegga Member. These two members reach a thickness of only 20-30 m.

Depositional History:

The basal shales and siltstones of the Sassendalen Group may disconformably overlie the siliceous siltstones of the underlying Permian Tempelfjorden Group (Steel and Worsley 1984). An erosive boundary is only occasionally demonstrable, especially over the Sørkapp-Hornsund High. The Sørkapp-Horn-

sund High was not fully submerged until Dienerian times. The base of the Sassendalen Group is considered to be of Griesbachian to Smithian age, the youngest boundary occurring on Barentsøya and Edgeøya (Mørk et al 1982).

The basal shales and siltstones of the Sassendalen Group (Vardebukta Formation and Deltadalen Member) represent a marine transgression which initiated Triassic sedimentation over the whole of the Svalbard Archipelago (Mørk et al 1982; Steel and Worsley 1984). The occurrence of a hiatus between deposition of the uppermost Permian beds and the initial Triassic transgression cannot be established with any certainty (Mørk et al, 1982).

The siltstones and fine-grained sandstones of the upper Vardebukta Formation have been interpreted as representing a barrier bar system, with associated tidal inlets and back-barrier lagoonal systems (Figure 2.4.5: Mørk et al, 1982). The Sørkapp-Hornsund High is thought to have been intermittently emergent at this time. The occurrence of dessication cracks at the Selmaneset locality may indicate intermittent sub-aerial exposure (Mørk et al, 1982). The shale-siltstone succession of the laterally-equivalent Deltadalen Member is thought to represent deposition of sediments below normal wave-base on a gradually deepening, storm-influenced continental shelf.

An increase in the frequency of shale and siltstone beds in the upper part of the Vardebukta Formation precedes the early Dienerian transgressive event which initiated the deposition of the shales of the overlying Tvillingodden Formation in western Spitsbergen (Mørk et al 1982). The early mud deposition of the Tvillingodden Formation (possibly under anoxic or dysoxic conditions; Mørk et al 1982) was followed by renewed progradation and deposition of storm-influenced siltstone beds. The coarsening-upwards sequence of the Tvillingodden Formation terminated with the deposition of bioturbated and bioclastic sandstones around wave-base in the Isfjorden area. In southern area, this sequence terminates in delta-front sandstones (Steel and Worsley 1984). The Sørkapp-Hornsund high was finally submerged during this time, leading to the deposition of a sequence of conglomerates, shales and sandstones (Kistefjellet Formation) on Hekla Hoek basement.

In central and eastern Svalbard, this period is represented by the deposition of the dark shales of the Sticky Keep Member. These shales are thought to have been mainly deposited below storm-wave base. A poor macrofossil fauna is considered to indicate that deposition of these shale occurred under partly anoxic conditions (Mørk et al, 1982).

A major transgression event in early Anisian times is reflected by the deposition of the black phosphatic shales of the Bravaisberget Formation and the Botneheia Member (2.4.6). In the western outcrop areas, deposition of the basal black shales of the Bravaisberget Formation is followed by deposition of increasingly higher energy deposits up to the deposition of delta-front sandstones towards the middle and top of the formation. The deposition of these sandstones is interrupted by shallow shelf or lagoonal siltstone deposition in northern occurrences of this formation. Over the Sørkapp-Hornsund High, a simpler coarsening-upwards cycle resulted in the deposition of delta-plain and tidally-influenced tidal channel sediments.

East of the Pretender Lineament, deposition during the Anisian-early/mid-Ladinian is represented by deposition of dark, phosphatic shales of the Botneheia Member. Phosphatic nodules in these shales often show a distribution which suggests that they may represent an infilled burrow system (Mørk et al, 1982). Deposition of these shales occurred in a low-energy environment, probably below storm-wave base. A restricted fossil fauna and high organic carbon contents indicate a mainly anoxic or dysoxic depositional environment. Downwarping along the line of previous lineaments may be reflected in thickness variations in the sequence.

Deposition of these basinal or deep shelf shales is thought to have coincided with the establishment of an upwelling current system, resulting in a high organic productivity. Individual bioturbated siltstone beds are thought to represent intermittent ventilation events or local shoal deposits (e.g. Barentsøya). Mørk et al (1982) and Steel and Worsley (1984), suggest the presence of a distant eastern sediment source at this time based on variations in the nature of the organic matter present in the rocks.

Korchinskaya (1982) considers the boundary between the Sassendalen and Kapp Toscana Groups to be of late Ladinian age. At many localities, this boundary may coincide with a depositional hiatus (Steel and Worsley 1984). Marine shales of the Tschermaksfjellet and Austjøkelen Formations overlie the uppermost beds of the Bravaisberget and Barentsøya Formations, often showing a sharp contact. These formations are not recognised in the western Triassic outcrop area between Bellsund and Isfjorden or on the Sørkapp-Hornsund High, where deltaic influence continued.

The marine shales of the Tschermaksfjellet Formation are progressively

overlain from the east by prograding delta-front and delta-top sediments of the De Geerdalen Formation. The coarsening and thickening of the deltaic sands towards the east suggests initiation or rejuvenation of sediment source areas to the east and northeast, possibly as a result of uplift.

The deltaic sands of the De Geerdalen Formation in eastern Svalbard show evidence of significant wave-reworking and redistribution of the sediment in a shallow shelf environment, with development of offshore bar sands (Figure 2.4.7). More proximal deltaic developments are seen in eastern areas where the sediments show evidence of both fluviatile and shallow marine wave processes (Mørk et al, 1982). In western areas, after an initial period of delta progradation, deltaic influence on sedimentation decreases with time and more evidence of wave-reworking is seen. This is thought to reflect the decreasing importance of the western deltaic system and an eastwards shift of the upper Triassic depo-centre.

A regional transgression of Norian/Rhaetian age is marked by the transition from the sandstones of the uppermost De Geerdalen Formation to the basal phosphatic conglomerates and marine shales of the Wilhelmøya Formation. Deposition of marine shales was superseded in Pliensbachian-Toarcian times by deposition of reworked coastal or mouth-bar sands in northeastern Spitsbergen, and by back-barrier, lagoonal, swamp and marsh sediments in Kong Karls Land. The sandstones of the Wilhelmøya Formation appear to reflect westwards progradation as in the underlying sandstones of the De Geerdalen Formation. However, extensive reworking of the Wilhelmøya sandstones is thought to reflect a low sedimentation rate and a low clastic input due to low relief in the sediment source area (Mørk et al, 1982).

The rocks of the Wilhelmøya Formation thin westwards towards the Billiefjorden Fault Zone, where a radical decrease in the thickness of this formation to less than 50 m, is observed (Figure 2.4.8). There is an accompanying decrease in the sandstone content of the Wilhelmøya Formation towards the Billiefjorden Fault Zone. Frequent lag conglomerates on and adjacent to the Sørkapp-Hornsund High are thought to reflect erosional episodes, although, in contrast the the earlier formations, the Wilhelmøya Formation shows a tendency to thicken onto the Sørkapp-Hornsund High. The uppermost boundary of the Wilhelmøya Formation is represented by the phosphatic conglomerate bed of the Brentskardhaugen Bed which is thought to represent a period of transgression-regression and transgression during Toarcian to Bathonian times.

The area of the Svalbard Archipelago is considered to have drifted from a latitude of ca. 45°N during the early Triassic, to a latitude of ca. 60°N during the Rhaetian (Smith and Briden, 1977).

Organic Geochemistry:

Early work by Bjorøy (1978) concerned organic-rich shales of the Kapp Toscana Group from Nordaustlandet. More comprehensive work was carried out on the Triassic succession at IKU over the period 1978 to the present as part of an ongoing Arctic study programme. Some of this material, mainly concerned with the Sassendalen Group, has been partially published by Bjorøy et al (1980), Forsberg and Bjorøy (1983), Mørk and Bjorøy (1984), and Schou et al (1984). Most of this work was based on the collection of samples held at IKU and collected during the late 70's and early 80's (Appendices A.1 and A.2; Enclosures E.2 and E.3).

Throndsen (1979) reported a consistent northeastwards decrease in the thermal maturity of kerogen from rocks of the Kapp Toscana Group, with vitrinite reflectance values which decrease from 0.6-0.8 % in the Isfjorden area to less than 0.4 % in Nordaustlandet. The kerogen in Triassic rocks from the western foldbelt and Bjørnøya were reported to be thermally post-mature.

Forsberg and Bjorøy (1983) investigated the influence of weathering on the organic matter of shales of the Botneheia Member in central Spitsbergen and Edgeøya. Their results indicated that only the EOM in the rocks is affected to any extent and often shows evidence of both oxidation and microbial degradation. Vitrinite reflectance values were found to decrease from ca. 0.9 % at Festningen to ca. 0.5-0.6 % in central Spitsbergen to ca. 0.4 % on southern Edgeøya (Figure 2.4.9).

In addition, an eastwards increase in organic carbon content was also noted, varying from 1.3-2.9 % in shales at Festningen to ca. 7.5 % in the eastern outcrop localities. This variation in organic richness is paralleled by a steady increase in the bitumen content of the Botneheia shales from west to east (i.e. 500-1500 ppm at Festningen to 1300-4300 ppm on Edgeøya). Inconsistencies between the maturity of the bitumens and the maturity of the kerogen in the enclosing rocks was used to infer the occurrence of migrated bitumen in the Botneheia shales at some localities.

Mørk and Bjorøy (1984) considered the organic geochemistry of the rocks of

both the Sassendalen and Kapp Toscana Groups (Table 2.4.1). Shales of the Deltadalen Member and the Vardebukta Formation were characterised by organic carbon contents of <1.0 % (Figure 2.4.10), consisting mostly of type III kerogen, although the proportion of type II kerogen in the Deltadalen Member is reported to increase towards the northeast.

The shales of the Sticky Keep Member and the Tvillingodden Formation are more organic-rich than those of the underlying units. Organic carbon contents in these two formations vary from 0.5 % to 6.0 %, with most samples having organic carbon contents of between 1.5 % and 3.0 % (Figure 2.4.10). The lowest organic richnesses tend to be found in the shales of the Tvillingodden Formation. The kerogen is described as being typically type III, although the proportion of type II kerogen is reported to increase towards the northeast. Samples from the Sticky Keep Formation were found to contain appreciable concentrations of relatively mature bitumen. The occurrence of this bitumen appears to be inconsistent with the maturity and kerogen type in these rocks and is thought to be of non-indigenous origin.

The phosphatic shales of the Botneheia Member and the Bravaisberget Formation are the most organic-rich rocks described from the Triassic succession in Svalbard, with organic carbon contents of >2.0 %, and up to ca. 10 % in eastern Spitsbergen and the islands of Barentsøya and Edgeøya. An upwards increase in the organic carbon content of the Botneheia shales occurs in these areas (Forsberg and Bjorøy 1983; Mørk and Bjorøy 1984).

The alternation of organic-rich shales and less organic-rich siltstone beds in the Botneheia Member are thought to reflect periodic storm ventilation of a normally anoxic basin. An increase in the organic richness of the Botneheia Member to the east of the Billiefjorden Lineament is thought to reflect the enhancement of anoxic bottom conditions due to relatively greater subsidence in this area.

Mørk and Bjorøy (1984) indicate that the kerogen in these middle Triassic shales typically consists of type II, mainly amorphous kerogen. Higher hydrogen index values are reported from eastern areas on Nordaustlandet, Barentsøya and Edgeøya, where values typically vary from 400-600 mg/g TOC. The upper part of the Botneheia tends to contain more hydrogen-rich kerogen than the lower part in these areas. Forsberg et al (1984) reports significant occurrences of tasmanitid algal debris from these eastern areas, especially from the lower part of the Botneheia succession at Torrellnesfjellet on Nordaustlandet. However, they also report that the matrix marine amor-

phous material may have had more influence on the overall character of the kerogen, and therefore on the composition of the currently generated bitumens.

Mørk and Bjorøy (1984) indicate that the bitumen in the Botneheia shale samples is mostly indigenous, while that in the siltstones is largely non-indigenous. Work by Schou et al (1984) on the bitumen in these rocks indicated that there is little variation in the composition of the bitumen from one locality to another, suggesting a common source for which the shales of the Botneheia Member could not be excluded. The biomarker data from these bitumens typically show relatively abundant tricyclic terpane compounds and a prominence of the C_{27} and C_{29} compounds amongst the regular steranes.

Schou et al (1983) considered that long-range migration is not a major process in these rocks on the basis of observations that the least mature bitumens occur in the least mature sections, and vice versa. Short-range migration is considered to be the main process controlling the occurrence and composition of the bitumens.

Mørk and Bjorøy (1984) report that the organic carbon content of shales from the Kapp Toscana Group are typically less organic-rich than those from the Sassendalen Group. The kerogen in the Kapp Toscana shales is also less hydrogen-rich and tends to consist of type III or type IV kerogen.

The high thermal maturity of the kerogen in the Triassic rocks occurring in the western fold-belt restricts the use of organic-geochemical data in these rocks. Mørk and Bjorøy (1984) report vitrinite reflectance values of between 1.0 % and 1.5 % from this area.

In conclusion, various authors have indicated that the dark, phosphatic shales of the Botneheia Member of the Barentsøya Formation represent the most promising hydrocarbon source-rocks in the Triassic succession. The kerogen in these rocks is thermally immature on Nordaustlandet, Barentsøya and Edgeøya; thermally mature in central and eastern Spitsbergen (especially below the central Tertiary Trough (Mørk and Bjorøy, 1984)); and thermally post-mature in the western fold-belt, if any potential source-rocks actually occur in this area.

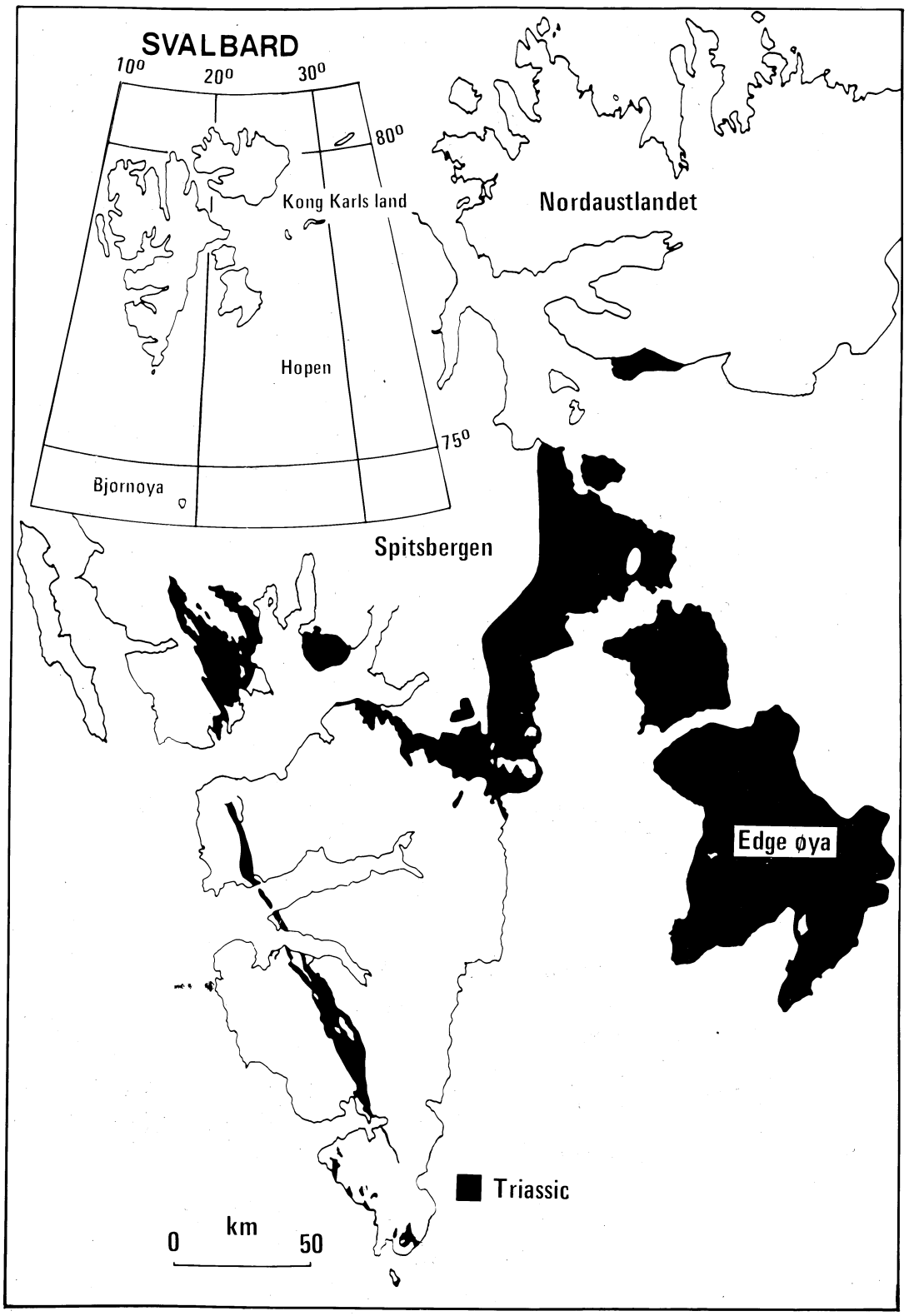

Figure 2.4.1. Map showing outcrop of Triassic strata in the Svalbard Archipelago (Mørk et al 1982).

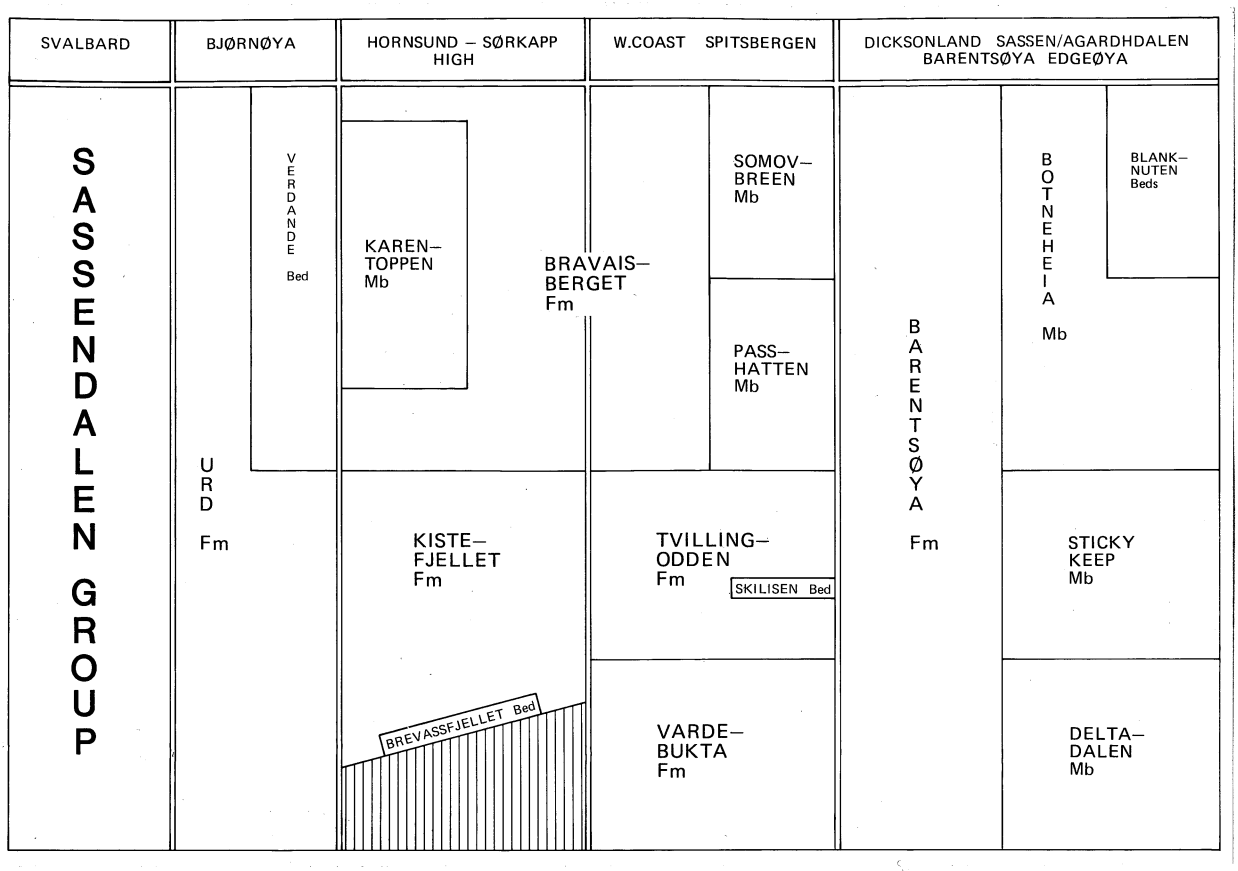

Figure 2.4.2. Proposed lithostratigraphy of the Sassendalen Group (Mørk et al 1982).

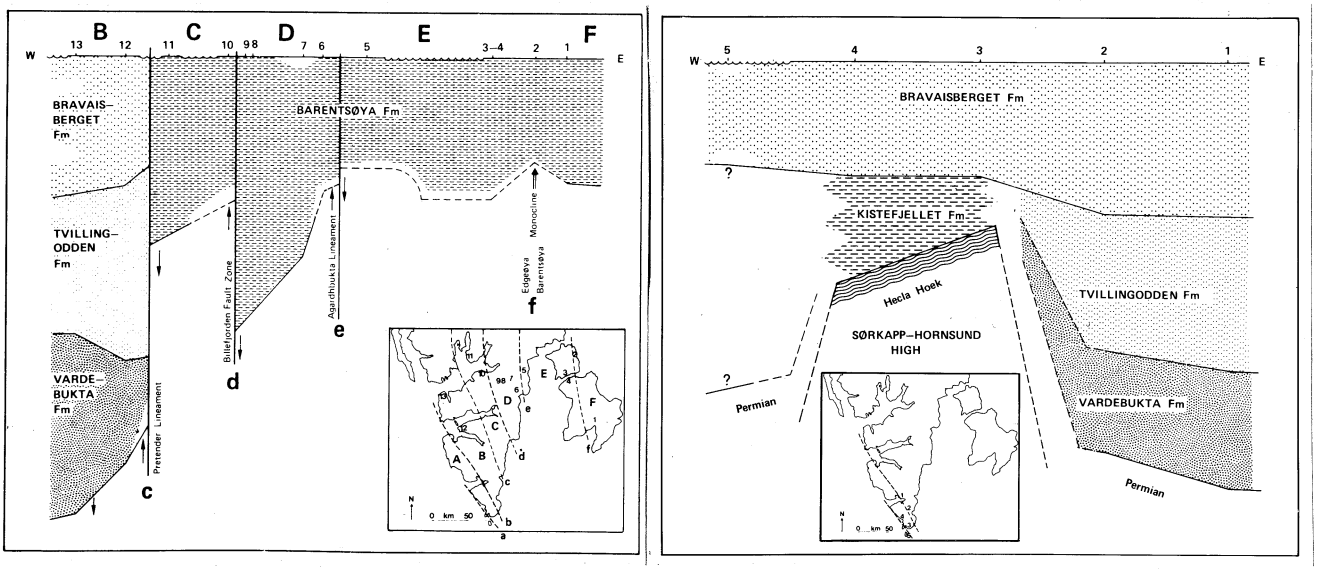

Figure 2.4.3. Schematic fence diagrams showing thickness variation and distribution of formations within the Sassendalen Group (Mørk et al 1982).
(A) Sørkapp-Hornsund High; (B) Central Basin; (C) Nordfjorden High; (D) Billiefjorden Trough; (E&F) Stable platform areas.

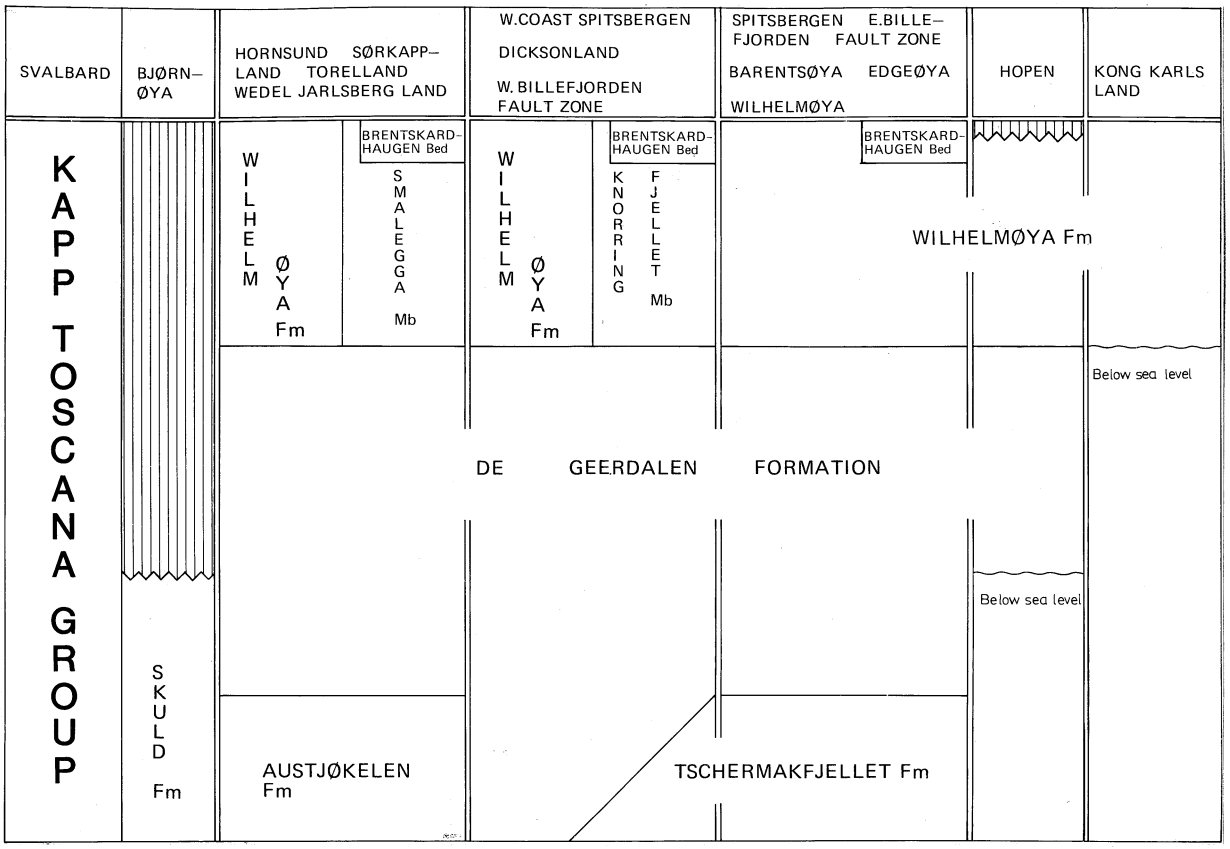

Figure 2.4.4. Proposed lithostratigraphy of the Kapp Toscana Group (Mørk et al 1982).

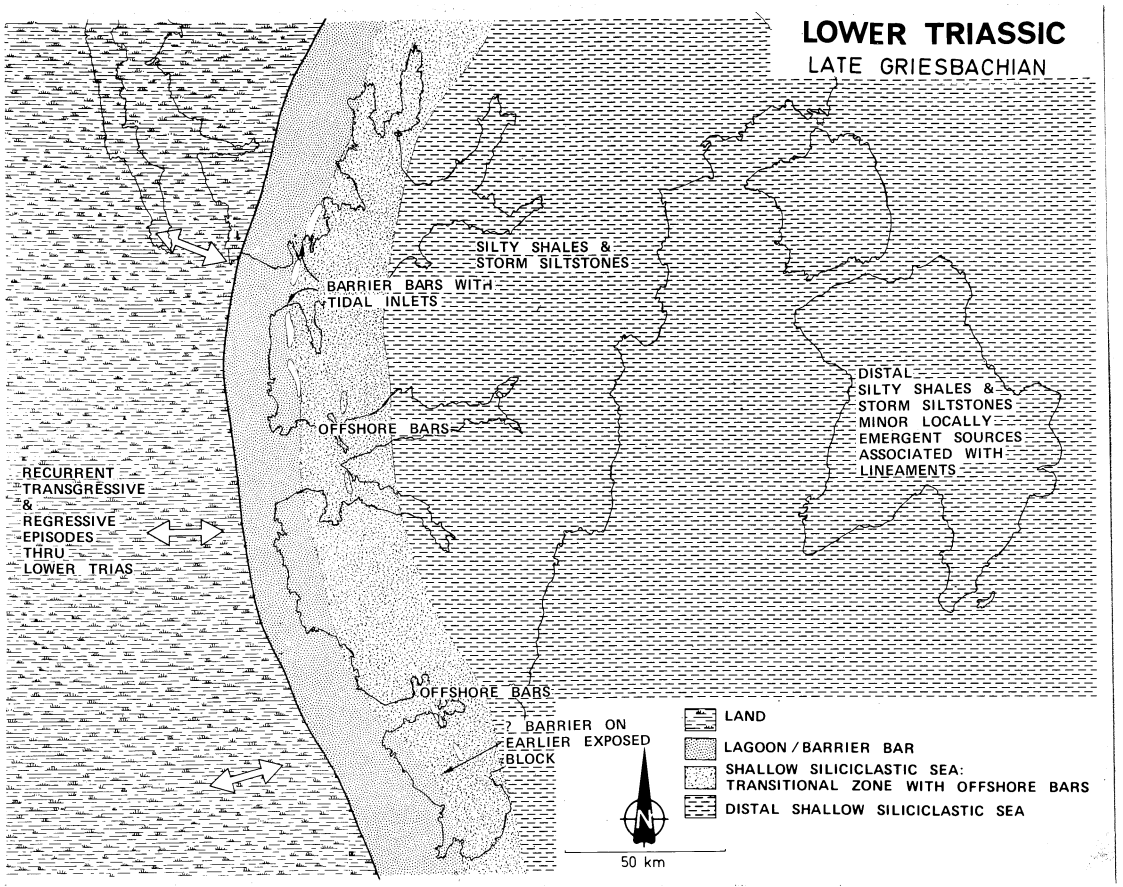

Figure 2.4.5. Palaeogeographical synthesis of depositional regiemes in the Lower Triassic (Mørk et al 1982).

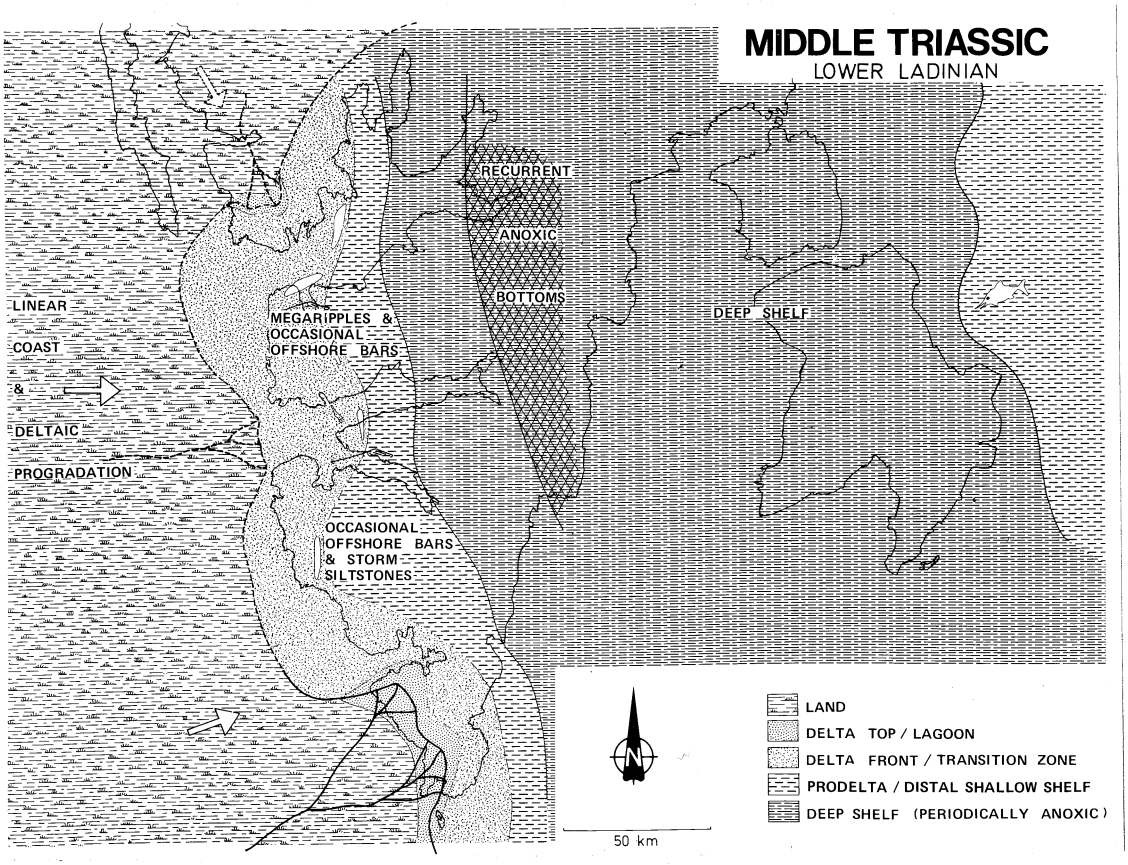

Figure 2.4.6. Palaeogeographical synthesis of depositional regiemes in the Middle Triassic (Mørk et al 1982).

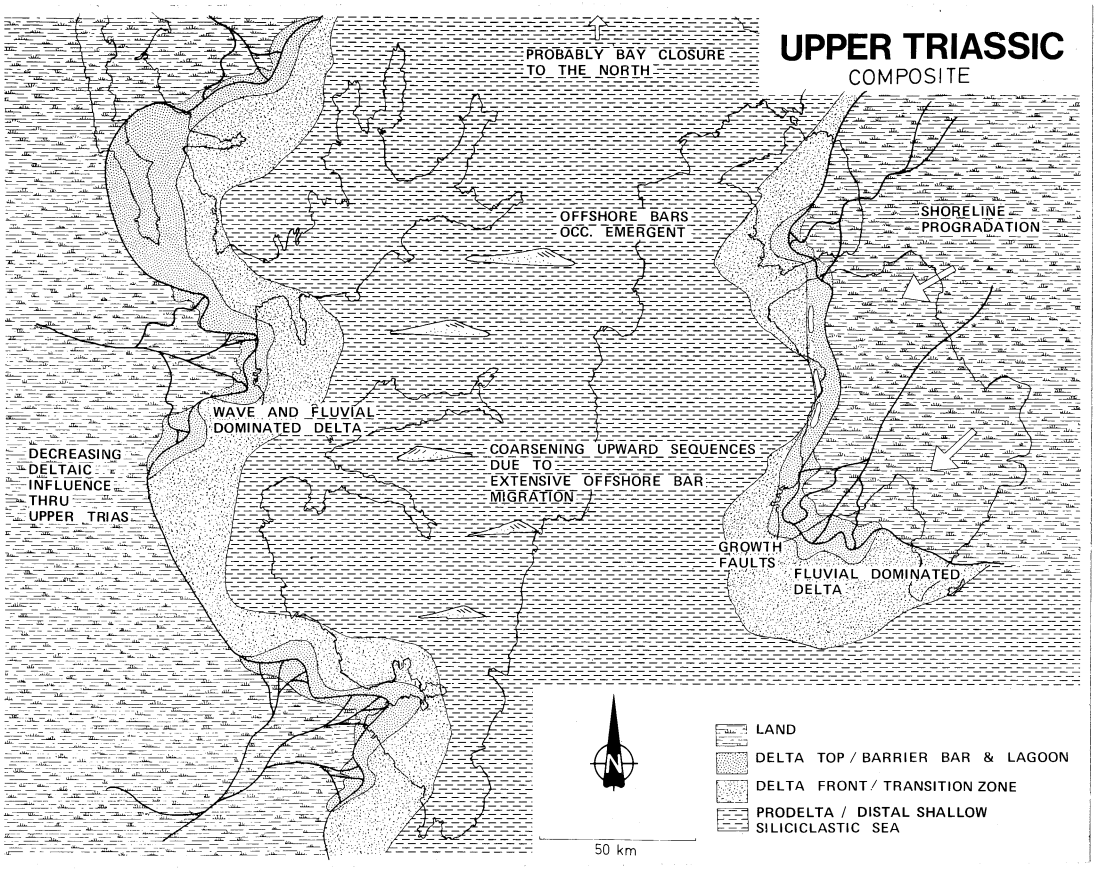

Figure 2.4.7. Palaeogeographical synthesis of depositional regiemes in Karnian-Norian times (Mørk et al 1982).

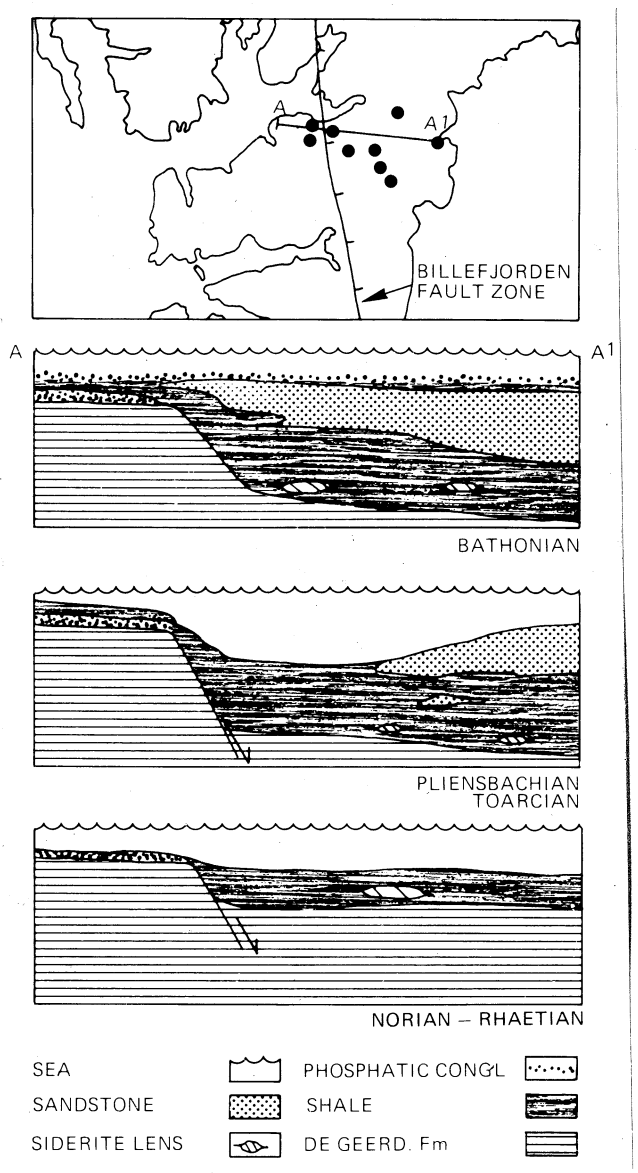

Figure 2.4.8. Schematic section over the Billiefjorden Lineament showing the development of the Wilhelmøya Formation and the uppermost phosphatic conglomerate of the Brentskardhaugen Bed (Mørk et al 1982).

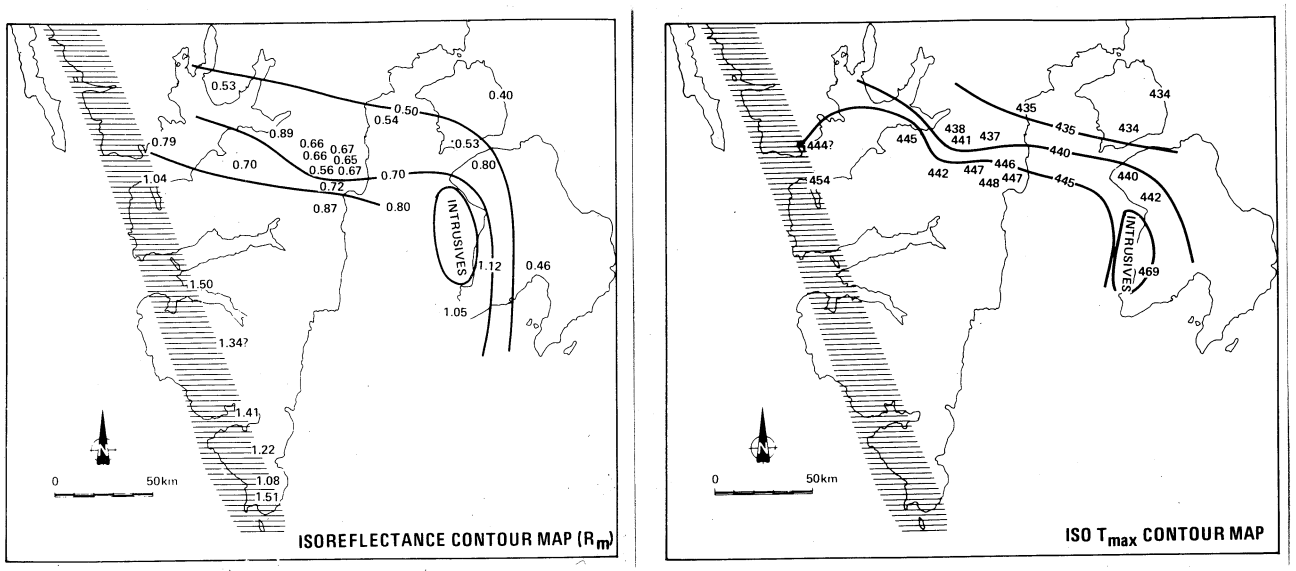

Figure 2.4.9. Regional variation in thermal maturation of the middle Triassic strata from vitrinite reflectance and Rock-Eval Tmax data (Mørk and Bjorøy 1984).

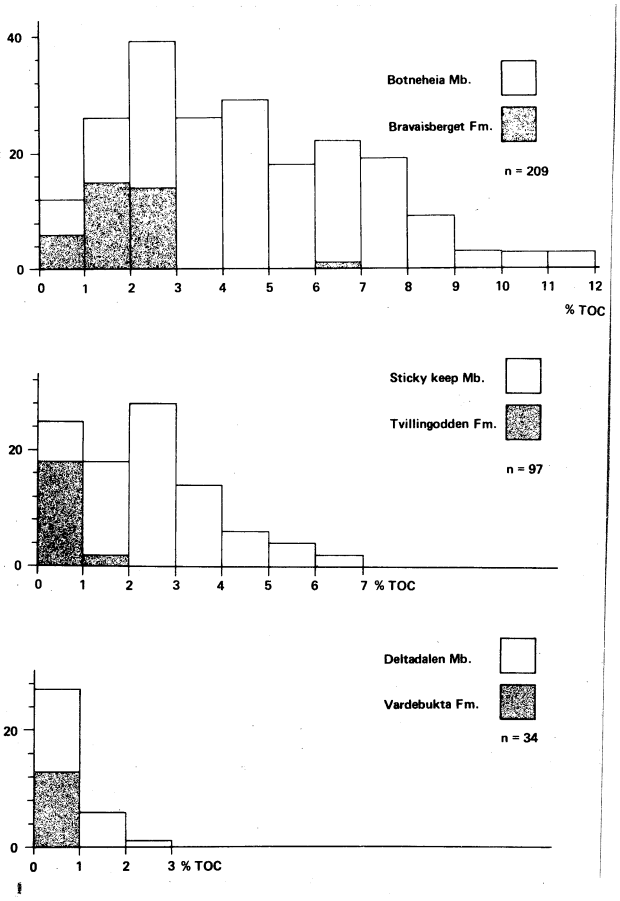

Figure 2.4.10. Histograms showing variation in organic carbon content within the rocks of the Sassendalen Group (Mørk and Bjorøy 1984).

2.5 The Triassic Succession of Bjørnøya

Bjørnøya is a small island of around 180 sq km lying on the Barents Shelf, southeast of Spitsbergen. The geological succession on the island is represented by around 3000 m of PreCambrian to Triassic rocks.

The outcrop of Triassic rocks is restricted to the three summits of Miseryfjellet, which is situated in a central position on the eastern coast of the island (Figure 2.5.1). Measurements by early workers in the area (Andersson, 1900; Horn and Orvin, 1928) indicated that the Triassic succession on Bjørnøya is around 200 m thick.

Krasilshchikov and Livsic (1974) indicated that the Kazanian and Tatarian stages are not represented in the underlying Permian carbonates of the Miseryfjellet formation, implying a major depositional hiatus immediately prior to the deposition of the Triassic sediments. Pcelina (1972) and Mørk (1986) have suggested that the Triassic sediments of Bjørnøya were deposited in the same depositional basin as the Triassic sediments of Svalbard.

Worsley et al (in press), indicate that the upper Permian and Triassic rocks of Bjørnøya were deposited in a largely stable platform setting, unaffected by significant faulting or rotation.

Stratigraphy:

The 200 m thick Triassic rock succession on Bjørnøya has been divided into three units named after the three summits of Miseryfjellet (Figure 2.5.2).

The Urd Formation represents the lower 60-65m of the Triassic succession, and has been assigned an Induan to Olenekian age by Pcelina (1972) on the basis of the occurrence of Smithian ammonites in the upper beds. Mørk (1986) has indicated that all or part of the Spathian may be missing from this formation.

The basal beds (ca 5m) consist of sandstone/siltstone beds with a sharp contact to the weathered surface of the underlying Permian carbonates of the Miseryfjellet Formation. These basal beds contain reworked Permian material and show evidence of wave ripples.

Overlying these basal beds, are approximately 17m of interbedded shales and siltstones. Wave ripples are observed in the lower part of this sequence,

but become less conspicuous towards the top of the sequence. The shales are parallel-laminated and are unfossiliferous.

The remaining 38m of the Urd Formation consist of a series of interbedded dark shales, siltstones and dolomites, the latter two lithologies becoming more common towards the top of the formation. Smithian ammonites have been reported from this sequence, and Pcelina (1972) noted a bituminous smell from these rocks. No evidence of wave-action or bioturbation has been observed in this part of the Urd Formation. A marked darkening of the shales in this sequence is noted relative to the shales of the underlying beds.

The Verdande Bed (Mørk et al 1982) is a conspicuous 20 cm thick phosphorite layer consisting of reworked phosphorite nodules of varying shape which lie on an eroded surface (Pcelina, 1972). The concretions tend to be flattened and vary in composition. Pcelina (1972) assigned a middle Triassic age to this bed.

The Skuld Formation comprises the remaining 140 m of the Triassic succession on Bjørnøya. Previously, a Karnian age was suggested for the entire Skuld formation. However, more recent work compiled by Mørk (1986), suggests that only the uppermost rocks of this formation are of Karnian age. The rest of this formation has now been assigned a Ladinian age on the basis of macrofossil and palynological data.

Mørk (1986) described this formation as consisting of a series of coarsening-upwards (c-u) sequences. The lower 50 m of this formation comprises the first c-u cycle, and consists of interbedded dark shales and siltstones, with the latter lithology becoming more common towards the top of the sequence. Asymmetrical ripples, hummocky cross-lamination and wave ripples are seen in the siltstones. Abundant plant debris is often seen on the top of the siltstone beds. Siderite nodules are seen in this formation, in contrast to the dolomite nodules/beds of the Urd Formation.

Overlying this thick c-u sequence, are 3 minor c-u sequences which grade from grey fissile shale to silty shales or siltstones.

The uppermost c-u sequence grades from a fissile shale to a 20 m thick sandstone bed in which abundant plant fragments, bivalve imprints and occasional ammonites are seen. Wave ripples have been observed in the interbedded siltstones and large low-angle cross-beds have been observed in the sandstone. A Karnian age has been assigned to this sequence on the basis of

macrofossil, floral and palynological evidence.

Depositional History:

Mørk (1986) has suggested that the weathered crust on the top of the carbonates of the Miseryfjellet formation represents a submarine hiatus rather than a sub-aerial hiatus.

The beginning of Triassic siliciclastic deposition may coincide with the earliest Griesbachian transgression event recognised by Embry (in press) in the Sverdrup basin. The presence of reworked Permian material in the basal Triassic sandstones has been recognised elsewhere on Svalbard, although not in successions deposited near the Triassic depo-centre in west-central Spitsbergen.

Mørk (1986) noted similarities between the lower part of the Urd formation and the Vardebukta Formation, and the upper part of the Urd Formation and the Tvillingodden Formation of Svalbard. It has been suggested that all or part of the Spathian succession is absent from the Triassic rocks of Bjørnøya.

The Urd Formation is thought to represent a transition from deposition under shallow marine conditions (Induan), with a marked transgression leading to the deposition of the darker Olenekian shales in a deeper marine shelf environment. The coarsening of the rocks towards the top of the formation may reflect the onset of a regression event. Pcelina (1972) suggests that the upper part of this formation represents a condensed sequence deposited during a reduction in sediment supply. Pcelina (1972) and Mørk (1986) have both indicated a western source for the sediments of the Urd Formation.

The Verdande Bed is thought to represent a remainé conglomerate derived through erosion and winnowing of a much thicker middle Triassic sequence. Mørk et al (1982) and Mørk (1986), based on study of the nodules, have suggested that the eroded succession originally consisted of a series of sandy deposits, oolite bars and sediments containing sponges, radiolaria and glauconite (cf. middle to upper Bravaisberget formation). Worsley et al (in press) suggest that the Verdande Bed represents local uplift following the Anisian transgression seen elsewhere in Svalbard and Greeenland. Mørk (1986) has speculated on the existence of a basin between the Hornsund/Sørkapp High and Bjørnøya at this time.

Pcelina (1972) noted mineralogical changes between the Urd and Skuld Formations, recognising similarities between the rocks of the Skuld Formation and rocks of similar age on Svalbard (e.g. Kapp Toscana group). Both Pcelina (1972) and Mørk (1986) suggest that the Urd and Skuld Formations had different sediment sources.

The rocks of the Skuld Formation are thought to have been deposited in a generally shallow marine setting, with plant debris and tetrapod fossils suggesting proximity to a land-mass. There is a general indication of a shallowing of the marine setting as the sediments get younger, i.e. a generally regressive sequence.

Organic Geochemistry:

Organic geochemical data on the Triassic succession of Bjørnøya has been reported by both Pcelina (1972) and Bjorøy et al (1980, 1983), the latter work being the more detailed (Table 2.5.1).

Pcelina (1972) noted the bituminous nature of the Olenekian part of the Urd formation. The TOC data presented by Pcelina (1972) are similar to that presented by Bjorøy et al (1980, 1983). TOC contents vary from 0.4 % to 1.8 % in the Urd Formation, the lowest values being found in the dolomites and siltstones. Samples from the Verdande Bed gave a TOC value of 1.1 %, and the rocks of the overlying Skuld Formation gave TOC contents of between 0.2 % and 2.0 %, the lowest values again being found in the siltstone and siderite samples.

Microscopic observations of these rocks showed a marked difference in the kerogen composition of the Urd and Skuld Formations (Table 2.5.2). The kerogen of the Urd Formation is described as consisting largely of amorphous material of probable marine origin. Pcelina (1972) identifies algal and phytoplankton debris. Bjorøy et al (1980, 1983) also indicate the presence of appreciable amounts of herbaceous and woody material (i.e. ca. 50%). The presence of dolomite in the sequence may have resulted in degradation of any kerogen hydrocarbon generation potential, as dolomitization is often associated with the destruction of organic matter.

The kerogen in most of the samples from the Skuld Formation is dominated by terrestrial debris (Bjorøy at al 1980). This would agree with the presence of plant material and other evidence of proximal setting from geological

observations.

The Rock-Eval data reported by Bjorøy et al (1980, 1983) suggest that the bitumen in these rocks is largely, if not totally, allochthonous. Hydrogen indices from the kerogen are very low and are typical of strongly degraded kerogen (cf. D85-K). If the hydrogen indices merely reflected the effects of thermal degradation during hydrocarbon generation, then values of 100 to 200 mg/g TOC would be expected from marine amorphous kerogen, similar to that seen in the Urd Formation, at the reported vitrinite reflectance values of around 1.0%. Pcelina's (1972) vitrinite reflectance value of 1.77% is inconsistent with other data she presents, and the data presented by Bjorøy et al (1980, 1983) is probably more correct.

Both Pcelina (1972) and Bjorøy et al (1980, 1983) reported significant amounts of extractable hydrocarbons from these rocks, although the data presented by Pcelina (1972) are rather hard to interpret due to differences in procedure. In general, the extractabilities obtained from both formations were similar, higher extractabilities tending to found in the siltstones. The extractabilities are mostly higher than can be explained by local generation. Bjorøy et al (1983) suggested a Triassic or Jurassic source for the bitumens, which originally lay downdip of the currently exposed rocks on Bjørnøya.

The bitumens from the Urd Formation are typically more aliphatic in nature than those from the Skuld Formation, the latter bitumens showing evidence of a significant input of waxy hydrocarbons. The occurrence of waxy hydrocarbons is often associated with a terrestrial input and could reflect a contribution from the more terrestrial organic matter in the rocks of this formation. The GC-MS data presented by Bjorøy et al (1983) is of only very limited use in indicating the source of these bitumens.

In conclusion, the rocks of the Triassic succession on Bjørnøya do not have any hydrocarbon generation potential as currently exposed. The shales of the Urd Formation do, however, contain features in common with more organic-rich shales on Spitsbergen.

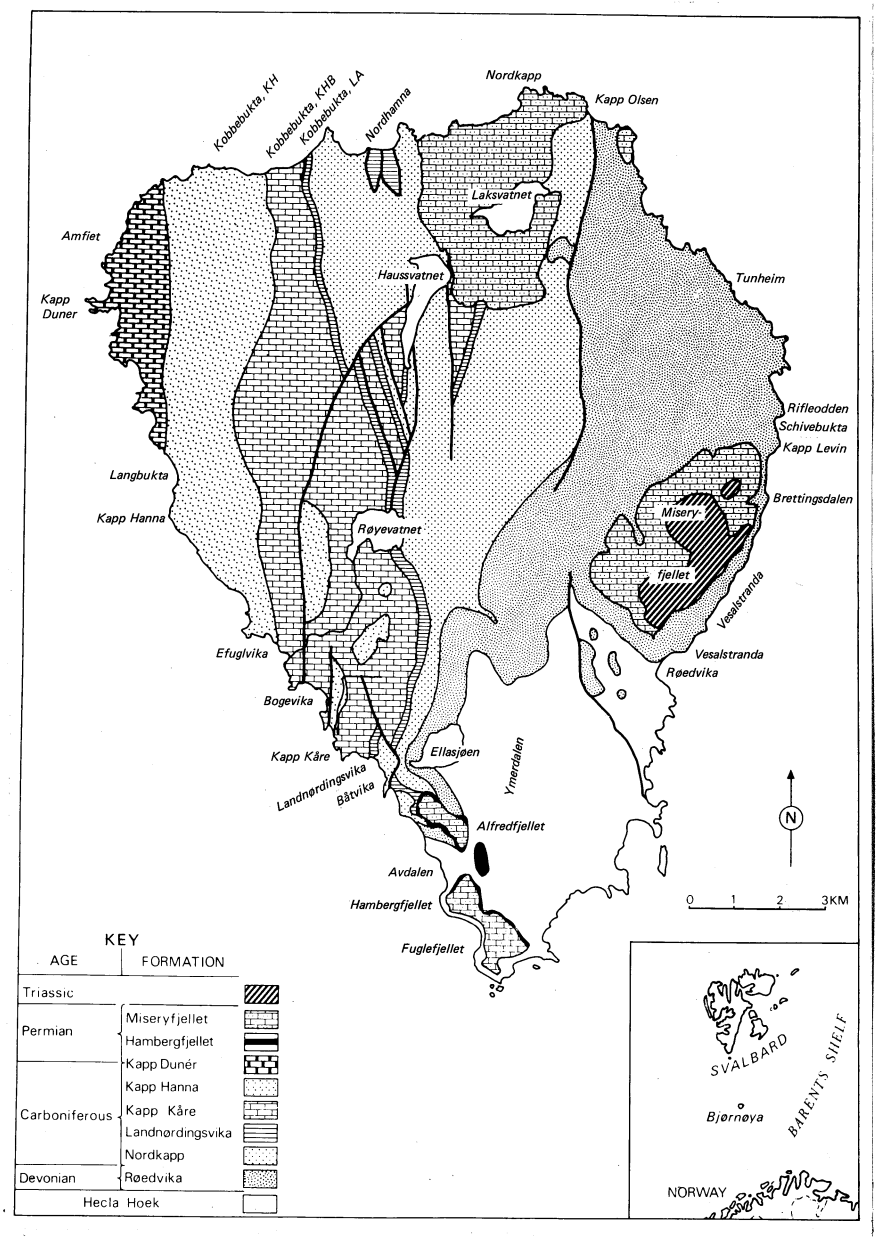

Figure 2.5.1. Map showing outcrop of Triassic strata on Bjørnøya (Mørk 1986).

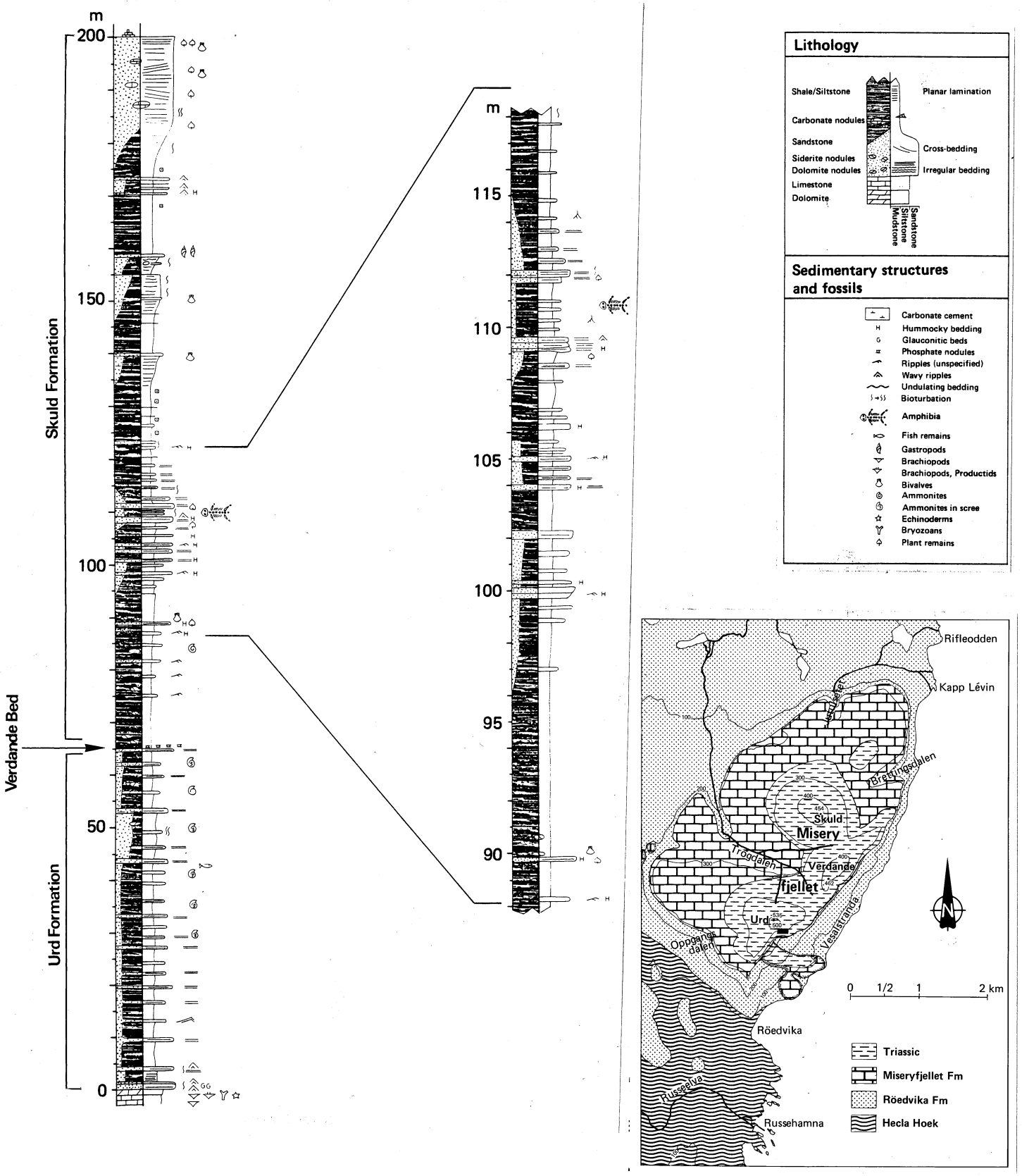

Figure 2.5.2. Interpretive sedimentological section through the Triassic strata on Bjørnøya (after Mørk 1987).

TABLE 2.5.1. SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR THE TRIASSIC SUCCESSION OF BJØRNØYA

		ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
		MEAN	MEAN	MEAN	MEAN	MEAN	Mean		MEAN	MEAN	MEAN
UNIT	MAIN	TOC	H.I.	O.I.	TMAX	V.R.	Concentration		HC	PrPh	$PrnC_{17}$
NAME	LITHOLOGY	(wt%)	(mg/g TOC)	(mg/g TOC)	(°C)	(%)	(ppm)	(mg/g TOC)	(%)		
Skuld Fm.	sh/siltst	0.9	24	205	nr	1.1	1150	77.6	51.4	1.7	2.4
Verdande Bed	phosporite	1.1	10	88	nr	1.1	1303	116.0	58.6	1.2	0.5
Urd Fm.	sh/siltst	0.8	11	270	nr	1.1	1157	86.8	47.7	2.1	0.4

H.I. = Hydrogen Index; O.I. = Oxygen Index; V.R. = Vitrinite Reflectance
sh = shale; siltst = siltstone; nr = data not reliable.

IKU SINTEF-GRUPPEN

IKU SINTEF-GRUPPEN

TABLE 2.5.2. KEROGEN COMPOSITION AND MATURITY VARIATION
(Triassic Succession of Bjørnøya)

FORMATION NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Skuld	533	5	25	50	5	15	5.5	1.10	7-8
	526	--	30	30	10	30	5.5	na	na
	512	--	30	60	10	Tr	5.5	1.19	8
	481	--	20	50	50	--	5.5	nr	7-8
	442	--	20	35	45	--	5.5	1.19	7-8
	422	--	65	25	10	--	5.5	1.22	na
Verdande Bed	408	--	50	50	--	--	5.0	nr	7-8
Urd	385	--	50	50	--	--	5.5	nr	7-8
	369	--	20	30	50	--	5.5	0.99	na
	334	--	65	20	15	--	5.5	1.14	na

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

2.6 The Triassic Succession of Franz Josef Land

The islands of the Franz Josef Land Archipelago lie in a line between 40°E and 65°E, and immediately to the north of the 80°N parallel. The majority of the islands in this archipelago are rather small in size. The largest islands lie at the western (Zemlya Alexsandry and Zemlya Georga) and eastern (Zemlya Vilcheka and Ostrov Graham Bell) extremities of the archipelago.

The Franz Josef Land Archipelago lies towards the southern edge of the Grumant Uplift at the northern boundary of the Barents Shelf (Figure 2.6.1). Sedimentation in this area is represented by an eastwards-thickening wedge of Triassic, Jurassic and lower Cretaceous rocks. On the westernmost island, Zemlya Alexsandry, the sedimentary succession consists of 240 m of Carboniferous rocks, 1400 m of lower-middle Triassic rocks and 290 m of lower Cretaceous volcanics (Kulakov 1984). On the easternmost island, Ostrov Graham Bell, >2000 m of Triassic clastic/volcanic rocks are overlain by 1500 m of upper Jurassic shales/siltstones and lower Cretaceous volcanics. North-south and east-west Cretaceous faults divide the Grumant Uplift into a series of blocks.

Stratigraphy:

No formalised stratigraphy was available for the borehole successions described by Vojcechovskaja (1985), and therefore, this part of the review will restrict itself to a brief discussion of the Triassic succession (Figure 2.6.2).

Vojcechovskaja (1985) describes a sequence of marine shales of Induan-Olenekian age from Alexsandra Land. These shales are unconformable on a thin layer of Carboniferous rocks. The lower Triassic rocks are overlain by shales of Ladinian age, which are bisected by a siltstone bed/beds. It is not known if the absence of Anisian rocks represents uncertainties in dating or a hiatus. These Ladinian rocks are directly overlain by lower Cretaceous rocks.

Moving eastwards to Hayes Island and Graham Bell Island, the Triassic rocks are of Anisian to Rhaetian age. The existence of lower Triassic rocks is uncertain, as the wells at both these localities were halted in rocks of Anisian age. The middle Triassic rocks are shale-dominated, with thin siltstone or sandstone beds. The overlying upper Triassic rocks have a higher

content of arenaceous beds, and coaly beds of Karnian age are reported. The upper Triassic succession on Graham Bell Island is more arenaceous in nature than that on Hayes Island.

The Triassic successions at all three sites contain thin dolerite beds, although Vojcechovskaja (1985) reports that these appear to have had little effect on the organic matter in these rocks.

Ulmishek (1985) describes three formations recognised from outcrops of rocks of Norian to Liassic age by Dibner (1970). The lowermost formation, the Vilchekov Formation, consists of ca. 200 m of coarsening-upwards, often siliceous, quartzose sandstones and siltstones with shale beds and conglomerate lenses. The overlying Vasilyev Formation consists of ca. 300 m of interbedded sandstones, shales, siltstones, conglomerates and limestones. The sandstones are more feldspathic than those observed in the underlying Vilchekov Formation. Thick coal beds (up to 2 m) occur in the upper part of this formation. The uppermost unit, the Tegetkoff Formation, consists of ca. 200 m of quartzose sandstones, with shale, clayey limestone, conglomerate and coal interbeds. These rocks are considered to have been derived from a northern sediment source.

Depositional History:

Vojcechovskaja (1985) suggested that the lower Triassic shales on Franz Josef Land represent deep marine deposits which may have been influenced by periods of increased salinity. The middle Triassic rocks of Hayes Island and Graham Bell Island are also thought to be of marine origin, with an apparent increase in the salinity of the waters from west to east. The upper Triassic rocks are thought to have been deposited under marginal marine to lagoonal conditions, with the depositional waters increasing in salinity eastwards towards Graham Bell Island.

Organic Geochemistry:

The Triassic rocks of Franz Josef Land described by Vojcechovskaja (1985) typically have TOC contents of below 1 wt% (Table 2.6.1). Higher TOC contents are reported from coaly beds of Karnian age. The relatively low TOC contents suggest that the majority of the shales are normal marine shales which have not experienced any significant degree of anoxia.

Based on microscopic examination of the kerogen, Vojcechovskaja (1985)

indicates that algal/marine sapropel accounts for a significant proportion of the kerogen, and suggests that these rocks accumulated under at least intermittent reducing conditions (Figure 2.6.2). This apparent contradiction may suggest that although anoxic/dysoxic conditions were established in this area during the lower and middle Triassic, the supply of organic matter was relatively low. The kerogen in the rocks from Graham Bell Island contains phytoplankton which suggest shallow marine to freshwater lagoonal conditions.

Extractable bitumens are reported from these rocks, typically having concentrations of less than 1000 ppm. Higher concentrations of ca. 2000 ppm to 17000 ppm are associated with coaly or carbonaceous shale horizons of Karnian age. Hydrocarbon compounds typically account for ca. 50 % of the extractable bitumen, although hydrocarbon contents in excess of 80 % are reported from rocks on Graham Bell Island. The generally high hydrocarbon contents of the extractable bitumens suggest at least oil-window levels of thermal maturity.

No maturation data is available from the kerogen in these rocks, making it difficult to evaluate the influence of the igneous rocks in the succession. The microscopic descriptions suggest that the kerogen is reasonably preserved, and that the maturity is not higher than is normally associated with the oil window.

Although traces of bitumens are reported from these rocks, the TOC data suggest that the rocks of the Triassic succession on Franz Josef Land are unlikely to represent major hydrocarbon source rocks. An analogy with the succession on Bjørnøya may be apt.

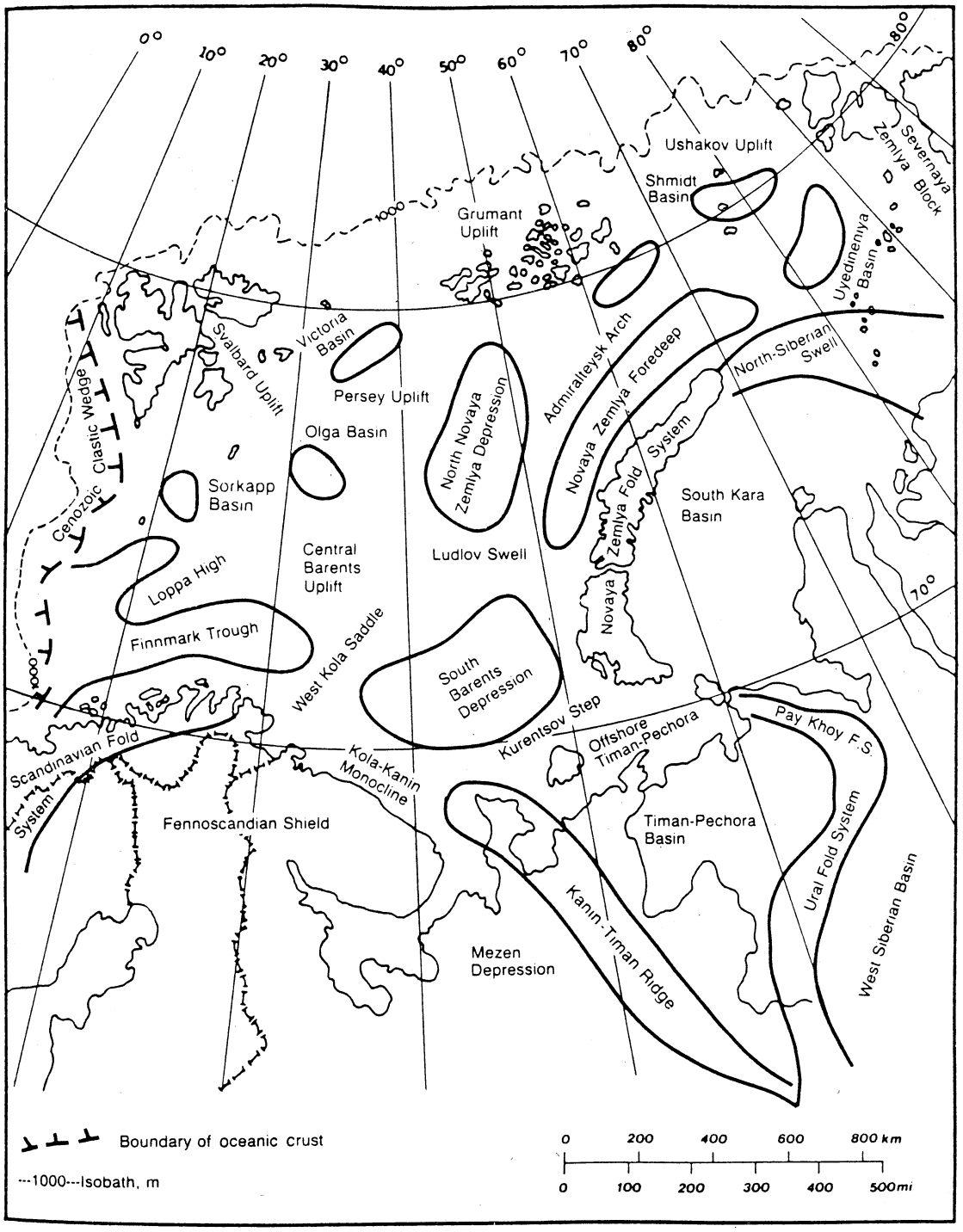

Figure 2.6.1. Position of Franz Josef Land with relation to the main structural features of the Barents-Northern Kara Shelf (Ulmishek 1985).

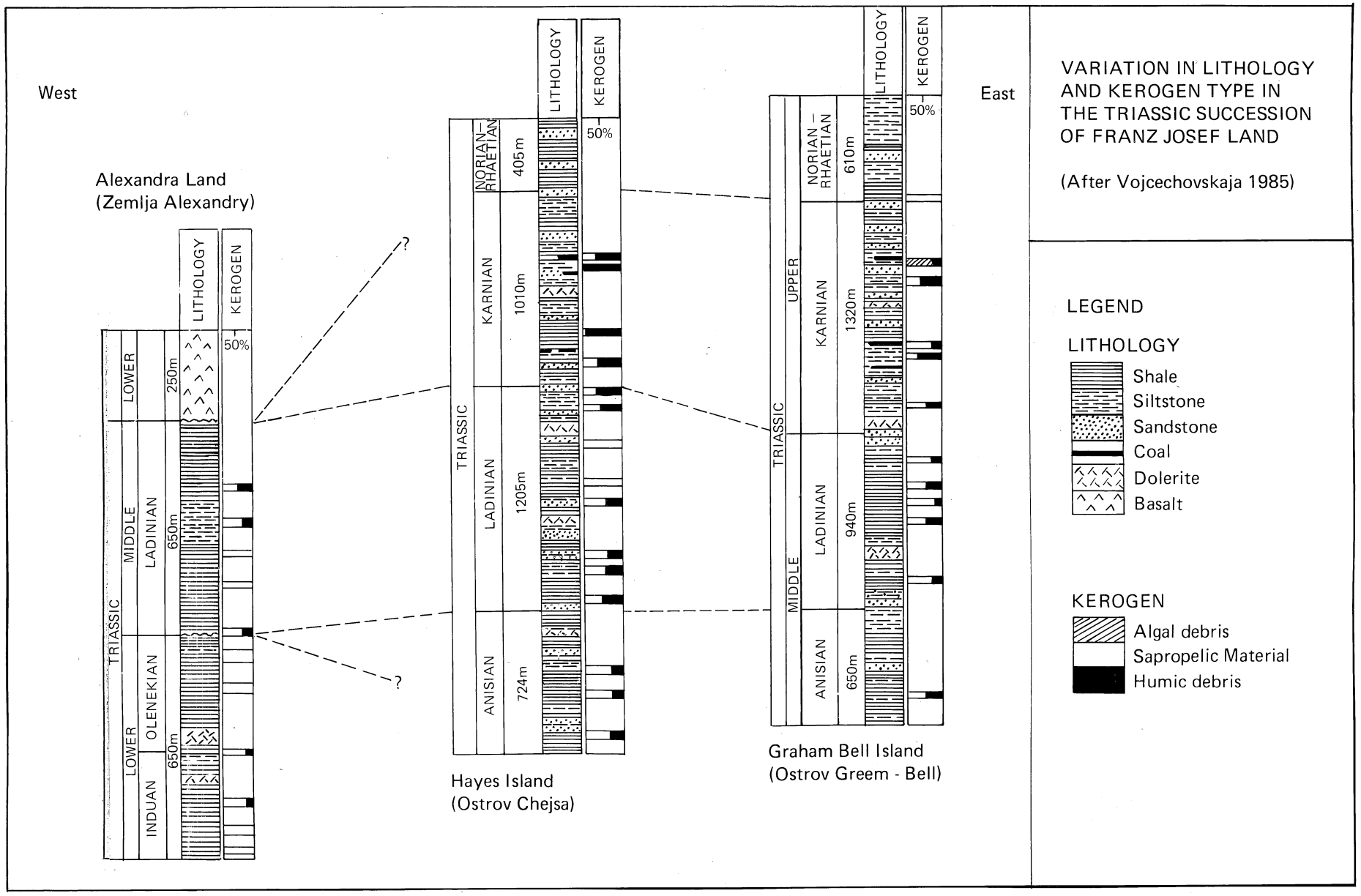

Figure 2.6.2.

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TABLE 2.6.1

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR THE TRIASSIC SUCCESSION ON FRANZ JOSEF LAND

UNIT AGE	LITHOLOGY	TOC (wt%)			EXTRACTABLE ORGANIC MATTER Concentration (ppm)			HC (%)		
		I	II	III	I	II	III	I	II	III
Karnian	Shale	--	1.3	1.7	--	200	16600	--	41.7	85.5
	Siltstone	--	1.0	--	--	800	--	--	49.9	--
	Coaly Rocks	--	11.0	2.7	--	2700	700	--	54.5	84.8
	Siltst/sst	--	0.4	0.7	--	80	200	--	na	na
	Carbonates	--	0.8	0.5	--	60	10	--	na	na
Anisian-Ladinian	Shale	0.9	0.9	1.2	200	100	800	na	38.1	47.6
	Siltstone	--	0.7	0.6	--	100	100	--	50.7	87.5
	Siltst/sst	0.8	0.2	0.9	200	50	60	na	na	na
	Carbonates	--	0.2	0.3	--	40	20	--	na	na
Induan-Olenekian	Shale	0.9	--	--	100	--	--	44.5	--	--
	Siltstone	0.7	--	--	400	--	--	51.4	--	--

na = data not reported; siltst = siltstone; sst = sandstone.
I = Alexandra Land (Zemlja ALeksandry); II = Graham Bell Island (Ostrov Greem Bell); III = Hayes Island (Ostrov Chejsa)

2.7 The Triassic Succession in the Timan-Pechora Basin

The Timan-Pechora Basin occupies an area of ca. 300,000 km^2 in the northern Russian SSR, lying immediately to the west of the Ural Mountains (Figure 2.7.1). The basin is bounded to the southwest by the low-lying Timan Ridge, and opens northwards into the Barents Shelf. The Timan-Pechora Basin is a major hydrocarbon province of the Soviet Union, with an estimated 6-10x10^9 bbls of recoverable oil and 2-3x10^{12} m^3 of recoverable gas.

The Timan-Pechora Basin is a Palaeozoic feature (Meyerhoff 1980) and contains a rock succession of Ordovician to Triassic age which varies from a thickness of ca. 1 km, in the western part of the basin, to greater than 10 km in the western Uralian Foredeep (Figure 2.7.2). Deposition of sedimentary rocks ceased during the Triassic, but was resumed between middle Jurassic and early Cretaceous times.

Sedimentation during the Triassic in this area was dominated by the Ural Mountain Belt which became developed during late Permian times and up into Triassic times.

Fuller reviews of the geology of the Timan-Pechora Basin are given by Meyerhoff (1980) and Ulmishek (1982, 1985). The review given in this report is only intended to be cursory and, for more detail the reader is referred to the above publications.

Stratigraphy:

A detailed stratigraphy was not available for the Timan-Pechora Basin and therefore, the Triassic succession will only be considered in a general sense (Figure 2.7.3).

The Triassic succession consists of a series of sandstones, siltstones, shales and conglomerates.These sediments reach a maximum thickness of up to 4000 m in the Korotaikha Trough, but are absent in the adjoining Kosyu-Rogov Trough. Meyerhoff (1980) indicates a thickness of 50m to 700 m as being a more typical development of the Triassic succession in the Timan-Pechora Basin. The base of the Triassic succession is represented in many areas by a conglomerate bed overlying the Permian coal-bearing sequences.

The Triassic succession may be divided into: the red-beds of the Charkabozh Suite (Lower Triassic), the variegated beds of the Skapkina Suite (Middle

Triassic) and the grey-coloured clastics of the Naryanmar Suite (Upper Triassic). Grey-coloured beds are more common towards the northwest. The sandstones of the Triassic succession occur mainly in local lens-shaped bodies. However, more laterally extensive sandstones occur at the base of the Charkabozh Suite, at the base and middle of the Skapkina Suite and at the base of the Naryanmar Suite. The degree of sorting and the roundness of the sand grains increases towards the top of each sandstone, and from east to west.

Coarser clastics represent the Charkabozh and Naryanmar Suites in the Upper Pechora, Bolshesyna and Korotaikha Troughs, and along the Pay-Khoy ridge where a basal Triassic conglomerate unit is found.

Depositional History:

The review of Ulmishek (1982) suggests that the terrestrial molasse sedimentation of the Triassic represents a continuation of Permian sedimentation, with the exception of coal deposition which stopped at the end of the Permian. The sediments are considered to have been deposited by fan and alluvial systems in the Ural foothills and adjacent areas. In more distal locations to the north and northwest, the sediments are thought to have been deposited in a lacustrine setting. Accumulation of these sediments reflects the block-trough system which became established during the late Permian.

Occurrence of Oil and Gas:

The Timan-Pechora Basin has been an oil-producing area since 1870, when the first well was drilled. Since than, an estimated 6×10^9 bbl of recoverable oil and 1.7×10^{12} m^3 of recoverable gas have been discovered. In addition, up to half again as much oil and gas is thought to be undiscovered. The main oil and gas fields lie in the southern point of the basin in the Izhma-Pechora and Upper Pechora regions, and in a belt comprising the Pechora-Kolva region (Figure 2.7.4).

The main oil-source horizon is thought to be the deep water, calcareous Domanik association of late Devonian-Tournaisian age (TOC up to 20 %). The grey, coal-bearing sequences deposited during the late Permian, and the grey clastic rocks deposited during the late Triassic contain significant amounts of humic material and are thought to contain potential gas-source horizons.

In the Izmha-Pechora region, the main reservoirs lie in clastic horizons of middle Devonian to lower Frasnian age. The Pechora-Kolva region is now the major producing region in the basin. The major producing horizon in this region is the Starooskol Horizon of middle Devonian age. In addition. deposits of heavy oil are found in the upper part of a Permo-Carboniferous carbonate sequence. In the Khoreyver region, deposits of heavy (0.9 g/cm^3), high sulphur (2.4 %) oils occur in Upper Ordovician-Lower Silurian and Upper Carboniferous-Lower Permian carbonates. The remaining regions are rather poorly explored at present, but similar horizons are expected to be productive.

Organic Geochemistry:

Geyro (1972) indicates that the Triassic terrestrial sediments of the Timan-Pechora Basin are typically organic-lean, and contain little or no bitumen.

Krems et al (1973) indicates an average geothermal gradient of ca. 20-25°C/Km for the Timan-Pechora Basin. Devonian rocks are indicated to have oil-window maturity in the platform areas of the basin, and gas-window maturity in the foredeep. Evidence for the lower Permian succession suggests that the Triassic sediments have not attained oil-window maturity.

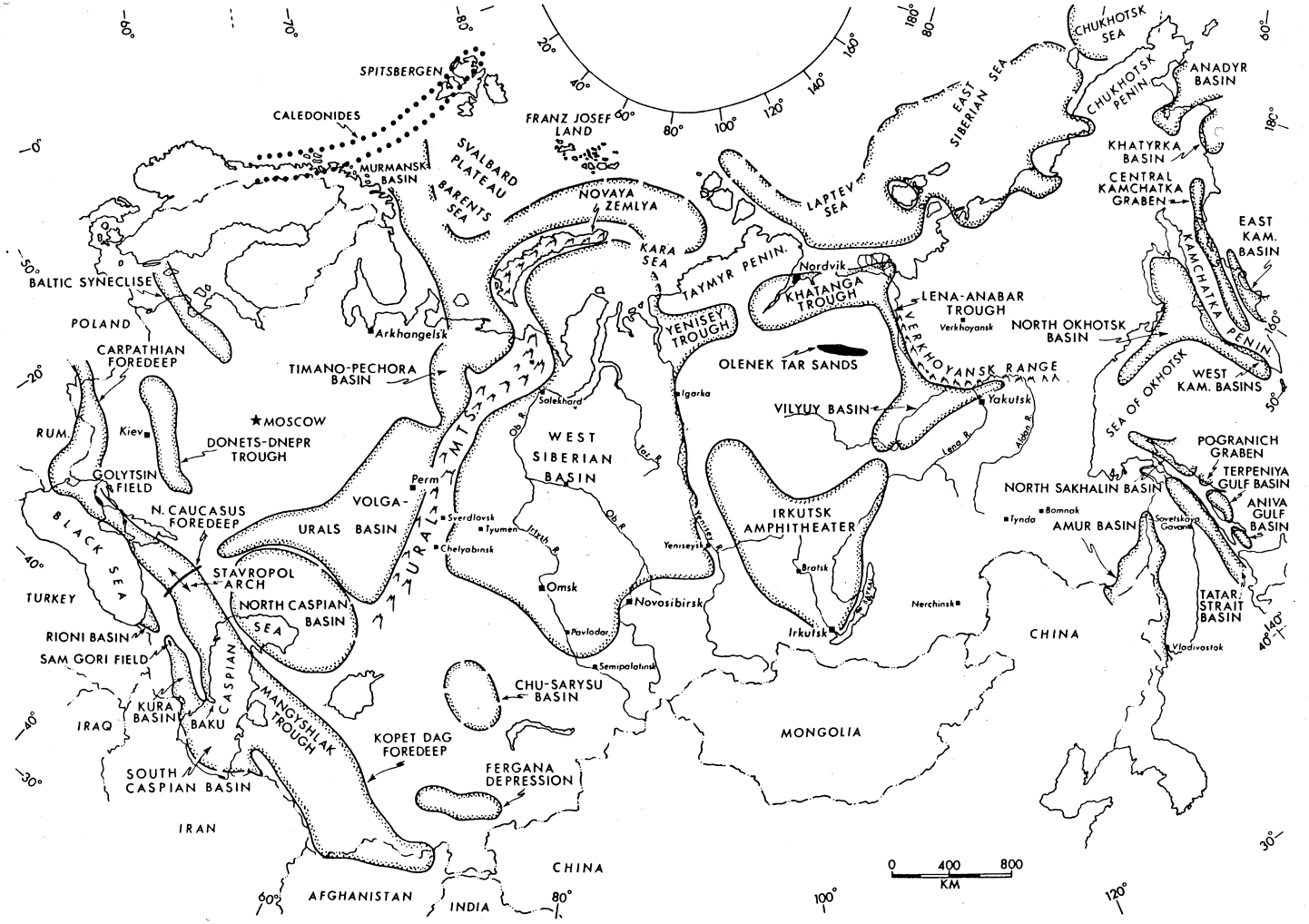

Figure 2.7.1. Location of the Timan-Pechora Basin with respect to the main petroliferous basins of the USSR (Meyerhoff 1980).

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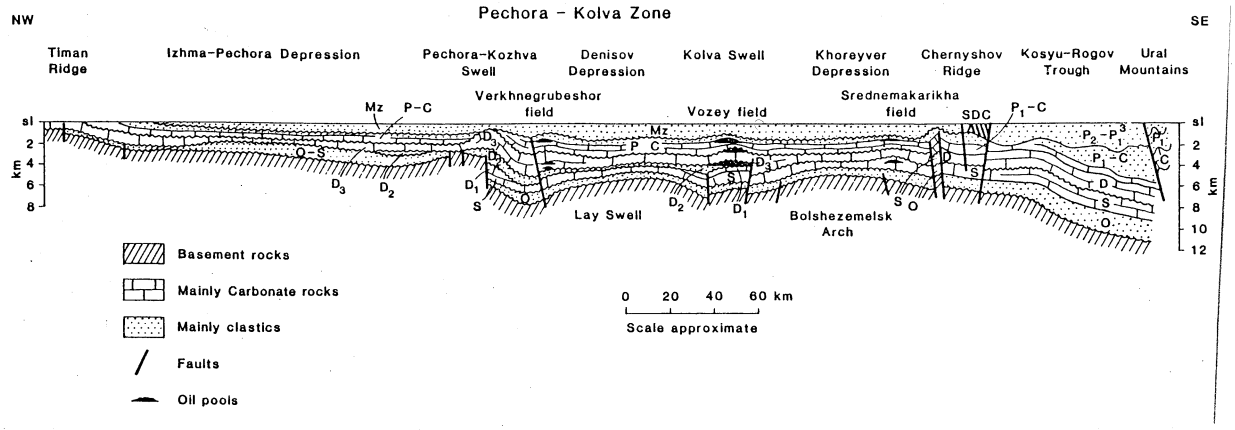

Figure 2.7.2. Cross-section through the Timan-Pechora Basin (Ulmishek 1982).

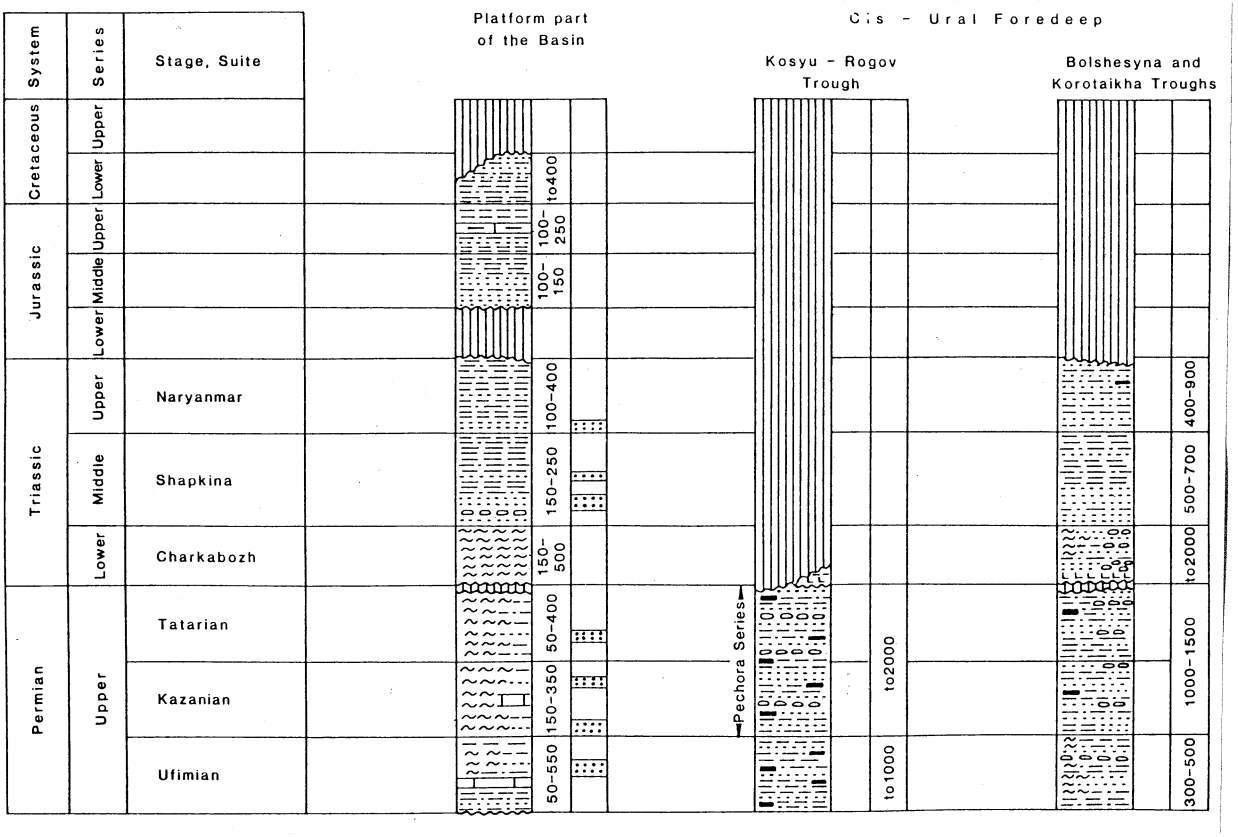

Figure 2.7.3a. Geological sequence of Upper Permian-Mesozoic rocks in the Timan-Pechora Basin (Ulmishek 1982).

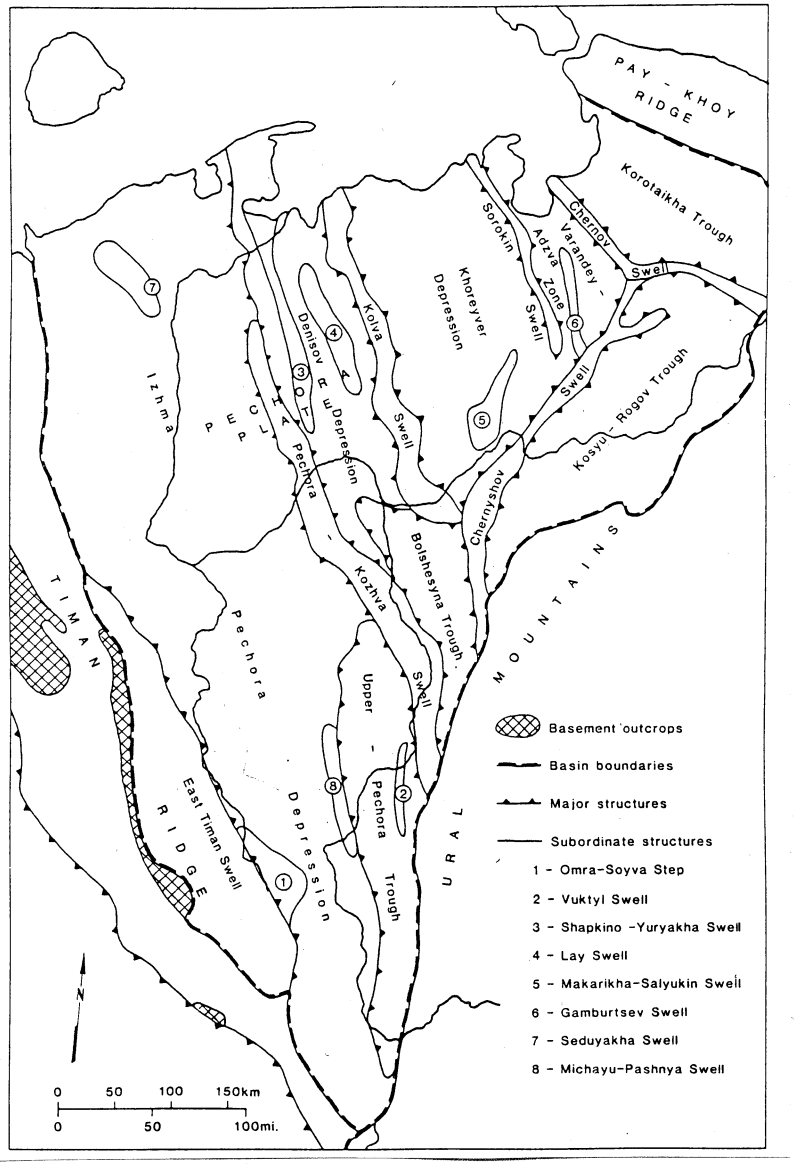

Figure 2.7.3b. Major structures of the Timan-Pechora Basin (Ulmishek 1982).

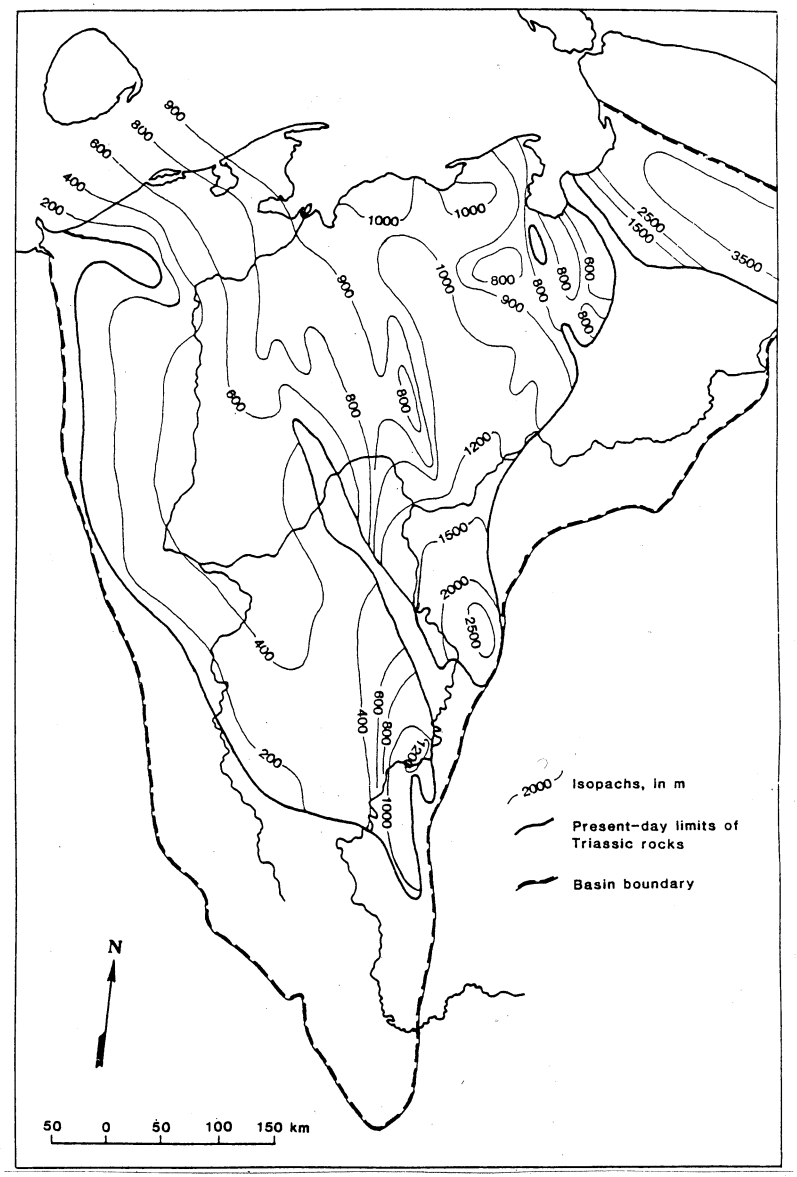

Figure 2.7.3c. Thickness of the Triassic sedimentary sequence in the Timan-Pechora Basin (Ulmishek 1982).

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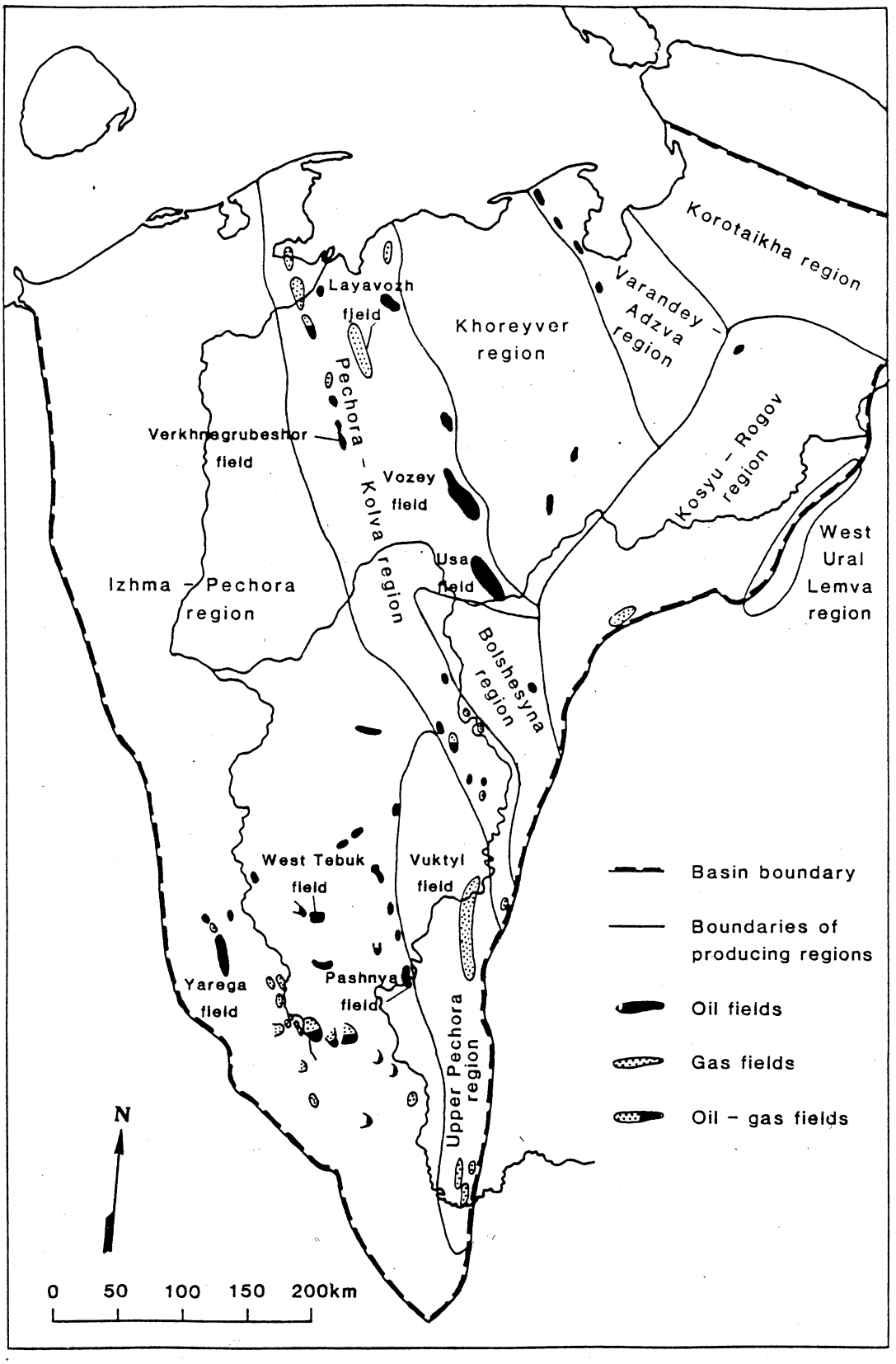

Figure 2.7.4. Producing regions of the Timan-Pechora Basin (Ulmishek 1982).

2.8 The Triassic Succession of the Barents Shelf

Zeigler et al (1986) described the Barents Shelf as a large intracratonic platform covered by sediments of Palaeozoic to Cenozoic age. The shelf is bounded to the south by the Fenno-Scandian shield of Norway, to the east by the Ural-Novaya Zemlya orogenic belt, to the north by a poorly known passive margin in the Nansen Sea and to the west by a rifted and sheared continental margin overlain by Tertiary sediments (Figure 2.8.1).

The Barents Shelf has been divided into a number of structural regions by the various workers in the area, few of which are consistent. The number of structural units has decreased from the eight units of Hinz and Schlüter (1978) to the four of Eldholm and Talwani (1977), to the three of recent workers such as Rønnevik (1981), Faleide et al (1984) and Zeigler et al (1986).

Rønnevik (1981), recognises an increase in structural complexity from a simple tectonic basin east of 25°E, to a more complex basin-ridge system between 25°E and 20°E, to a structurally complex continental margin west of 20°E. Faleide et al (1984) and Zeigler et al (1986) recognise an east-west trending basinal province between 74°N and the Norwegian coast, a western continental margin and a stable platform area to the north and east.

The formation of the deep basins currently found on the Barents Shelf is relatively recent, recognisable structural provinces only becoming established during the Kimmerian tectonic phase of late Triassic to late Jurassic times. These structural features were accentuated by reactivation during late Cretaceous to Tertiary times associated with the main opening of the North Atlantic.

The Barents Shelf is thought to have been a quietly subsiding, epeirogenic shelf area during the Triassic. Of the current structural features (Figure 2.8.2), the Loppa High had developed in the early Permian, although it was covered again by onlapping Triassic sediments. Zeigler et al (1986) also considered that the Bjørnøya and Tromsø basins may have been initiated in the early Permian and, together with the Nordkapp Basin, may have been shallow, sag-like basins at this time. These basins are thought to be superimposed on older Caledonian trends. The status of the Stappen High at this time is uncertain, although it may have been a relatively positive feature. Gage and Doré (1986) have suggested that the Hornsund - Senja Alignment may have influenced sedimentation during the Triassic.

Most authors consider that Triassic deposition occurred within one large basin in the Barents Shelf (Figure 2.8.3), and similarities are recognised with the sedimentary successions in the Sverdrup Basin and North Greenland. Bergsager (1986) summarized rocks of the upper Devonian, lower to middle Triassic and upper Jurassic as representing the most encouraging source rock horizons.

Stratigraphy:

At the current time, no formal lithostratigraphy for the Triassic sediments of the Barents Sea has been published, although this may be rectified in the light of the recent drilling activity in the area.

Bjorøy et al (1983), Jacobsen and van Veen (1984) and Berglund et al (1986) described the Triassic succession from the Troms 1 area, and identified seven units of Griesbachian to Rhaetian age. More recent work at IKU (Vigran et al 1986) has described parts of a Smithian to Ladinian/Karnian succession from the Dia-Structure at the north-northeast corner of the Loppa High.

Jacobsen and van Veen (1984) indicated that the 1900 m of Triassic rocks in two Troms 1 wells (Figure 2.8.4) represents an almost complete succession of marine to terrestrial sediments deposited under relatively humid, temperate climatic conditions.

The lowest unit (ca. 10 m), of Griesbachian age, is unconformably-bounded and consists of fluvial sandstones/siltstones. A significant hiatus to the underlying Permian sediments is suggested by an abrupt maturation change. The marine to marginal marine grey shales and occasionally sandstone interbeds of unit 2 (Dienerian; ca. 110 m) are also unconformably-bounded, the sandstone content of the samples increasing upwards.

Unit 3 (Smithian) consists of a development of dark marine shales (ca. 170 m), which are overlain by the marginal marine to deltaic? sandstones and siltstones of unit 4 (Spathian - Anisian). A possible hiatus in unit 4 is indicated. The overlying Anisian sediments (ca. 170 m) differ from the Spathian sediments (ca. 280m) in an absence of glauconite and micro-plankton, together with the presence of coal stringers in the upper part of the sequence.

The Ladinian to Norian age unit 5 (ca. 970 m) consists of a generally regressive sequence of basal marine shales, coarsening-upwards through a series of multi-coloured shales into a series of marginal marine to alluvial/lacustrine sandstones with coal stringers. The terrestrial sediments at the top of unit 5 change rapidly into the dark marine shales of unit 6 (Norian; ca. 35 m), which contain open marine microplankton and kerogen. These sediments are overlain by the thick marginal marine, well-sorted sandstones with siltstone/claystone/coal interbeds of the upper Norian to Rhaetian unit 7 (ca. 170 m). This latter unit may coincide with the Ytterøy Formation of Berglund et al (1986), which is decribed as a 200 m thick sandstone-shale-coal sequence. The thick sandstone bodies are thought to represent distributary channel deposits with an eastern/southern source.

The lower to middle Triassic succession at the Dia-structure described by Vigran et al (1986) can be described on the basis of seismic sequences recognised from shallow seismic data (Figure 2.8.5).

The lowest seismic sequence was sampled by three cores, and shows a broadly fining-upwards succession from a ca. 15 m thick turbiditic sandstone through a series of siltstones and silty shales or claystones which are mostly bioturbated to some extent. Minor coarsening-upwards sequences were noted in some of the cores. These sediments are thought to represent shelf deposits which were influenced to varying degrees by storm and current activity.

At the upper boundary of this sequence (7323/7-U-3), there is a marked change to a succession of dark silty shales with calcite, phosphorite, pyrite and dolomite nodules or beds and, occasionally, graded siltstone or sandstone beds. Bivalve, fish and ammonite fragments are generally quite common. In the upper core of this sequence (7323/7-U-1), there is a change to a bioturbated dark silty claystone with evidence of some storm-influence.

The upper boundary of this sequence is penetrated by core 7323/7-U-1, above which there is a marked change to a siltstone-dominated succession. This sequence consists of bioturbated clayey to sandy siltstones with graded sandstone beds and calcite/phosphorite nodules. Some siderite cementation is seen in the 7323/7-U-1 section. Bivalve, ammonite and wood fragments, among others, are found. The upper five metres of this sequence in the lower part of core 7323/7-U-9 consist of a strongly bioturbated sandstone with abundant phosphorite nodules and some bivalve, ammonite and wood frag-

ments.

Above this sandstone, the overlying sediments change to a dark grey silty shale with abundant phosphorite nodules, the lower 1.5 m of the sequence being calcareous and bioturbated. The next two cores (D85-K and 7323/7-U-5) suggest a coarsening from the dark shales of 7323/7-U-9 through slightly coarsening-upwards grey silty shales (D85-K) to a coarsening-upwards, bioturbated sandy to clayey siltstone with graded sandstone beds (7323/7-U-5).

The remaining sequence is poorly sampled by 7323/7-U-2, and the boundary was not penetrated. The thin section sampled consisted of bioturbated clayey siltstones with graded sandstone beds and phosphorite nodules.

Depositional History:

Most palaeogeographical reconstructions of the Barents Shelf during Triassic times have been based on seismic data and extrapolation from outcrops on Svalbard and Bjørnøya. The most comprehensive reviews of the palaeogeography of the Barents Sea area during the Triassic (Figure 2.8.6) have been published by Jacobsen and van Veen (1984) and Ulmishek (1985).

Jacobsen and van Veen (1984) suggested that early Triassic deposition followed a late Permian phase of uplift, at least in the Troms area and possibly on the Loppa and Stappen Highs. The Hornsund-Senja Alignment may also have been positive for periods during the Triassic (Gage and Doré, 1986), thereby separating the Barents Sea area from the Norwegian-Greenland Rift system (Figure 2.8.7). The Billiefjorden Fault zone of Spitsbergen and the Trølle Land Fault Zone of Northeast Greenland may also have been active at this time.

In general, palaeogeographic reconstructions by Rønnevik (1981), Jacobsen and van Veen (1984), Ulmishek (1985) and Gage and Doré (1986) all show the Barents Sea area during Triassic times as a marine embayment of varying southwesterly and southeasterly extent. This embayment is thought to have opened north-northwestwards into an Arctic basin and/or the proto-Pacific.

It is generally accepted that the Barents Shelf area experienced a temperate, rather humid climate for most of the Triassic. Periods of more arid climatic conditions occurred in late Anisian-early Ladinian times and in Karnian-Norian times as plate movement recommenced (Jacobsen and Van Veen 1984).

The majority of these reconstructions are generalised to the whole Triassic. In a more detailed consideration, Jacobsen and van Veen (1984) describe a mainly marginal marine shelf to fluvio-deltaic succession from the Troms 1 area. Deeper open marine deposition was only established during Smithian, early Ladinian and Norian times. Fluvial conditions occurred during deposition of the Griesbachian age rocks of unit 1, the uppermost Karnian rocks of unit 5 and the Norian to Rhaetian rocks of unit 5. The last two sequences contain coal stringers and interbeds.

The lower to middle Triassic succession penetrated by the IKU drilling programme (Vigran et al 1986) is thought to represent a transition from marginal marine shelf conditions in Smithian times, to deep marine dysoxic to anoxic conditions during Spathian to Anisian times. In upper Anisian times there is evidence of a change back towards shallower marine shelf conditions, which became more established during Ladinian times. Evidence of storm-influence is seen in the shallow marine shelf sediments, and the presence of wood fragments in the Smithian and upper Anisian successions may indicate relative proximity to a land area. All of the shallow marine rocks show evidence of bioturbation.

Organic Geochemistry:

Preliminary organic geochemical data was presented by Bjorøy et al (1983) for the Troms 1 area. Jacobsen and van Veen (1984) also made some observations on the occurrence of potential hydrocarbon source intervals in the Triassic of the Troms 1 area, based on palynological observations. More recent work includes the description of Spathian - Anisian organic-rich shales from the north-western flank of the diapiric "Dia-structure" on the Loppa High (Vigran et al 1986). Work on Bjørnøya and Svalbard is reviewed elsewhere, although reference will be made to these areas.

Bjorøy et al (1983) described the organic geochemistry of a claystone-dominated, fining-upwards, upper Triassic sequence from 7120/12-1 at the top of which is a ca. 10 m thick sandstone horizon. This may represent units 5, 6 and 7 of Jacobsen and van Veen (1984) although, as no coaly material was reported from the sequence analysed by Bjorøy et al (1983), this is only a tentative correlation.

An trend towards decreasing TOC content up the well section is observed, with TOC contents decreasing from 1 - 2 wt% below ca.3200 m, to below 1 wt%

above ca.3000 m. The higher values obtained from the uppermost sandstone horizon may reflect only isolated claystone lenses or caving.

The chemical nature of the kerogen from this succession appears to be rather constant, although a marked decrease in HI at around 3000 m coincides with some low TOC values at this depth. The kerogen is dominated by terrestrial organic matter below 2900 m. Between 2900 m and ca. 2550 m, the kerogen becomes increasingly dominated by amorphous material, before the dominance of terrestrial material is restored in the upper part of the succession. This increased content of amorphous may reflect upper unit 5 and unit 6 of Jacobsen and van Veen (1984), although this interval does not appear to be represented by higher TOC values as might be expected.

Relatively high concentrations of extractable bitumen were recorded in the lower, more sandy, part of the succession, the bitumen having the characteristics of thermally mature, terrestrially-sourced material. The more argillaceous layers were found to contain only poor concentrations of extractable bitumen.

With vitrinite reflectance values of around 0.6 %, the organic matter in this Triassic succession may be considered to be only moderately mature, and the relatively unpromising nature of even the more amorphous-rich layers cannot be explained by elevated maturity.

The Dia-structure succession described by Vigran et al (1986) is the only available, indisputable evidence of the presence of lower to middle Triassic organic-rich rocks in the Barents Sea area outside of Svalbard. Elsewhere, the evidence suggests that depositional conditions were not conducive to the preservation of oil-prone kerogen.

Organic-rich shales and claystones of Spathian to Anisian age occur in the upper part of core 7323/7-U-3, throughout 7323/7-U-4, in the lower part of 7323/7-U-1 and in the upper part of 7323/7-U-9 (Tables 2.8.1 and 2.8.2). The majority of these rocks occur in the first three cores which sample the succession between seismic reflectors 4 and 5. The rocks of the remaining cores, although often containing up to 2 wt% TOC, contain only oxidised kerogen.

The organic shales from the upper 8m of core 7323/7-U-3 and the lower 28m of core 7323/7-U-4 show little variation in TOC content, with values of 2 wt% to 4 wt%. The kerogen in these intervals has chemical characteristics

typical of mixed type II/III kerogen, with thin laminae of more hydrogen-rich kerogen types. The remaining 15m of core 7323/7-U-4 show an initial marked increase in TOC content and hydrogen index, followed by a gradual decrease in both parameters to the top of the core. The lower half of core 7323/7-U-1 shows marked fluctuations in both TOC content and kerogen type, the upper half of the core consisting of less organic-rich rocks containing poorer type III kerogen. These less organic-rich rocks are found in the cored section more organic-rich rocks containing more hydrogen-rich kerogen occur in the upper half of core 7323/7-U-9. The vertical persistence of this upper organic-rich interval is uncertain.

All of the cores contain immature organic matter based on vitrinite reflectance data. This is also reflected in the significant amounts of thermally immature bitumen which were extracted from the organic-rich intervals.

Migrated bitumen from Smithian and upper Anisian sandstones proved to be of Triassic origin, with source material similar to that found in the immature organic-rich rocks. This suggests that the occurrence of such rocks may extend some distance downdip.

Conclusions:

Marine conditions were fairly common over much of the Barents Shelf for much of the Triassic. However, conditions conducive to the accumulation of dark organic-rich shales appear to have been of more restricted occurrence during this time. Organic-rich shale deposition seems to have occurred mainly from Spathian to late Ladinian (in Svalbard) times and to have been largely restricted to the western Barents Shelf.

The organic-rich lower to middle Triassic shales of the Barents Shelf appear to have good to excellent potential for oil generation, where they reach optimum thermal maturity. Evidence for oil generation having already occurred in some areas is provided by the occurrence of mature bitumens in Smithian sandstones at the Dia-structure and in Triassic rocks on Svalbard.

The preservation of the organic matter in the Triassic shales on Bjørnøya suggest that organic-rich shales of significant source potential may be absent from the Stappen High. This is especially true if, as has been suggested, this structure was a relatively positive structure during the early to middle Triassic. The occurrence of organic-rich shale sections is suggestive of deposition in a number of small basins, which may or may not be

tectonically-controlled.

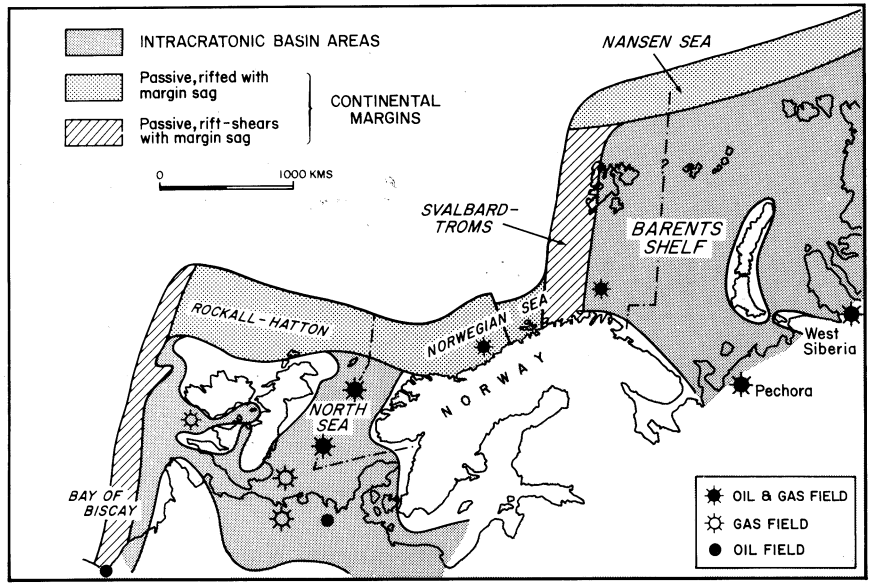

Figure 2.8.1. Basins and continental margins of North-west Europe (Zeigler et al 1986).

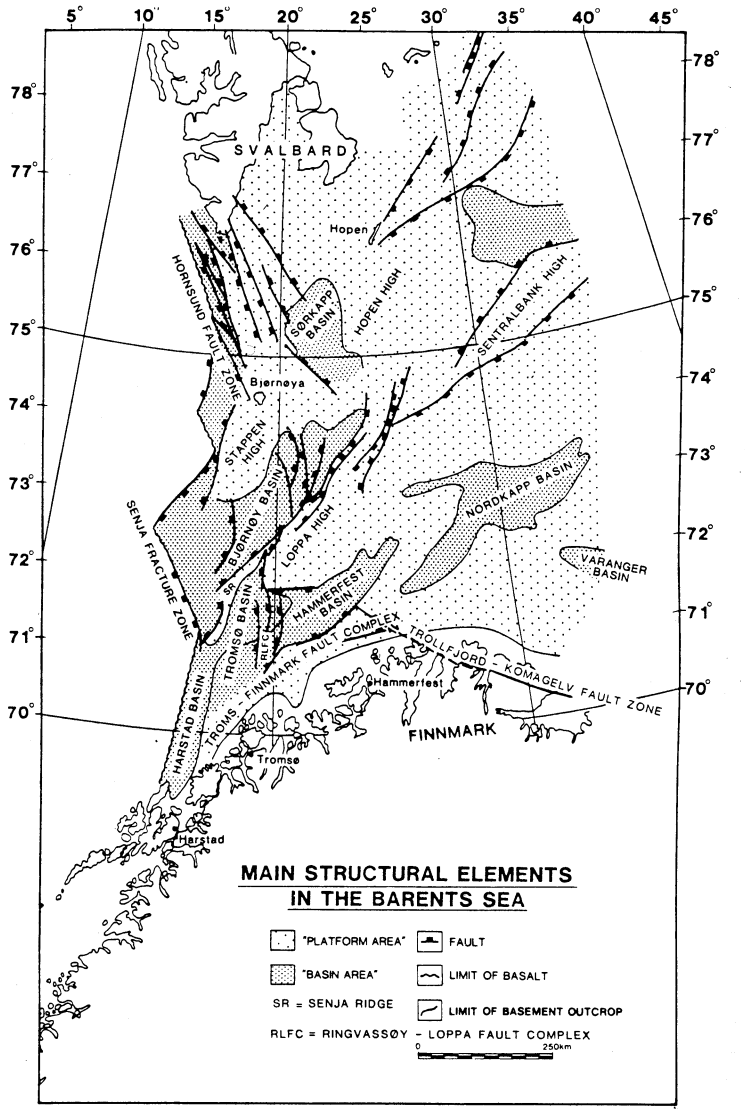

Figure 2.8.2. Major structural features in the Barents Sea (Gabrielsen 1984).

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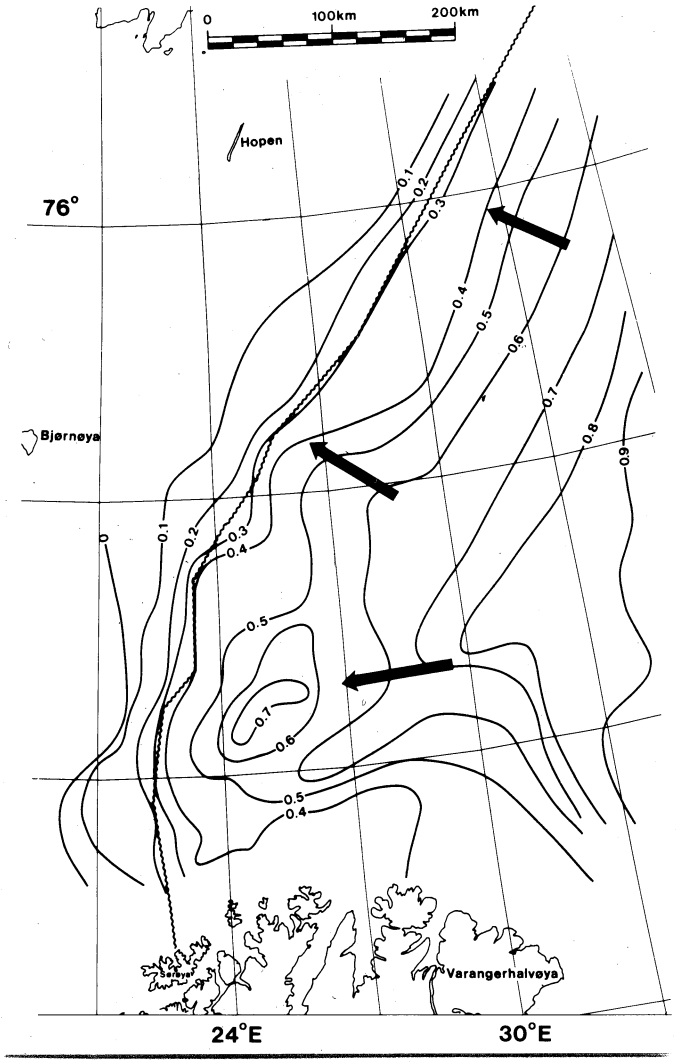

Figure 2.8.3a. Isochron map of Lower Triassic subsequence (Rønnevik 1981).

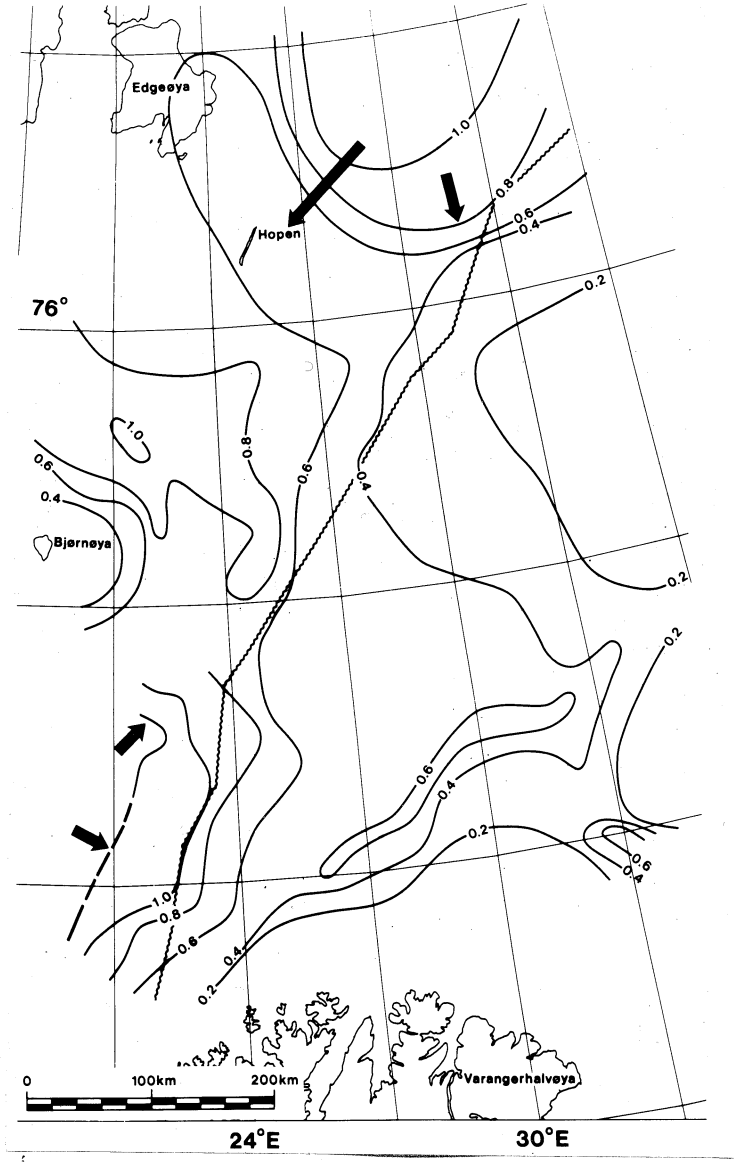

Figure 2.8.3b. Isochron map of Upper Triassic-Lower Jurassic subsequence (Rønnevik 1981).

(Two-way travel time in seconds; arrows show transport directions; wavy line shows position of Lower Triassic shelf edge).

IKU SINTEF-GRUPPEN

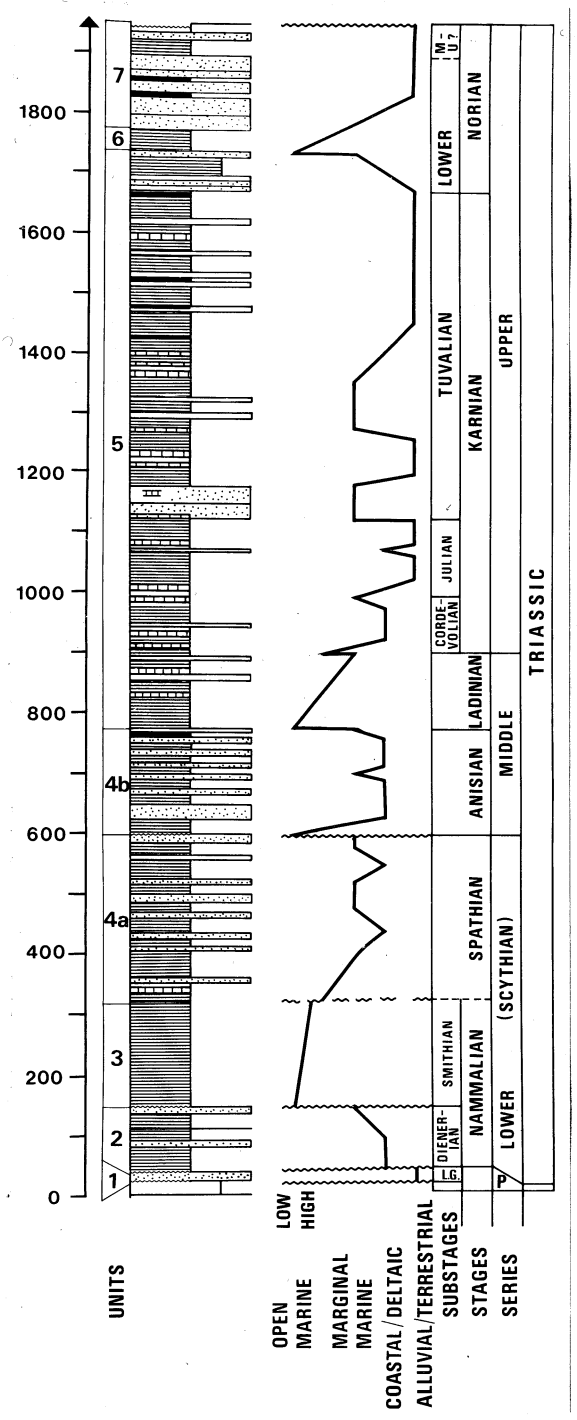

Figure 2.8.4. Composite Triassic section from Troms 7120/12 wells, with tentative environmental interpretation (Jacobsen and van Veen 1984).

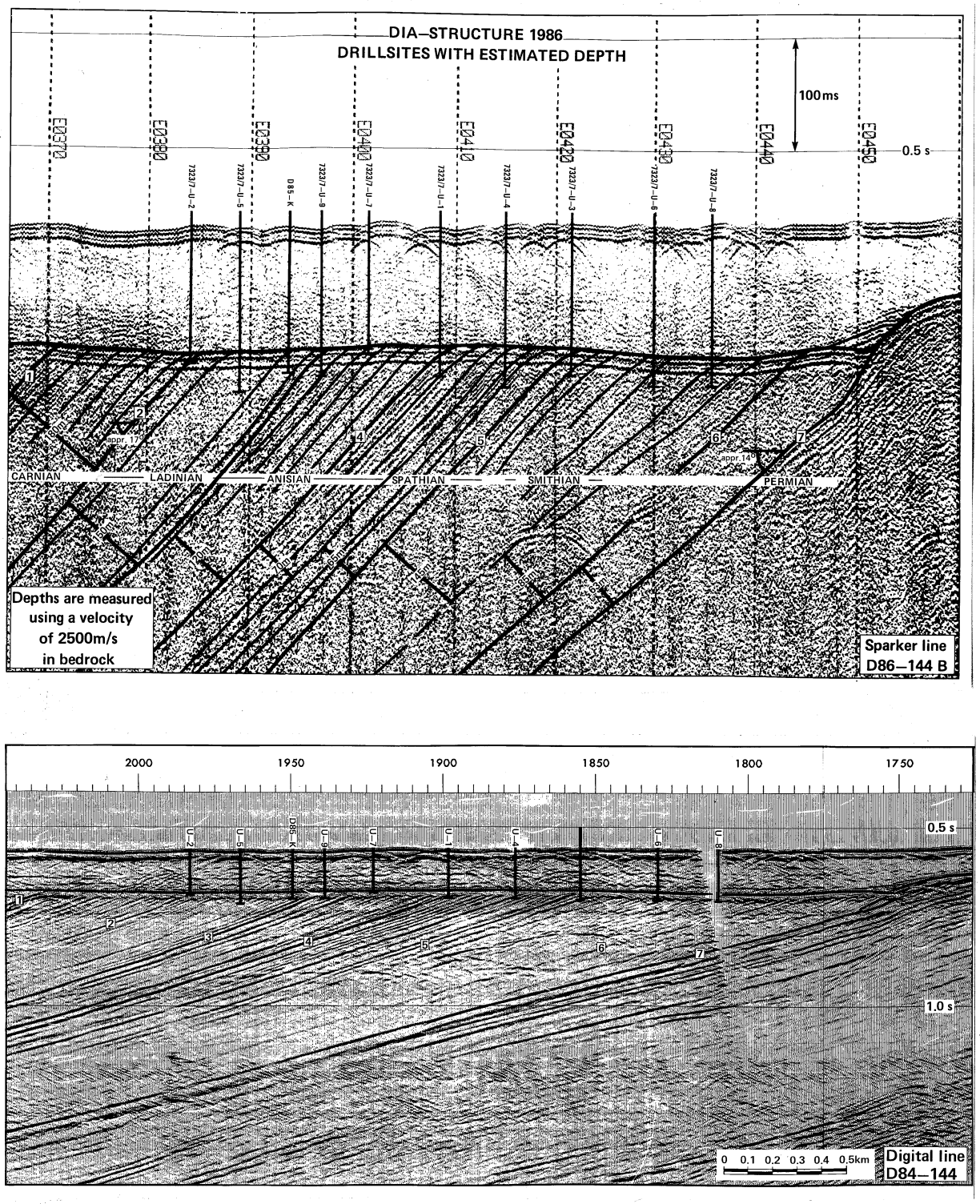

Figure 2.8.5. Seismic line section showing the Triassic sequence at the Dia-structure (Vigran et al 1986).

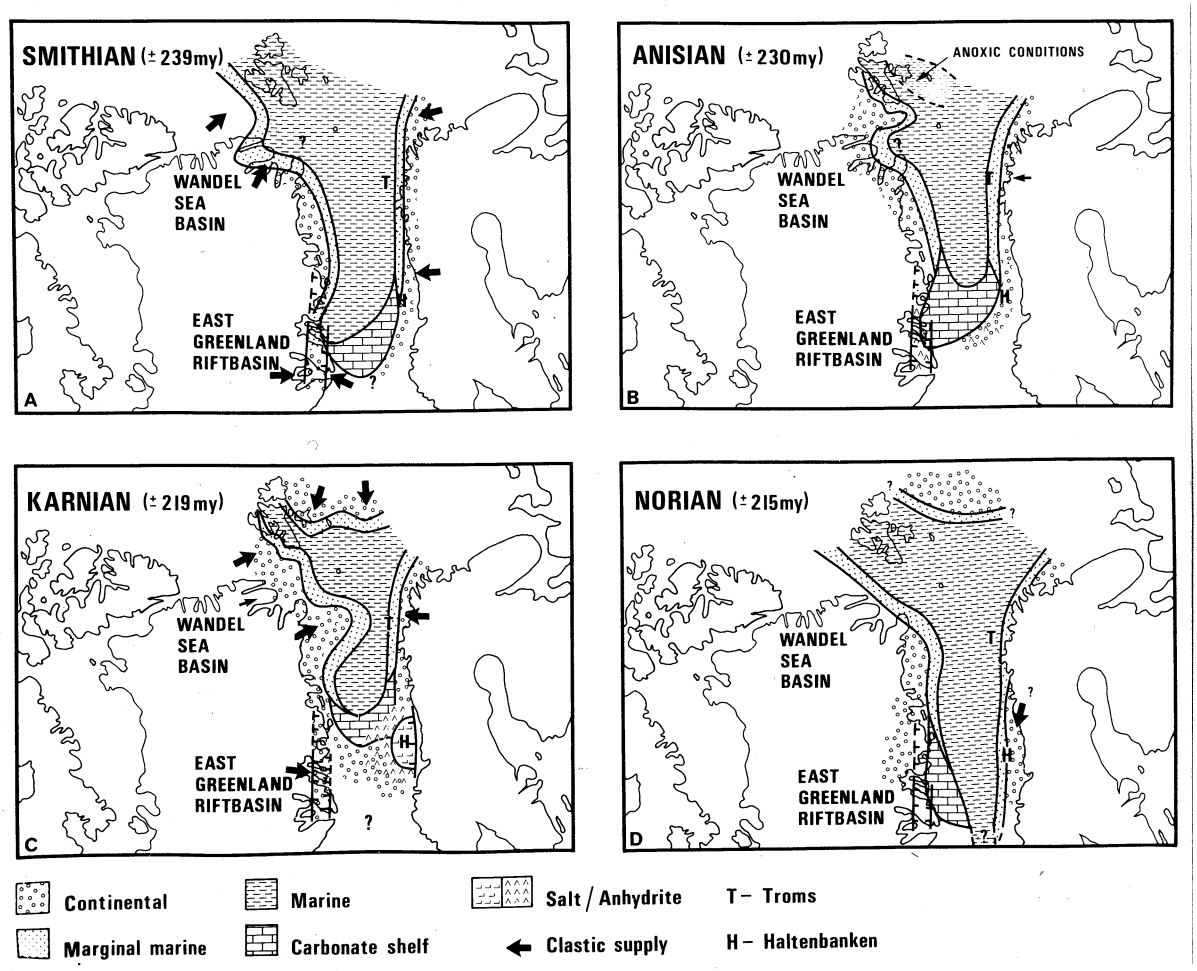

Figure 2.8.6. Sketch maps showing palaeogeographical development during the Triassic (Jacobsen and van Veen 1984).

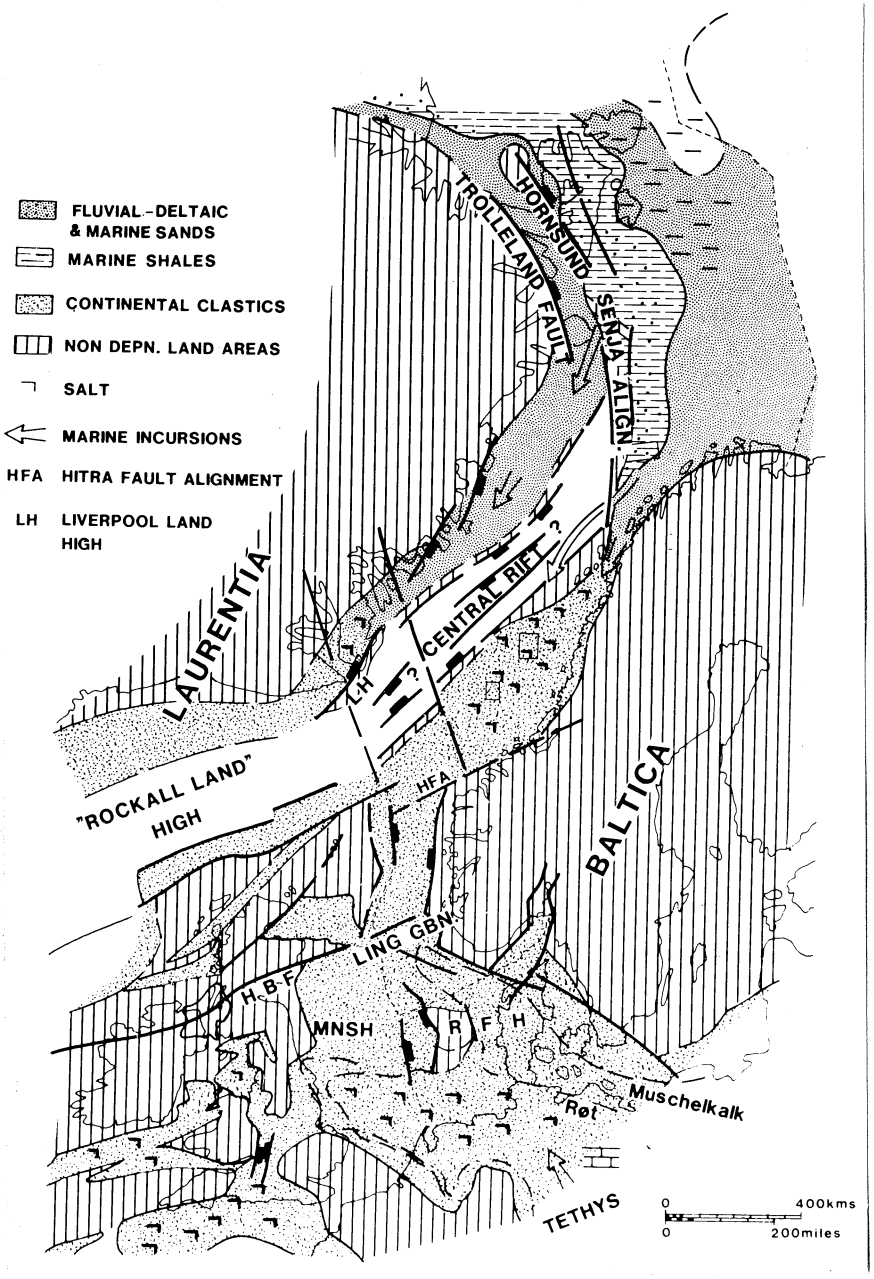

Figure 2.8.7. Sketch map showing generalized Triassic palaeogeography (Gage and Doré 1986).

TABLE 2.8.1. SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR THE TRIASSIC SUCCESSION AT THE DIA-STRUCTURE

		ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
		MEAN	MEAN	MEAN	MEAN	MEAN	Mean		MEAN	MEAN	MEAN
UNIT	MAIN	TOC	H.I.	O.I.	TMAX	V.R.	Concentration		HC	PrPh	$PrnC_{17}$
NAME	LITHOLOGY	(wt%)	(mg/g TOC)	(mg/g TOC)	(°C)	(%)	(ppm)	(mg/g TOC)	(%)		
U-2/IIIC	siltst/sst	1.0	42	61	434	--	--	--	--	---	---
U-5/IIH	siltst	1.2	42	218	436	0.44	696	172.1	21.0	1.1	0.8
D85-K	silty clst	1.1	76	180	435	0.46	802	67.4	40.4	1.3	1.4
U-9/IVD	sh	3.3	394	28	429	0.46	2614	71.4	26.2	0.9	3.7
U-9/IB	sst	2.2	nr	nr	nr	0.46	1300	722.2	21.2	1.2	3.5
U-9/IIG	siltst/sst	1.5	78	57	429	0.46	1444	184.1	46.3	1.2	1.0
U-7/IIF	siltst	1.8	122	44	431	0.38	--	--	--	---	---
U-1/IIE	siltst	1.3	79	31	430	0.44	840	70.5	49.4	0.9	1.6
U-1/IIIB	clst	3.8	350	22	430	0.44	3636	91.7	20.0	1.0	3.9
U-4/IVC	clst	2.1	251	20	425	0.34	--	--	--	---	---
U-4/IVB	sh	3.6	343	18	425	0.34	3778	95.9	25.7	1.0	5.7
U-3/IVA	sh	3.6	354	14	421	0.45	4650	116.8	21.4	1.6	6.0

H.I. = Hydrogen Index; O.I. = Oxygen Index; V.R. = Vitrinite Reflectance
sh = shale; siltst = siltstone; sst = sandstone; nr = data not reliable.

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TABLE 2.8.1. SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR THE TRIASSIC SUCCESSION AT THE DIA-STRUCTURE (cont'd)

UNIT NAME	MAIN LITHOLOGY	ROCK-EVAL DATA TOC (wt%)	H.I. (mg/g TOC)	O.I. (mg/g TOC)	TMAX (°C)	V.R. (%)	EXTRACTABLE ORGANIC MATTER Concentration (ppm)	Concentration (mg/g TOC)	HC (%)	PrPh	$PrnC_{17}$
U-3/IID	siltst/sst	0.7	nr	nr	nr	0.45	692	68.5	28.3	1.5	4.3
U-6/IIIA	sh/siltst	0.3	51	80	nr	--	322	119.4	39.6	1.0	0.5
U-6/IIC	siltst	0.3	54	59	nr	--	273	91.1	33.8	1.2	2.1
U-6/IIB	siltst	0.3	46	36	nr	--	--	--	--	---	---
U-8/IIA	siltst/sst	0.3	50	16	nr	nr	--	--	--	---	---
U-8/IA	sst	0.4	57	11	nr	nr	2636	--	41.9	1.3	1.1

H.I. = Hydrogen Index; O.I. = Oxygen Index; V.R. = Vitrinite Reflectance
sh = shale; siltst = siltstone; sst = sandstone; nr = data not reliable.

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TABLE 2.8.2. KEROGEN COMPOSITION AND MATURITY VARIATION
(Triassic Succession at Dia-structure)

UNIT NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI	V.R. (%)	SPOR
BLOCK 7323/7									
U-9/IVD	93.90	Tr	75	5	15	5	3.5-4.0	na	na
	99.65	--	75	15	5	5	3.5-4.0	na	na
	103.50	Tr	80	10	5	5	3.5-4.0	na	na
	107.80	--	80	10	5	5	3.5-4.0	na	na
	111.08	--	80	10	5	5	3.5-4.0	na	na
U-1/IIIB	107.00	Tr	80	5	10	Tr	3.5-4.0	na	na
	110.00	Tr	80	5	10	Tr	3.5-4.0	0.45	2-4
	114.00	Tr	80	5	10	Tr	3.5-4.0	0.44	3-4
	118.00	--	80	5	10	Tr	3.5-4.0	na	na
	121.00	--	85	5	5	5	3.5-4.0	na	na
	125.00	--	80	5	10	Tr	3.5-4.0	na	na
U-4/IVB	99.01	Tr	80	10	5	Tr	3.0-3.5	na	na
	103.20	Tr	75	5	15	5	3.0-3.5	na	na
	107.00	Tr	80	10	5	Tr	3.0-3.5	na	na
	112.00	Tr	80	10	5	Tr	3.0-3.5	na	na
	115.00	Tr	80	10	5	Tr	3.0-3.5	0.34	4-5
	123.0	Tr	70	15	10	Tr	3.0-3.5	na	na
	127.00	Tr	75	15	5	Tr	3.0-3.5	na	na
	132.00	Tr	80	10	5	Tr	3.0-3.5	na	na
	136.00	Tr	80	10	5	Tr	3.0-3.5	na	na
	138.52	Tr	80	10	5	Tr	3.0-3.5	na	na
U-3/IVA	99.00	--	80	Tr	15	Tr	3.0-3.5	na	na
	103.0	--	85	Tr	10	Tr	3.0-3.5	na	na
	107.0	--	85	Tr	10	Tr	3.0-3.5	na	na

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

3. VARIATIONS IN THE ORGANIC GEOCHEMISTRY AND GEOLOGY OF THE TRIASSIC STRATA

Globally, marine petroleum source-rocks of Triassic age account for only a small percentage of the Phanerozoic source-rocks of this type currently described (Fleet and Brooks 1987). The organic-rich shales of the Arctic region represent the main development of such rocks during the Triassic. The only other development of such rocks occurs in Northwestern Europe at the Anisian/Ladinian boundary and during Norian times when thin, organic-rich shales were deposited locally (Hallam 1987).

At this point, it is convenient to distinguish between organic-rich marine shales containing well-preserved, hydrocarbon-prone kerogen (MSS = Marine Shale Source rocks), and organic-rich marine shales containing poorly-preserved kerogen (MSN = Marine Shale Non-source rocks). Waples (1983) has demonstrated the importance of distinguishing between organic-rich and organic-poor marine shales. This report will be mainly concerned with the occurrence, and especially with the organic geochemistry, of the MSS.

The MSS are typically dark, laminated shales with organic carbon contents of between 1 wt% and 10 wt%, and hydrogen-rich type II or type II/III kerogen. These shales are generally thought to have accumulated on marine shelves under largely anoxic bottom conditions, possibly in association with upwelling current systems (Mørk et al 1982; Embry 1984; Vigran et al 1986; Brooks et al in press). Examples of these shales are the Botneheia Member of the Barentsøya Formation on Svalbard, the shales of the Murray Harbour and Hoyle Bay Formations of the Sverdrup Basin, and the Spathian-Anisian age shales in the Dia-structure area.

The MSN are typically grey shales which may show evidence of bioturbation, and which may have organic carbon contents of up to 4 wt%. The kerogen in these shales may often consist of amorphous material which appears to have been oxidised and is represented by hydrogen indices typical of type III and type IV kerogen. These shales are thought to have been deposited on more proximal marine shelves under generally oxygenated conditions. Examples of these shales are the shales of the Tschermaksfjellet Formation of Svalbard and the shales of the Barrow Formation of the Sverdrup Basin (Mørk et al 1982; Embry 1984; Brooks et al 1987).

3.1 Occurrence of Organic-Rich Rocks during the Triassic

Marine shales were deposited throughout the studied Arctic area during Induan and Olenekian times (Enclosure 1). In the eastern Barents Shelf area, coarser sediments probably derived from the Uralian Orogeny dominated sedimentation throughout the Triassic. Marine shale deposition during this period is represented by the Blind Fiord Formation of the Sverdrup Basin, the Wordie Creek and Parish Bjerg Formations of Greenland, the Vardebukta/ Tvillingodden Formations and Deltadalen/Sticky Keep Members of Svalbard, the lower Triassic shales of western Franz Josef Land, the shales of cores 7323/7-U-3 and 7323/7-U-4 from the Dia-structure and units 2 and 3 from Troms 1.

Although organic geochemical data from the rocks of these units is rather scanty, deposition of MSS at this time appears to have been largely restricted to the western Barents Shelf during Smithian-Spathian times. These are represented by the ca. 90 m thick, mainly shale sequence partly represented in cores 7323/7-U-3 and U-4; up to 120 m of shales represented by the Sticky Keep Member; and possibly by the 170 m thick shale sequence of Unit 3 in the Troms 1 area.

During Anisian/Ladinian times, organic-rich marine shales were deposited over much of the study area. Marine shales occur in the Murray Harbour Formation of the Sverdrup Basin; in the Gråklint Bed of Central East Greenland; in the basal Bravaisberget Formation, the Botneheia Member and the Tschermaksfjellet Formation on Svalbard; during the Anisian on Franz Josef Land; in cores 7323/7-U-4 through D85-K on Dia-structure; and at the base of Unit 5 in the Troms 1 area. On Bjørnøya during the early Middle Triassic, deposition is represented by the phosphatic remainé conglomerate of the Verdende Bed. The lower shale/siltstone unit of the Skuld Formation was deposited during Ladinian times in a shallow marine environment.

MSS are reported from most of these units, with the exception of the Tschermaksfjellet Formation, the Anisian age shales of Franz Josef Land and the lower part of the Skuld Formation on Bjørnøya. The thin, bituminous limestone/shale horizon of the Gråklint Bed of Greenland differs from the other organic-rich units deposited at this time. The rocks of the Gråklint Bed were deposited during a period when juxtaposition of high sea-level and tectonic movement permitted the inundation of an otherwise terrestrial basin.

The highest organic carbon contents occur in shales on Svalbard and at the Dia-structure with TOC values of between 2 and 10 wt%. Only a relatively small proportion of the middle Triassic succession on Dia-structure has been sampled (i.e. ca. 40 m) and marked variation in both organic richness and kerogen quality (i.e. from type II to type IV kerogen) is seen in the lower part of this succession.

The rocks of the Gråklint Bed are recognised as organic-rich largely on the basis of their bituminous nature (Henderson 1976), and are only of local importance. Jacobsen and van Veen (1984) suggest the occurrence of possible MSS in the basal shales of Unit 5 (Troms 1). Low TOC contents of ca. 1-2 wt% in these rocks tend to argue against this, although the relatively low hydrogen indices of less than 200 mg/g TOC should be considered in the light of the high thermal maturity of the kerogen (i.e. ca. >0.9 % VR).

Deposition of marine shales during Karnian times is represented by the Hoyle Bay Formation of the Sverdrup Basin and the Tschermaksfjellet/basal De Geerdalen Formations of Svalbard. Elsewhere in the area, deposition was largely arenaceous in nature.

MSS are only found in the shales of the Hoyle Bay Formation, where organic richnesses and kerogen quality similar to those observed from the Murray Harbour Formation are reported.

Deltaic sedimentation occurred over most of the study area during Norian-Rhaetian times, with deposition of delta-plain deposits in some areas. Marine shale deposition is only represented by the Barrow Formation of the Sverdrup Basin and Unit 6 in the Troms 1 area. Of these two units, only the shales of Unit 6 may represent MSS. Shales from this unit are reported to have TOC values of ca. 1.0 %, in which amorphous material, represented by hydrogen indices of up to 400 mg/g TOC, appears to represent the dominant kerogen component (Bjorøy et al., 1983a).

It is uncertain whether the shales of Unit 6 (Troms 1) represent the last occurrence of Arctic Triassic MSS deposition or whether these represent the northernmost occurrence of the thin, dark shales of Norian age reported from elsewhere in northwestern Europe (Hallam 1987).

3.2 Kerogen Variations in the Triassic Marine Shales of the Arctic

Within this discussion, it is intended to examine the organic geochemistry of the organic-rich marine shales on a time-slice basis. This will permit an easier visualisation of variations which occur through time.

3.2.1 Kerogen Variations

INDUAN (EARLY EARLY TRIASSIC)

Organic geochemical data from shales deposited at this time are available for the Sverdrup Basin (Powell 1978), Svalbard (IKU) and Franz Josef Land (Vojcechovskaja 1985). No data are available for the Wordie Creek and Parish Bjerg Formations of Greenland, but the sedimentology described by Perch-Nielsen et al (1974) and Håkansson and Stemmerik (1984) suggests that the shales of these formations may be classified as MSN.

High thermal maturity levels in the Induan age rocks of the Blind Fiord Formation of the Sverdrup Basin, the Vardebukta Formation of Svalbard and the lower part of the Urd Formation on Bjørnøya, hinder the use of organic geochemical data in the assessment of the kerogen in rocks from these units.

The shales and siltstones of the Blind Fiord and Vardebukta Formations are mostly organic-lean, with organic carbon contents of ca. 0.3 wt% or less. Similar low organic carbon contents have also been reported from western outcrops of the Deltadalen Member of Spitsbergen (Appendix A.1). Higher TOC values of ca. 0.9 wt% have been reported from rocks of the Deltadalen Member in the central areas of Spitsbergen, and although these shales are tentatively assigned to the Deltadalen Member on Edgeøya and Barentsøya, they may be of Olenekian age. Organic carbon contents of 0.7 wt% to 0.9 wt% are reported from the shales and siltstones of the Induan succession in western Franz Josef Land and the Urd Formation. On the Barents Shelf to the south of Bjørnøya, the Induan succession is more arenaceous in nature, and is consequently more organic-lean (i.e. TOC <0.5 wt%).

Rock-Eval data from the more organic-rich successions on Svalbard and Bjørnøya typically show that the kerogen currently contains little pyrolysable material (Figures 3.2.1 and 3.2.2). Microscopic observations from Franz Josef Land and Svalbard (Appendix A.2) indicate that the kerogen in the rocks is mostly amorphous in nature. Pcelina (1972), Bjorøy et al

(1978, 1980 and 1983b) and Vocechovskaja (1985) consider the amorphous material to be mainly derived from marine phytoplankton. Woody/coaly debris is an important kerogen component in the lower (Induan) part of the Urd Formation on Bjørnøya.

The observation of bituminous material in rocks of the Urd Formation on Bjørnøya (Pcelina 1972; Bjorøy et al 1980) and the generally high extractabilities observed in rocks of the Vardebukta Formation/Deltadalen Member on Svalbard (<2000 ppm and 100-200 mg/g TOC) probably represent non-indigenous material, given the poor quality of the kerogen. Low concentrations of bituminous material are associated with the equivalent rocks of the Sverdrup Basin (20-50 mg/g TOC) and Franz Josef Land (<500 ppm).

OLENEKIAN (LATE EARLY TRIASSIC)

Deposition of organic-rich shales began during this period on the western Barents Shelf adjacent to the Dia-structure (7323/7-U-3 and U-4), on Svalbard (Sticky Keep Member) and possibly in the the Troms 1 area (Unit 3 of Jacobsen and van Veen 1984). Elsewhere, deposition is represented by the MSN of the Blind Fiord/Bjorne Formations, the lower part of the Dunken Formation, the Tvillingodden Formation, the upper part of the Urd Formation and the Olenekian succession on western Franz Josef Land.

The often bituminous shales of the Sticky Keep Member (Smithian-Spathian) are organic-rich throughout occurrence, with organic carbon contents of typically around 2-3 wt% (Appendix A.1; Enclosures E.2 and E.3). Shales of the laterally equivalent Tvillingodden Formation and the equivalent succession on western Franz Josef Land are much less organic-rich, with organic carbon contents of less than 1 wt%. Similar organic carbon contents are found in the bituminous shales in the upper part of the Urd Formation on Bjørnøya. Adjacent to the Dia-structure, deposition of organic-rich shales began somewhat later (during ?Spathian times) than on Spitsbergen, and organic carbon contents in these rocks typically lie between 2 wt% and 5 wt%. South of the Dia-structure, in the Troms area, 170 m of marine shales were deposited during Smithian times with organic carbon contents of between 1 wt% and 2 wt%.

Hydrogen indices from the rocks of the Sticky Keep Member decrease from between 200 to 400 mg/g TOC on Barentsøya and Edgeøya, to less than 200 mg/g TOC in eastern and central Spitsbergen with increasing thermal maturity.

Rock-Eval data indicate that the kerogen in the Spathian succession at Dia-structure (Figure 3.2.3) is typically about 50% more hydrogen-rich (i.e. typically 300-500 mg/g TOC; type II to type II/III kerogen) than the kerogen from the rocks of the Sticky Keep Member (Figure 3.2.4: hydrogen index = ca. 200-300 mg/g TOC). This variation may reflect the generally higher thermal maturation level of the Spitsbergen material.

Data are not available from any of the other units deposited during this period, although the lower organic richnesses of these units suggest that the kerogen is unlikely to be more hydrogen-rich than the above two formations. The rocks of the upper Urd Formation (Figure 3.2.2) and the Tvillingodden Formation (Figure 3.2.4) appear to contain almost no pyrolysable kerogen, although the relatively high thermal maturity of the kerogen in these rocks makes evaluation of the data difficult.

Microscopic studies on the marine shales from Troms, Dia-structure, Bjørnøya, Svalbard and Franz Josef Land suggest that amorphous material is the main kerogen component in these rocks (Appendix A.2). This amorphous material is generally considered to be derived from marine phytoplankton and algae. Woody/coaly material occurs at some localities on Edgeøya/Barentsøya, around inner Isfjorden on Spitsbergen, and at Dia-structure where such material can account for 5-20% of the kerogen.

Although the kerogen from the upper part of the Urd Formation is largely inert as presently exposed, the distribution of the organic matter shows a net-like distribution. Similar distributions are seen in the equivalent rocks at Dia-structure and this similarity may indicate that the kerogen in the Urd Formation was originally similar to that in the Dia-structure succession.

The data available to this study suggest that there is little difference in the nature of the kerogen present in the Olenekian age rocks at Dia-structure and the Sticky Keep Member on Svalbard, although the preservation of the kerogen may be slightly better in the Dia-structure succession. This would suggest that conditions of deposition were similar in both areas at this time. Whether the two areas were connected is another question which cannot be satisfactorily resolved in this study.

The Olenekian age rocks in the Svalbard-Bjørnøya-Dia-structure-Troms area contain appreciable concentrations of bitumen. The origin of this material

will be considered more fully in section 3.3 of this discussion.

ANISIAN-LADINIAN (MIDDLE TRIASSIC)

Deposition of organic-rich marine shales appears to have reached its maximum areal extent during this period and affected nearly all the areas considered in this study. Dark-coloured, often phosphatic shales occur in the Murray Harbour Formation of the Sverdrup Basin, the Bravaisberget Formation/Botneheia Member of Svalbard, cores 7323/7-U-4, U-1 and U-9 at Dia-structure and possibly Unit 5 in the Troms 1 area.

The most organic-rich rocks occur in the Botneheia Member, where mean organic carbon contents vary from 4 wt% to 7 wt%. The highest organic carbon contents in this unit are found on northern Edgeøya and Barentsøya, where TOC values of up to 11 wt% are reported (Appendix A.1; Enclosures E.2 and E.3). Organic carbon contents decrease westwards and southwards from this area. Organic carbon contents increase up the succession at eastern outcrop localities, but tend to remain constant or decrease up the succession at outcrop localities in central Spitsbergen. The lowest mean organic carbon contents to be found in the Botneheia Member occur in the Isfjorden area. The dark-coloured marine shales of the equivalent Bravaisberget Formation in western Spitsbergen typically have lower average organic carbon contents of ca. 2 wt%.

Similar high organic carbon contents of up to 10 wt% have also been reported from middle Triassic rocks the Sverdrup Basin. Powell (1978) observed that organic carbon contents of ca. 1-2 wt% are typical of shales from the Schei Point/Blaa Mountain Groups. Brooks et al (in press), however, have observed organic carbon contents of between 2 wt% and 6 wt% as being typical of the Murray Harbour Formation. The most organic-rich shales in this formation occur in the north and north-east areas of the basin.

Rocks of Anisian age are absent from Bjørnøya, where they are represented by a thin phosphatic conglomerate of moderate organic richness (i.e. TOC = 1.1 wt%). The shallow marine shales and siltstones in the lower part of the Skuld Formation typically have organic carbon contents of ca. 1 wt%, and may be classified as MSN. Farther south, at the Dia-structure, middle Triassic shales and siltstones penetrated by cores 7323/7-U-4 to D85-K are of rather variable organic richness. Thin, organic-rich shales with organic carbon contents of up 8 wt% are observed in cores 7323/7-U-1 and U-9. Elsewhere in the cored succession, siltstones with lower organic carbon con-

tents of ca. 1-2 wt% are more typical. Similar low organic carbon contents are also found in the marine shales at the base of Unit 5 in the Troms area and in the Anisian/Ladinian marine shales on Franz Josef Land. The influence of Cretaceous igneous intrusions in the marine shales of Franz Josef Land could not be determined.

Kerogen data from middle Triassic shales in the study area is rather discontinuous, and most of the available data is concerned with Svalbard and Dia-structure. Consideration of the Murray Harbour Formation is based on data published by Powell (1978) and Brooks et al (in press), although nomenclature inconsistency limits the use of this data.

Microscopic observation suggests that amorphous material derived from phytoplankton and algae is the main component of the kerogen in the marine shales of the Sverdrup Basin, Svalbard, Franz Josef Land, Dia-structure and Troms (Appendix A.2). Terrestrial material is an important kerogen component in the rocks in the lower part of the Skuld Formation on Bjørnøya. Herbaceous material appears to be more abundant in the shales of the Murray Harbour Formation (i.e. 20-50 %), than in equivalent shales from the Barents Shelf (typically <20 %). Tasmanitid bodies of variable preservation have been reported from the Botneheia Member in eastern Svalbard and from the succession at Dia-structure. These typically account for less than 10 % of the kerogen, but may be locally important at particular horizons.

Rock-Eval hydrogen indices of up to 600 mg/g TOC have been reported from shales of the Murray Harbour Formation, although the majority of the shales in this formation are reported as having lower hydrogen indices (Brooks et al in press). These variations in hydrogen index are thought to reflect variations in thermal maturation, as well as changes in kerogen facies within the Murray Harbour Formation.

Although similarly high hydrogen indices have been reported from tasmanitid-rich horizons in the Botneheia Member on Nordaustlandet, the majority of the shales from the Botneheia Member have hydrogen indices of 200 mg/g TOC to 500 mg/g TOC (Figure 3.2.5). The highest mean hydrogen indices occur in outcrop sections on Barentsøya/Edgeøya and immediately adjacent to the western fold-belt at Bertilryggen. The lowest mean hydrogen index values occur in central and eastern Spitsbergen. These variations may reflect variations in thermal maturity, rather than changes in kerogen type.

At Stensiöfjellet, Vikinghøgda-Sticky Keep and Tschermaksfjellet in central

Spitsbergen, relatively high oxygen indices distinguish the kerogen from that occurring in the Botneheia Member at other localities (Figure 3.2.5; Appendix A.1). The mineralogy of the shales at these localities is not significantly different and this variation may therefore reflect a change in kerogen type/preservation. In sections on Barentsøya/Edgeøya and Bertilryggen, the kerogen in the upper part of the Botneheia Member is more hydrogen-rich than that in the lower part. This probably reflects changes in kerogen chemistry, as microscopic observations suggest that there is no marked change in kerogen composition.

More detailed pyrolysis-gas chromatography (Py-GC) data from sections of the Botneheia Member on Edgeøya, Barentsøya and Nordaustlandet indicate that the kerogen in this unit is highly aliphatic (Figure 3.2.6). The pyro-chromatograms of the kerogen are all dominated by an alkene/alkane homology. Aromatic peaks are almost non-existent above C_9, except in one sample from Skrukkefjellet. The similarity of the pyro-chromatograms to that of a tasmanitid concentrate from Torellnesfjellet on Nordaustlandet suggests that degraded algal material is an important component of the kerogen.

Certain variations in kerogen type/preservation within the Botneheia Member suggest the operation of some topographic effect during deposition. These may reflect the presence of shallow depressions in the middle Triassic shelf floor, where the kerogen was slightly better preserved. These may be coincident with the current locations at Bertilryggen, Vikinghøgda-Sticky Keep and Skrukkefjellet-Lomberget-Teistberget. Detailed study of the kerogen in these areas is required.

Carbon isotope data from kerogen at three localities on Barentsøya and Edgeøya show little variation (i.e. -30.4 to -30.3 °/oo). These values are consistent with a marine origin for the amorphous material, and Lewan (1986) would characterise this material as l-amorphous. This type of material is thought to accumulate in shallow (<200 m), restricted basins overlain by a stratified water column.

Further westwards, the kerogen in shales of the Bravaisberget Formation also consists of mainly amorphous material,although Rock-Eval data suggest that this kerogen is more inert than that in the laterally equivalent Botneheia Member. Pyrolytically, the kerogen in the Bravaisberget Formation varies from type III in northern exposures to type IV in southern exposures (Figure 3.2.5). This variation appears to be related to a southwards increase in thermal maturity from ca. 0.9 % at Festningen to 1.5-2.0 % at

Treskelen. The high thermal maturity of the kerogen in rocks of the Bravaisberget Formation causes difficulty in evaluating the original nature of the kerogen. Kerogen in rocks from the southernmost exposure of the Bravaisberget Formation at Karentoppen have similar Rock-Eval characteristics to those observed in the phosphatic conglomerate of the Verdande Bed.

In the core samples taken at Dia-structure, the most hydrogen-rich kerogen is found in the organic-rich horizons in cores 7323/7-U-1 and U-9. At these horizons, hydrogen indices vary from ca. 250 mg/g TOC to over 500 mg/g TOC (Figure 3.2.7). The occurrence of hydrogen-rich kerogen in the Dia-structure succession is less continuous than in the Botneheia Member. This kerogen also tends to be less hydrogen-rich than kerogen from sections of the Botneheia Member with an equivalent thermal maturity (i.e. on Barentsøya/ Edgeøya). In the less organic-rich siltstones at Dia-structure, hydrogen indices do not exceed 200 mg/g TOC and are commonly less than 100 mg/g TOC.

Pyrolysis-gas chromatography data from the organic-rich shales in cores 7323/7-U-1 and U-9 mostly show a good alkane/alkene homology, although the peaks appear to be generally less well-developed than is seen in samples from Svalbard (Figure 3.2.6). In addition, peaks representing unidentified aromatic compounds are more prominent in the Dia-structure samples than in the Svalbard samples. The prist-1-ene peak is more prominent and m+p-xylene/octene values are typically higher in the Dia-structure samples (i.e. 0.6-0.8), than in the analysed Svalbard samples (i.e. 0.4-0.5). These data may reflect the slightly greater content of terrestrial organic matter and/or the lower maturity of the kerogen in the Dia-structure shales.

All of the organic-rich shales considered here contain appreciable concentrations of bitumen (i.e. between 50 and 100 mg/g TOC). Variations in this bituminous material will be more fully considered in section 3.3 of this discussion.

KARNIAN (EARLY LATE TRIASSIC)

Marine shale deposition during this period is represented by the Hoyle Bay Formation of the Sverdrup Basin and the Tschermaksfjellet/basal DeGeerdalen Formations of Svalbard. Shale horizons occur on Franz Josef Land, but are associated with coaly beds and sandstones and may not be of marine origin.

Deposition of organic-rich MSS during this period is only represented by the shales of the Hoyle Bay Formation. These are similar in character to

the shales of the Murray Harbour Formation and typically have organic carbon contents of between 2 wt% and 6 wt%. Amorphous and herbaceous material accounts for most of the kerogen in these rocks, and hydrogen indices of up to 600 mg/g TOC are reported Brooks et al in press). Kerogen facies changes can be recognised within the formation, and the most organic-rich rocks occur in discrete horizons to the south and southwest of the basin.

The shales of the Tschermaksfjellet Formation are of Ladinian-Karnian age, and may be quite organic-rich in eastern Svalbard (i.e aver TOC = 2-3 wt%). The organic richness of this unit decreases westwards and southwards to ca. 1 wt% in central and western Spitsbergen. Although amorphous material accounts for 50-90 % of the kerogen in the rocks of the Tschermaksfjellet Formation, Rock-Eval data indicate that this kerogen is mostly inert (i.e. type IV). Hydrogen indices typical of type III kerogen were obtained from rocks on Barentsøya/Edgeøya (Figure 3.2.7). Shales of the basal DeGeerdalen Formation typically have organic carbon contents of less than 1 wt% and the kerogen in the these rocks is pyrolytically inert.

NORIAN-RHAETIAN (MIDDLE-LATE LATE TRIASSIC)

Marine shale deposition during Norian-Rhaetian times is represented by the shales of the Barrow Formation in the Sverdrup Basin, and possibly by the shales of Unit 6 (Jacobsen and van Veen 1984) in the Troms area.

Brooks et al (in press) indicate that the shales of the Barrow Formation are poor in organic matter and have no significant hydrocarbon generation potential.

Unit 6 (Jacobsen and van Veen 1984) is a thin development (ca. 35 m) of dark shales containing marine phytoplankton. These shales are reported to have organic carbon contents of ca. 1-2 wt%. The kerogen is thought to contain mostly amorphous material, with hydrogen indices of up to 400 mg/g TOC.

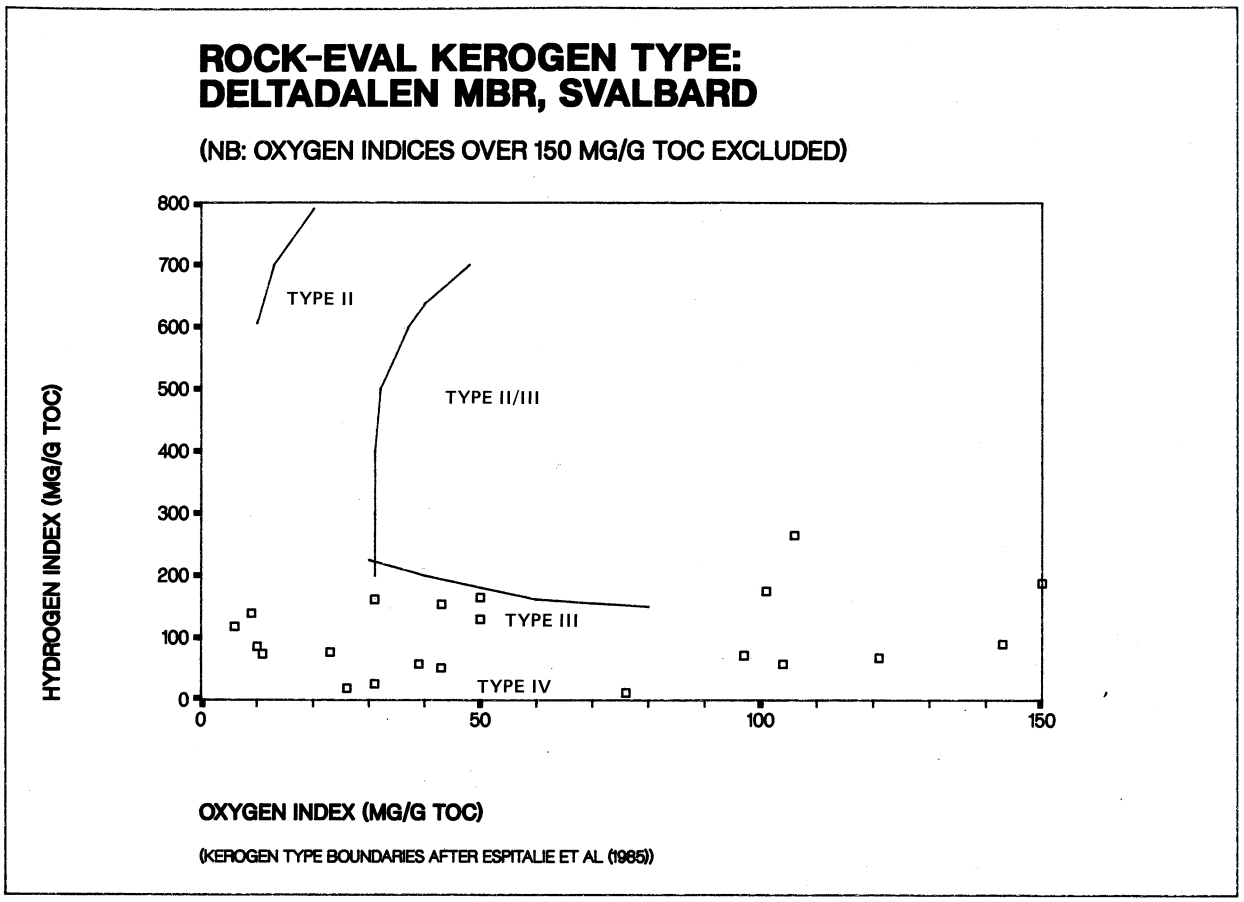

Figure 3.2.1a.

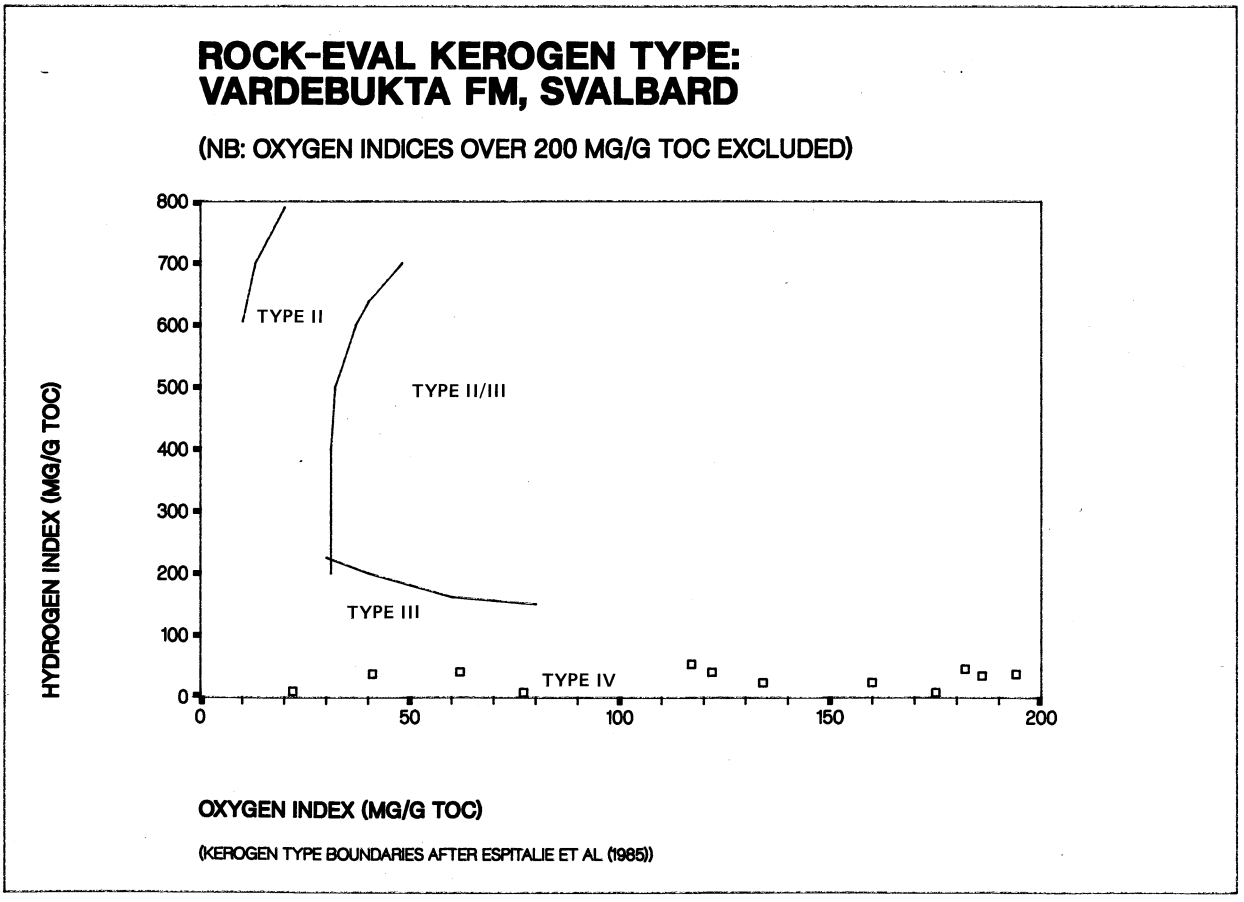

Figure 3.2.1b.

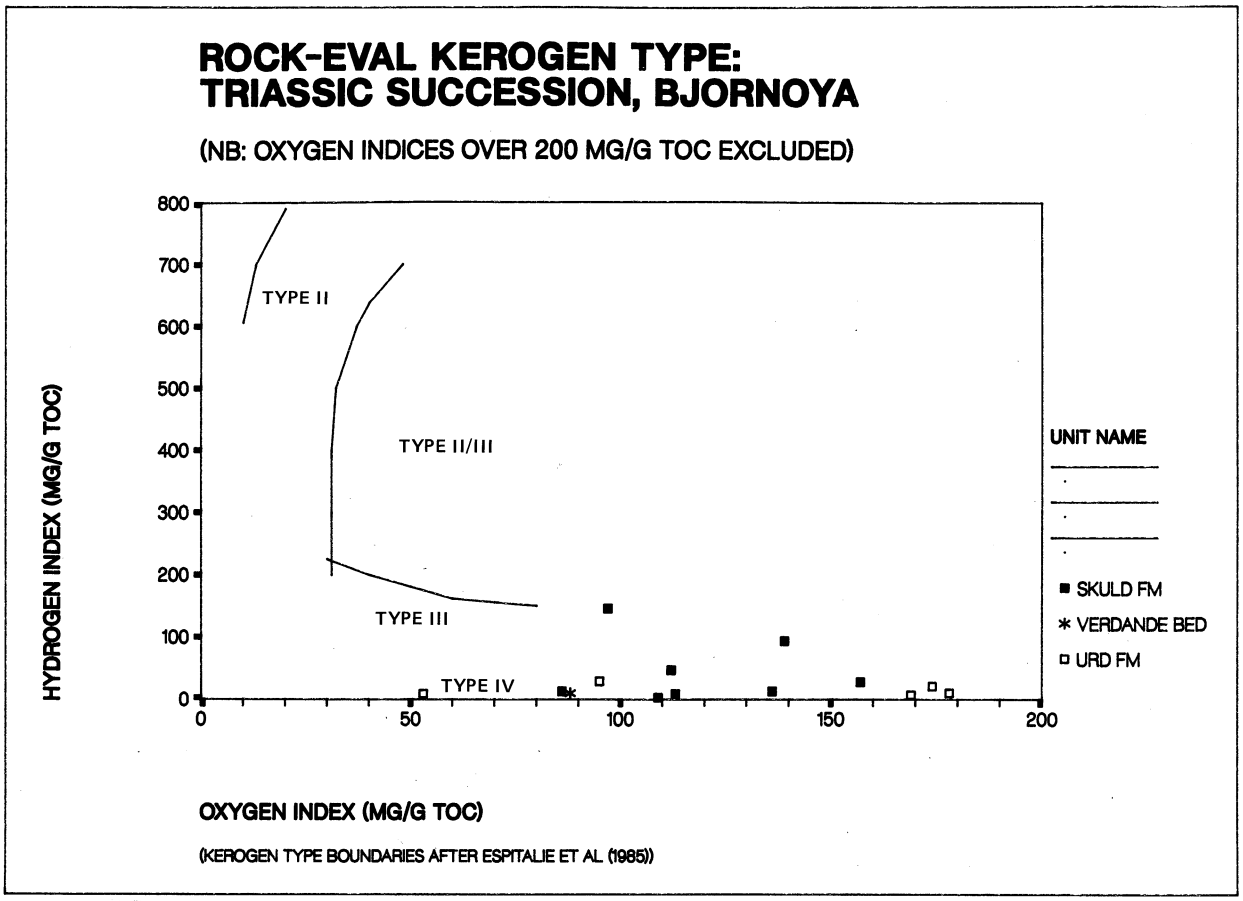

Figure 3.2.2.

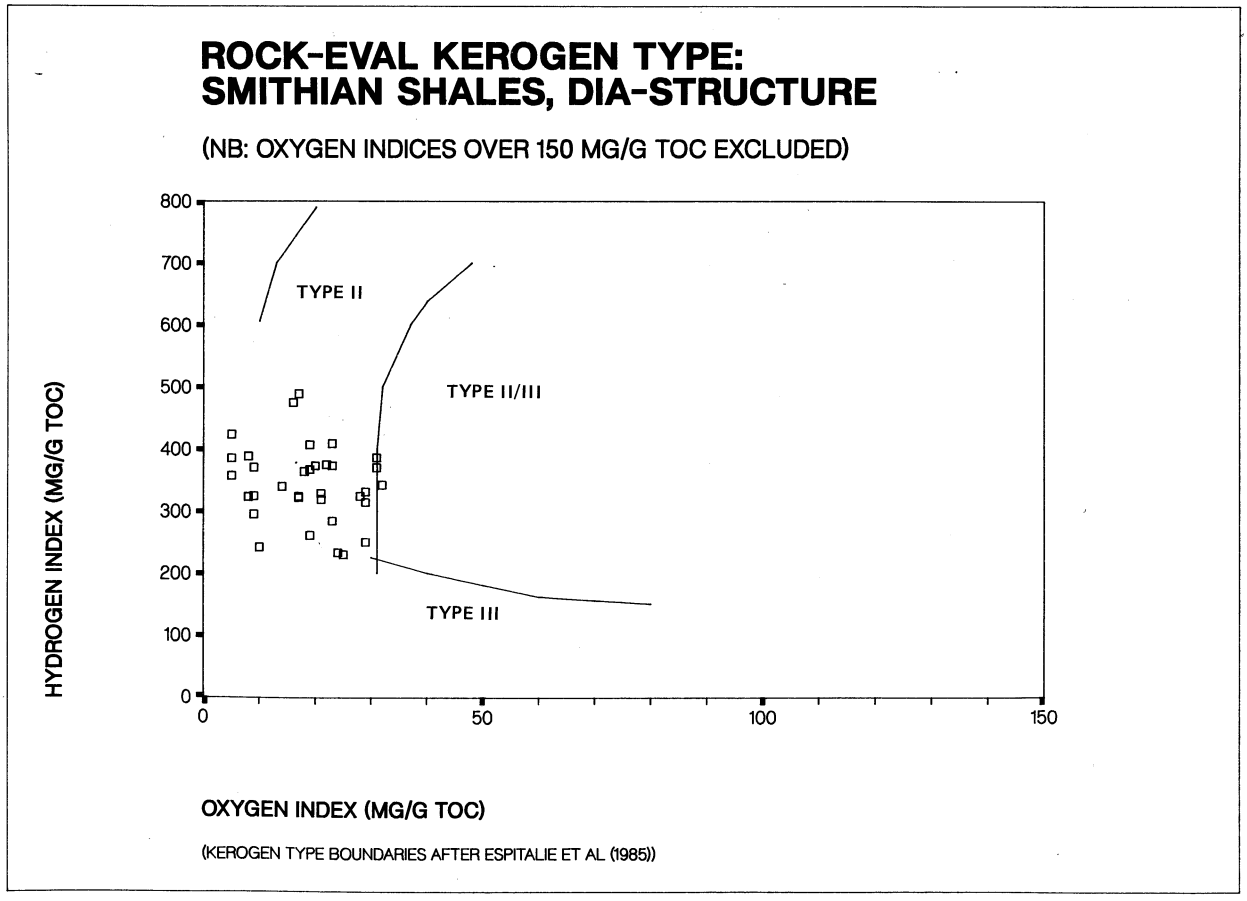

Figure 3.2.3.

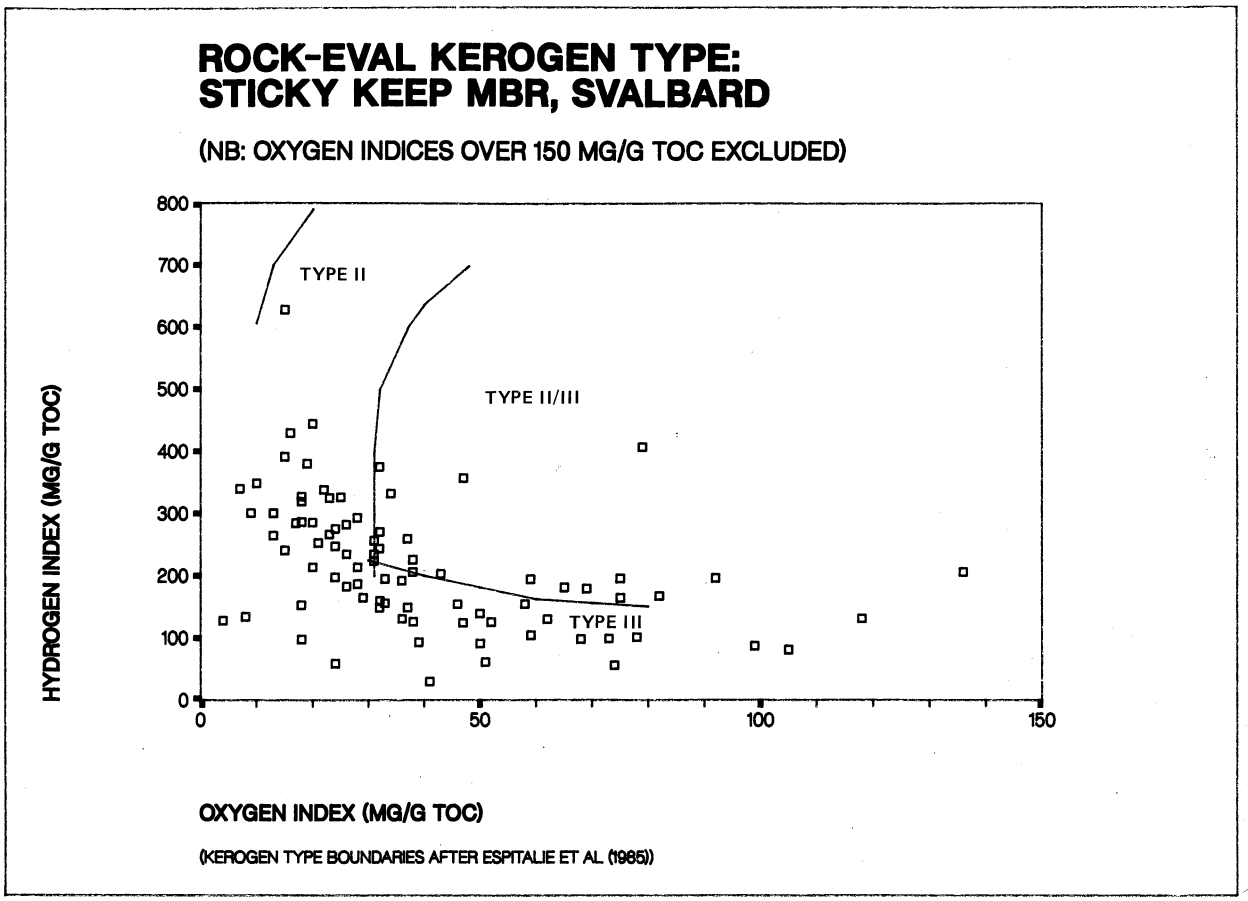

Figure 3.2.4a.

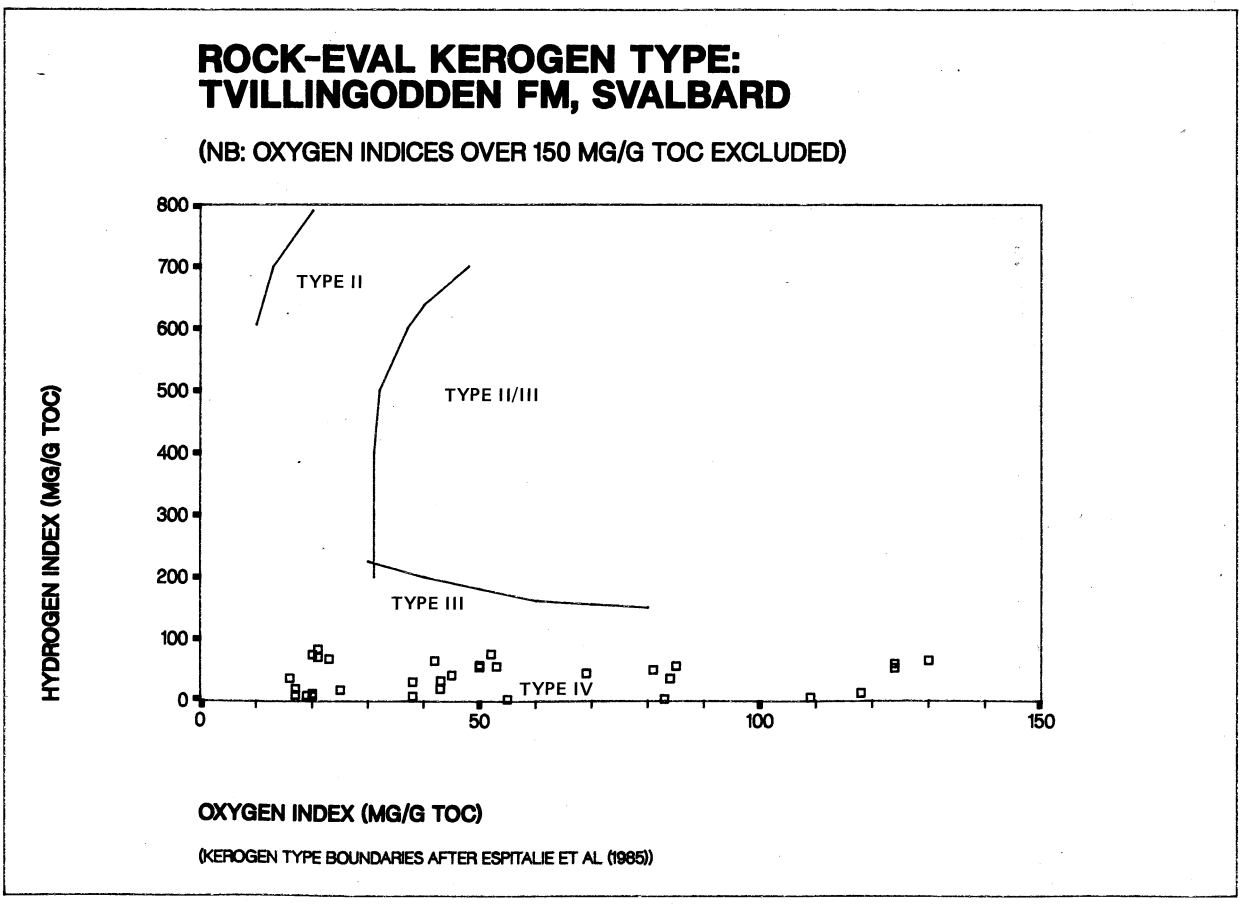

Figure 3.2.4b.

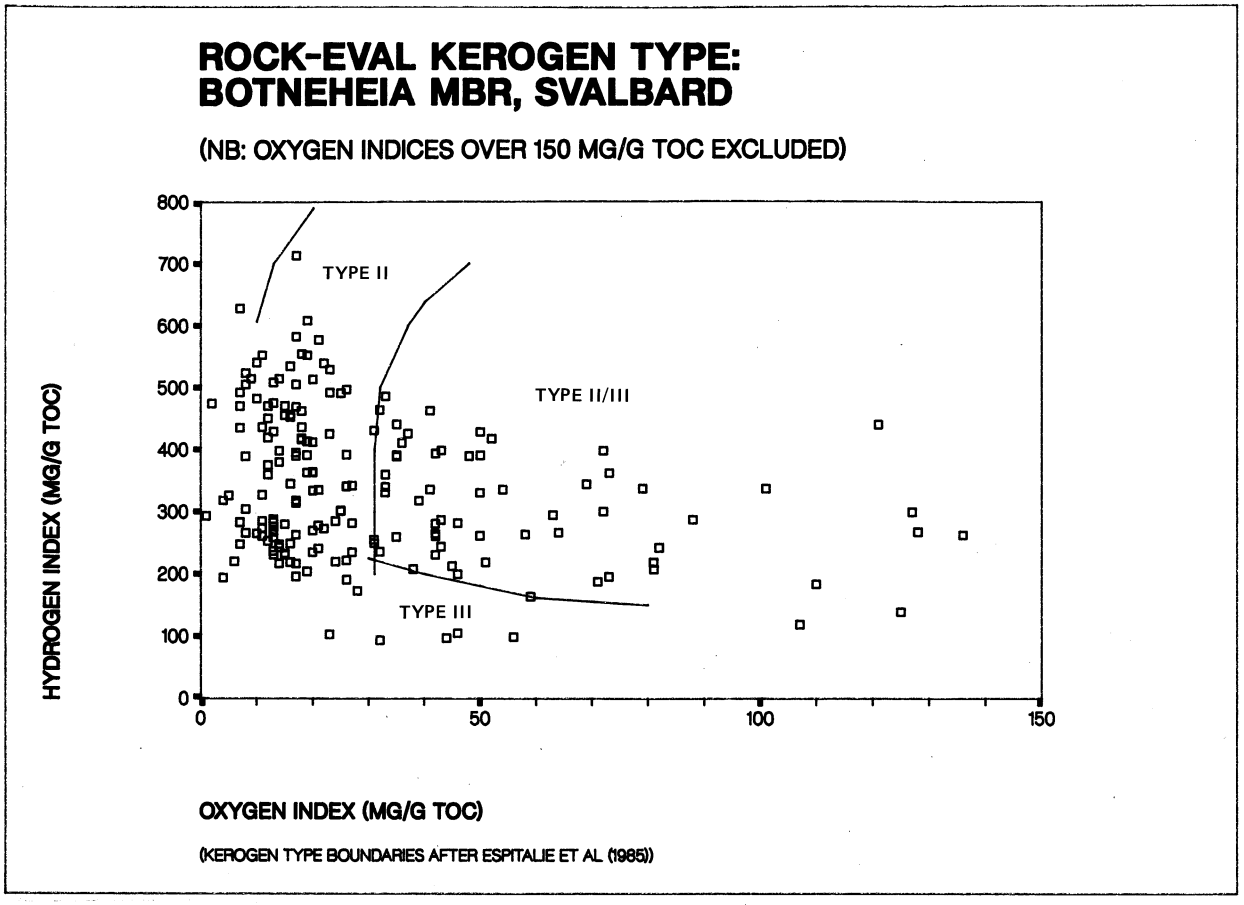

Figure 3.2.5a.

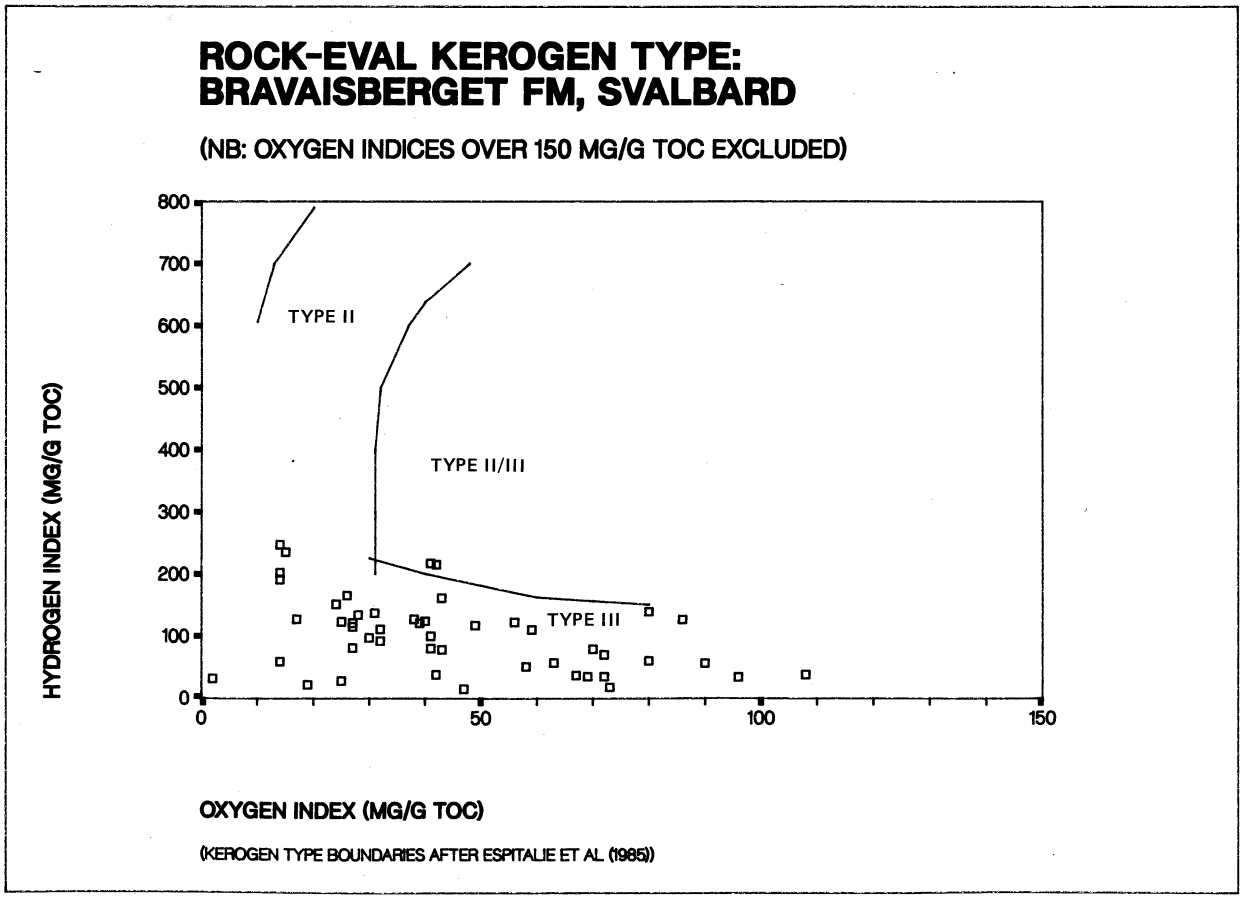

Figure 3.2.5b.

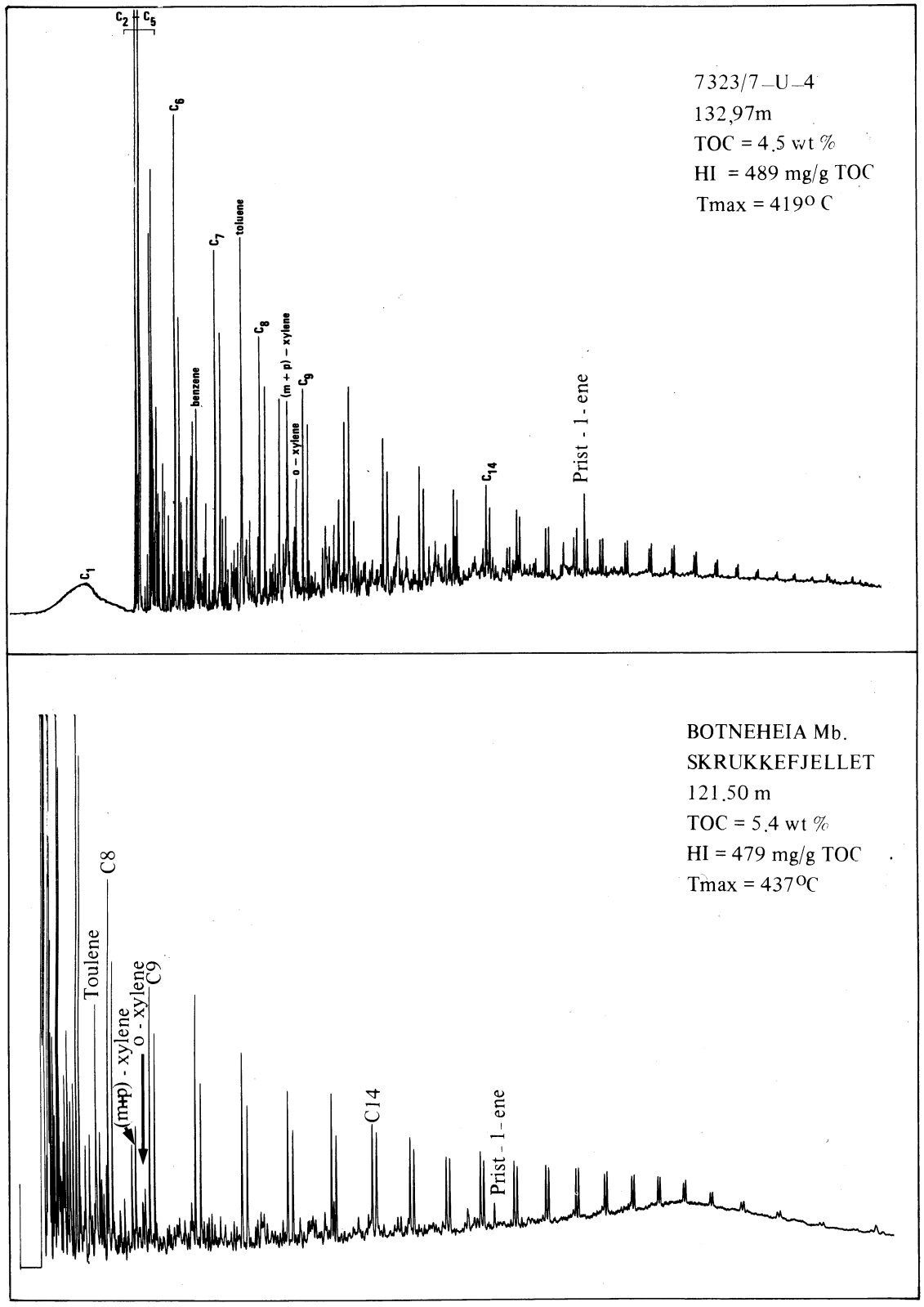

Figure 3.2.6. Typical pyrolysis-gas chromatograms (S_2) of whole-rock samples from the Triassic succession at Dia-structure and the Botneheia Member in Svalbard.

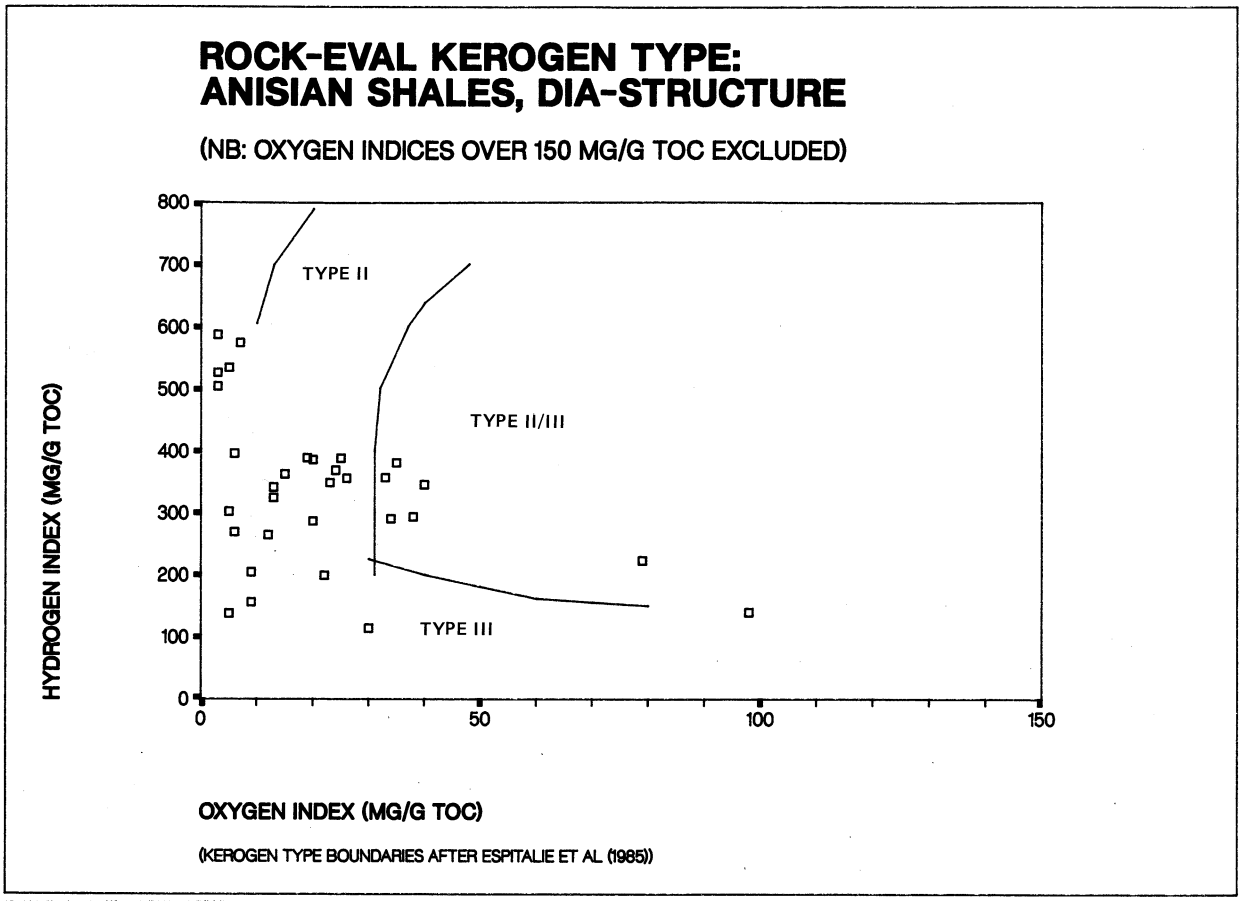

Figure 3.2.7.

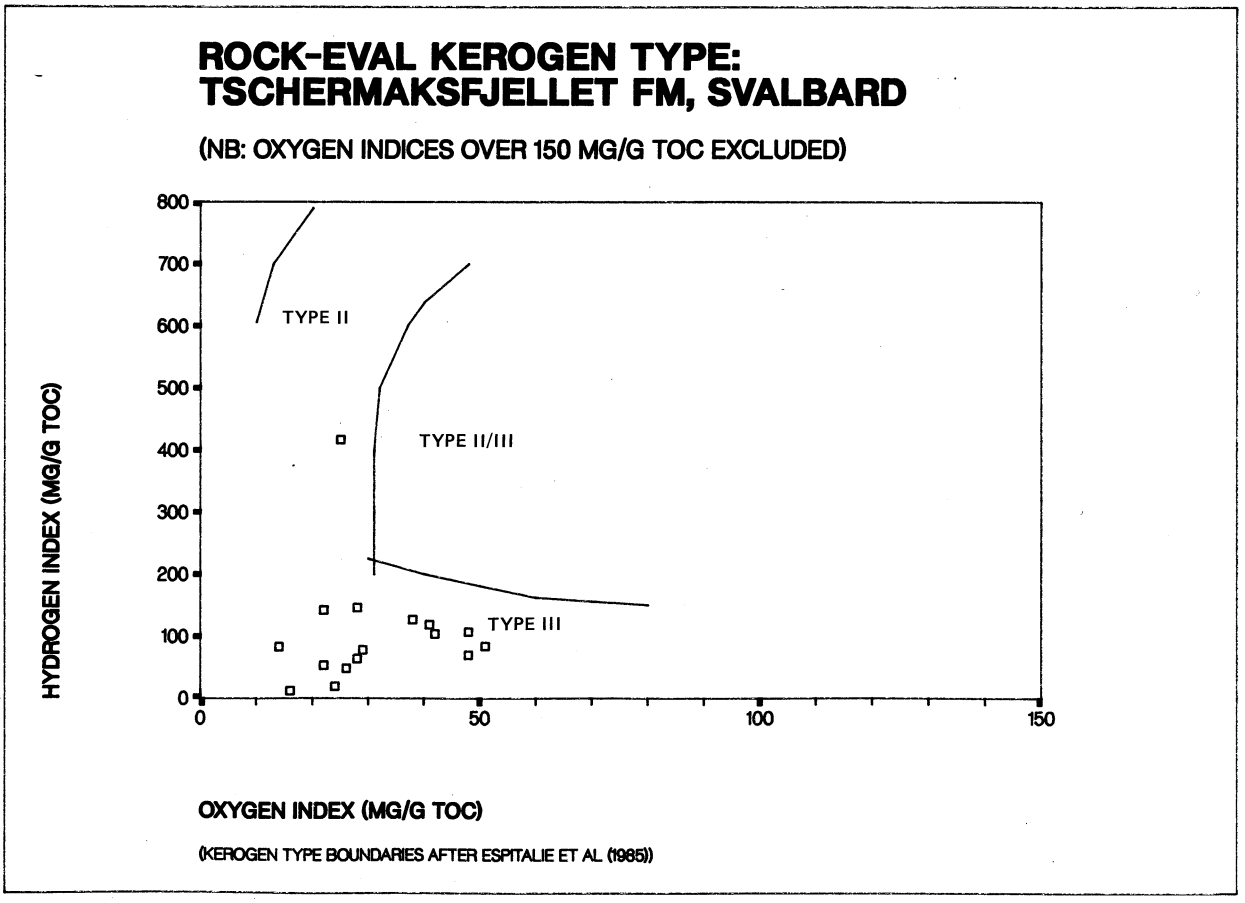

Figure 3.2.8.

3.2.2 Comments on the Rock-Eval characteristics of Lower-Middle Triassic shales of the Barents Shelf

Variations in the hydrogen richness of the kerogen in the Sticky Keep and Botneheia Members and in the equivalent shales at Dia-structure in response to maturity were investigated. This involved study of whole-rock and kerogen concentrates from common samples (Appendix A.3).

The kerogen in the Sticky Keep Member shales tends to be less hydrogen-rich (typically 50-100 mg/g TOC lower) than the kerogen in the Botneheia Member shales at equivalent thermal maturity levels, based on whole-rock measurements (Figure 3.2.2.1). Terrestrial herbaceous and woody debris may be slightly more common in the shales of the Sticky Keep Member and the Dia-structure succession than in the shales of the Botneheia Member, but otherwise there is little difference in kerogen composition. The kerogen from the Dia-structure shales shows little variation within the sampled succession and appears to be more similar in character to the kerogen in the Sticky Keep Member shales than to the kerogen in the Botneheia Member shales.

Analysis of kerogen concentrates resulted in generally higher hydrogen indices and lower oxygen indices relative to the results from whole-rock samples (i.e. type II kerogen as opposed to type II/III kerogen in whole-rock samples (Figure 3.2.2.2). In addition, when determined on kerogen concentrates, the difference between the kerogen in shales of the Sticky Keep and Botneheia Members was markedly reduced, both kerogen groups having similar Rock-Eval properties (Figures 3.2.3.3). The biggest change was seen in the oxygen indices of samples from the Botneheia Member, suggesting an input from carbonate minerals to the oxygen indices of the whole-rock samples. The deviations are generally greater than can be explained by variation inherent in the analytical technique (i.e. ca. 10% after Espitalié et al., 1985).

Rock-Eval data for the kerogen concentrates from the Dia-structure shales are similar to those for the Sticky Keep and Botneheia Members, although there is almost no variation in the oxygen index of the Dia-structure samples. This may reflect the lower carbonate content of these shales. The unexpectedly low TOC values obtained from some of the Dia-structure kerogen concentrates may indicate that the hydrogen indices from these samples are over-estimated.

Although Espitalié et al. (1980) and Crossey et al. (1986) have indicated that there is less variation between Rock-Eval data for whole-rock and kerogen concentrates in organic-rich samples (i.e. TOC > 5 wt%), this is not borne out from the data presented here. The variation in the data between the two suites of samples shows no relationship with TOC, mineralogy or thermal maturity. The apparent overestimation of hydrogen index in some samples from the Botneheia Member could reflect an influence from bitumen as suggested by Clementz (1979), but this cannot be conclusively demonstrated. There is no consistent variation in the mineralogy of the samples which would explain the observation.

The correlation obtained between hydrogen index was generally rather poor (Figure 3.2.2.3), suggesting that some factor over and above maturation is influencing the bulk pyrolysis characteristics of the kerogen. An obvious candidate is the kerogen itself, but as has been noted earlier, there is little visible deviation in the type of organic matter present. An alternative suggestion may lie in variable presentation of the organic matter, a phenomenon which cannot readily be observed from the available data. This possibility would not be inconsistent with the depositional setting of these rocks in the western Barents Sea.

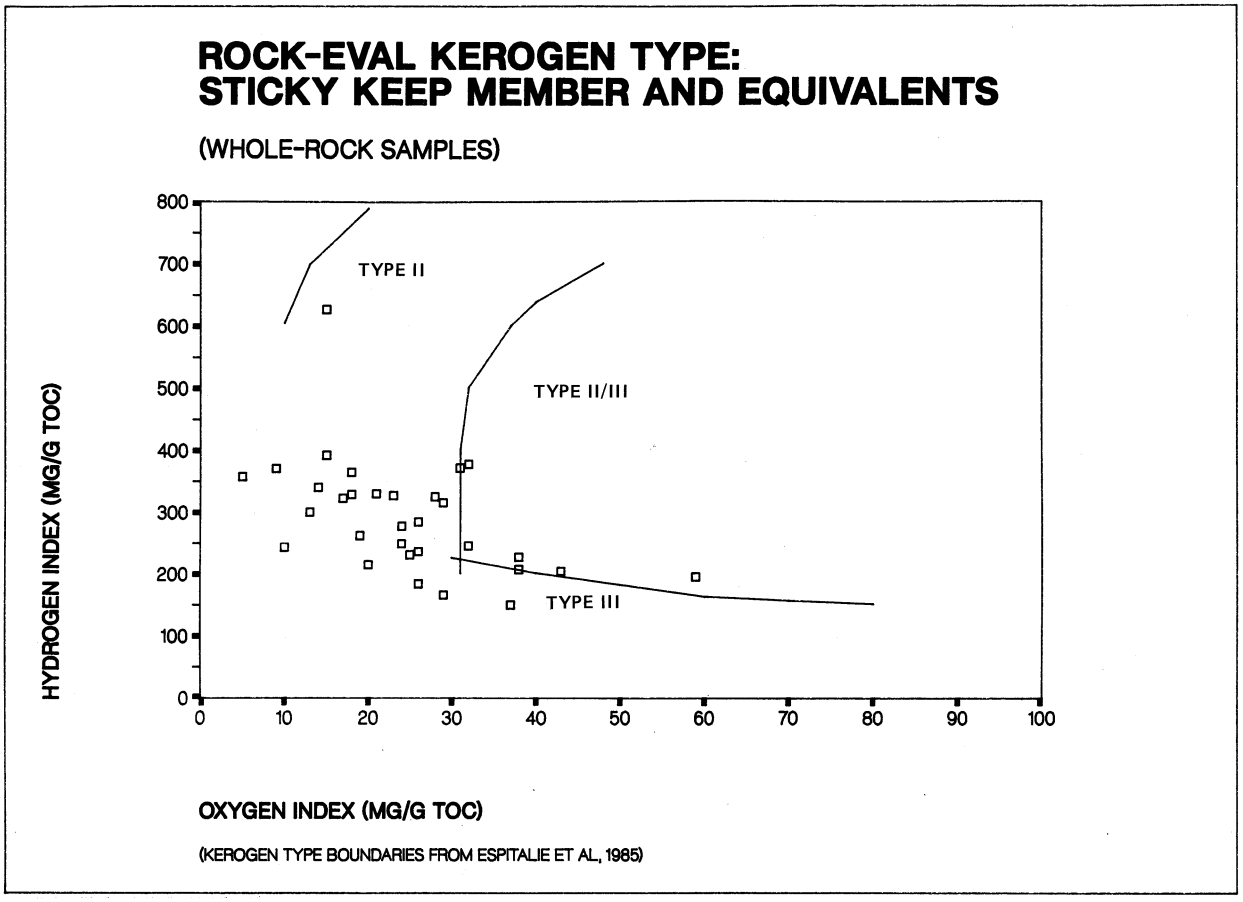

Figure 3.2.2.1a.

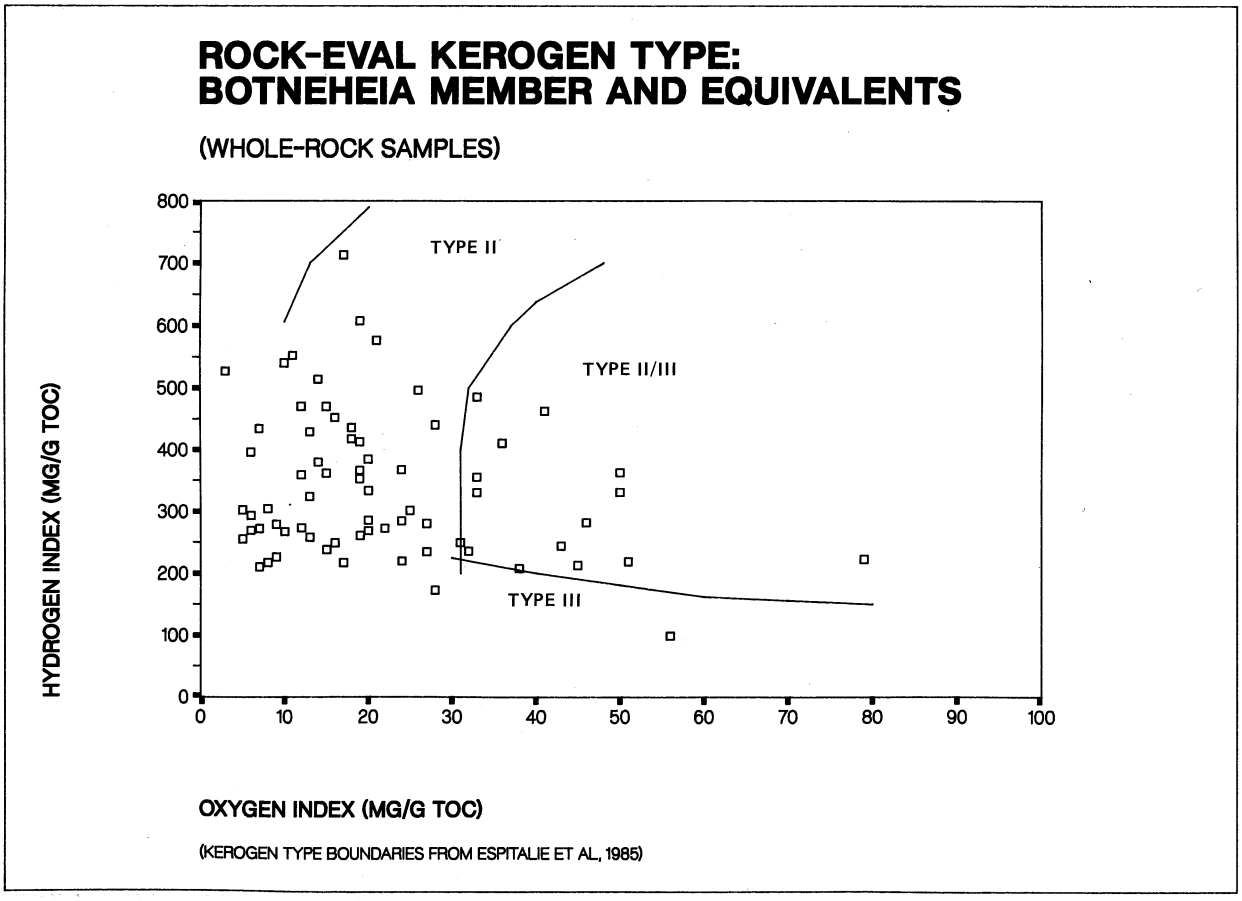

Figure 3.2.2.1b.

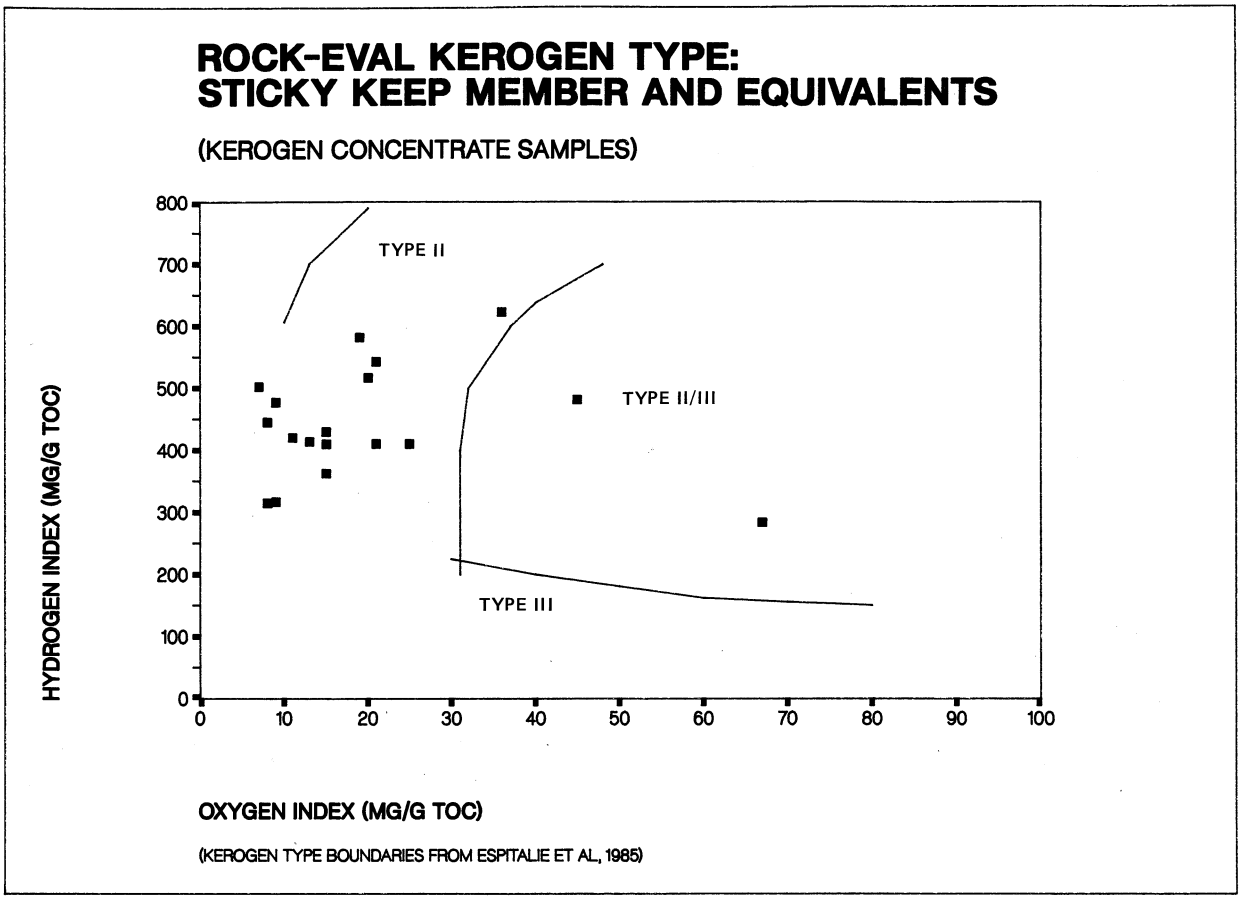

Figure 3.2.2.2a.

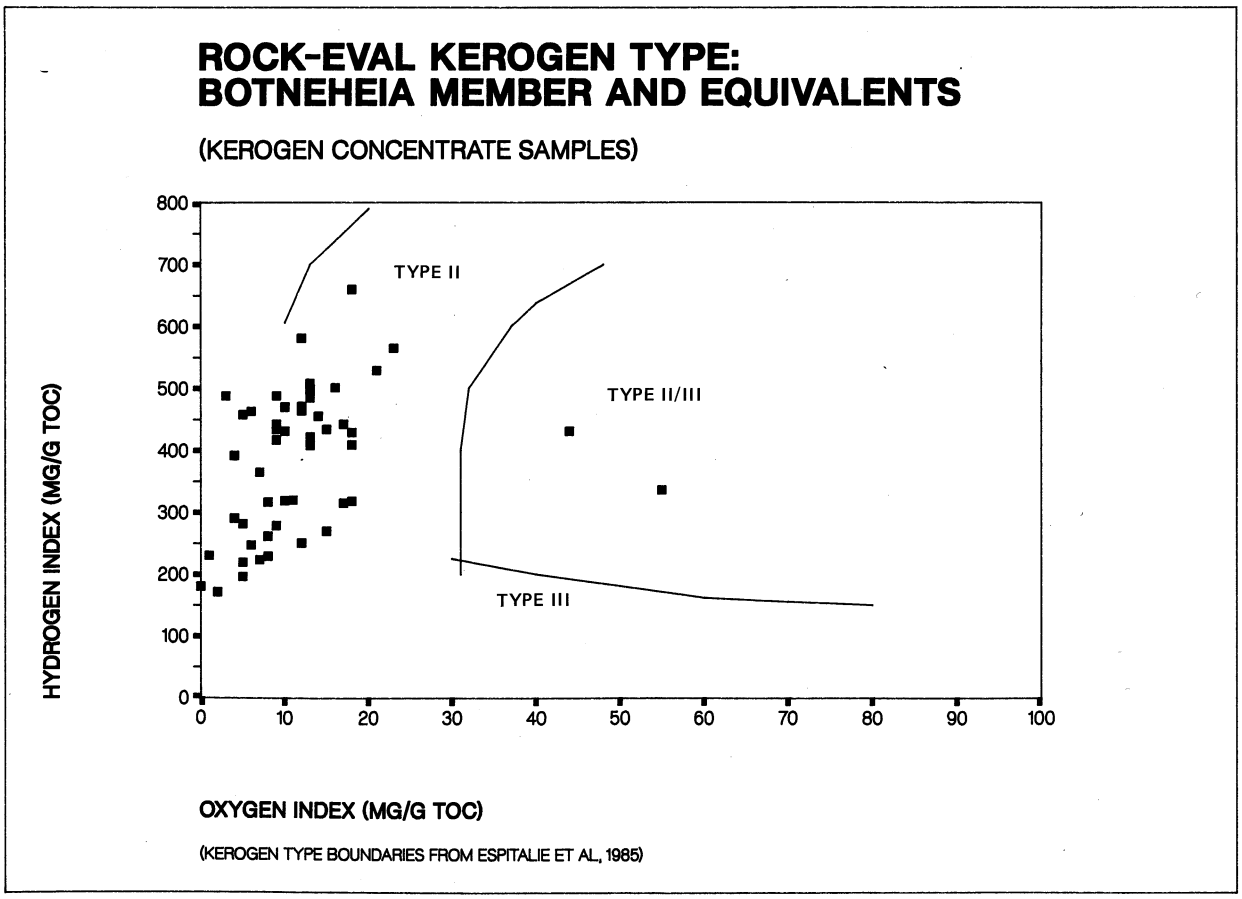

Figure 3.2.2.2b.

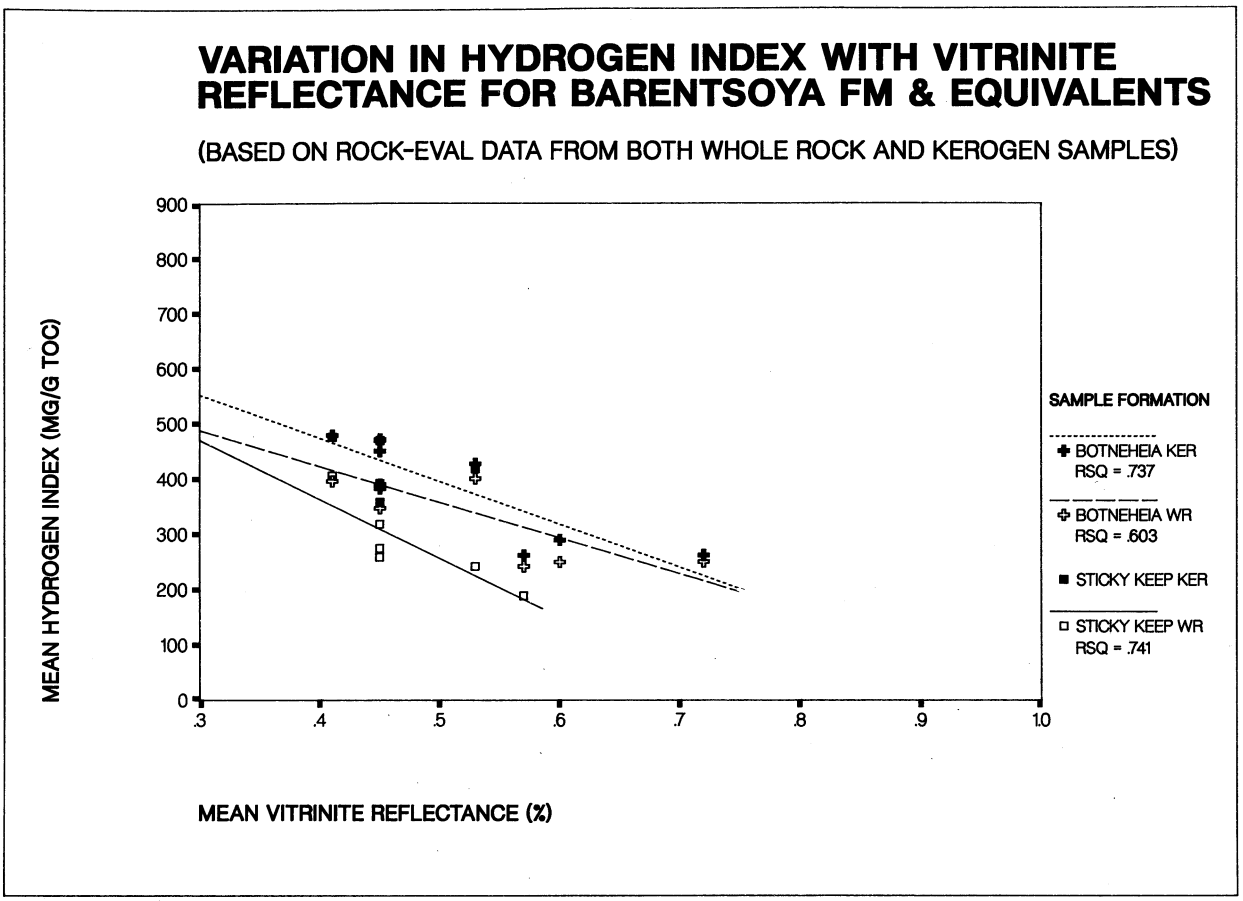

Figure 3.2.2.3a.

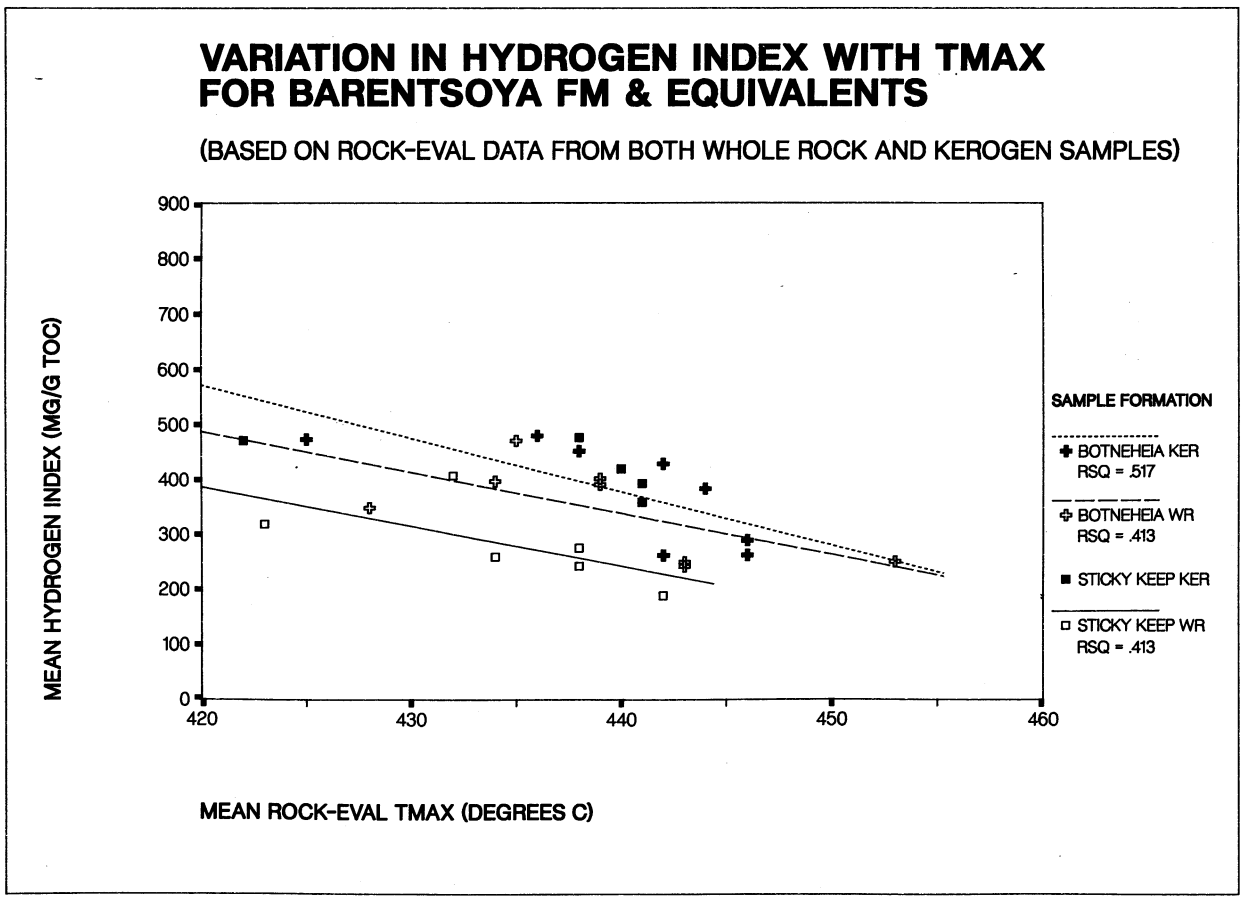

Figure 3.2.2.3b.

3.3 Extractable Organic Matter in the Triassic MSS of the Arctic

In the previous section of this discussion, it was noted that appreciable concentrations of extractable bitumen (EOM) are typically present in the Triassic organic-rich shales. The composition of this bitumen may provide an insight into variations in the source kerogen of the bitumen. Data on the bitumen or extractable organic matter (EOM) present in these rocks is available for most of the areas included in the study, although the quality of the data is variable. The most comprehensive data-set currently available to the study is from Svalbard and Dia-structure (Appendix A.1).

The highest mean EOM concentrations in the Barentsøya Formation are found in Edgeøya, Barentsøya and eastern Spitsbergen, where concentrations Of 2000 ppm to 5000 ppm are typical (Figure 3.3.1). The equivalent organic-rich shales of the Dia-structure succession show similar EOM concentrations (i.e. 3000 ppm-4000 ppm). There is a marked decrease in EOM concentration towards the west, the lowest concentrations typically being found in the rocks of the Vardebukta, Tvillingodden and Bravaisberget Formations (i.e. typically <1000 ppm). This variation may reflect the maturity trends in the Lower-Middle Triassic succession of Svalbard. In most localities, the concentrations of EOM in the rocks of the Sticky Keep and Botneheia Members are similar. EOM concentrations in the Deltadalen Member are typically at least 50 % lower. The concentration of EOM in the rocks of the Triassic succession is similar to that observed in the Deltadalen Member and the western Sassendalen Group (i.e. 1000 ppm).

Generally high mean extractabilities in the rocks of the Deltadalen and Sticky Keep Members (typically ca. 100 mg/g TOC and over) suggest that the EOM in these rocks may not be of wholly indigenous origin. This is especially true of the siltier rocks which comprise the Deltadalen Member. Extractabilities in the Botneheia Member are significantly lower than those in the underlying units and typically lie between 50 mg/g TOC and 80 mg/g TOC. There is relatively little variation in the extractability of the rocks of the Botneheia Member. Extractabilities in rocks of the western Sassendalen Group tend to be much lower than those of the eastern Barentsøya Formation (i.e. typically 5-25 mg/g TOC, with higher values in northern outcrop localities). Hydrocarbon compounds account for 40 % to 60 % of the EOM in all but the most immature outcrops of the Botneheia Member (i.e. Skrukkefjellet-Teistberget), where they account for only 20 % to 30 % of the EOM.

A similar pattern can be seen in the rocks of the Schei Point/Blaa Mountain Groups of the Sverdrup Basin. The shales in these groups tend to have lower extractabilities (60-75 mg/g TOC) than the siltstones and sandstones (75-105 mg/g TOC). Hydrocarbons typically account for 40-60 % of this EOM, with no significant differences between lithologies.

Extractabilities in the Dia-structure shales are more variable, with values of between 70 mg/g TOC to 120 mg/g TOC. The low percentage of hydrocarbon compounds (i.e. 20-25 %) in these shales suggest that the EOM is too immature to have migrated any great distance and is probably of indigenous or near-indigenous origin.

The EOM in the Triassic rocks on Bjørnøya are almost certainly of non-indigenous origin, based on high extractabilities of 80-120 mg/g TOC and the rather low organic carbon contents and hydrogen indices.

$\delta^{13}C$ data for the saturate and aromatic EOM fractions from the thermally immature organic-rich shales at Dia-structure (i.e. -33 to -31 °/oo) tend to be lower than the values for the saturate and aromatic EOM from the Botneheia Member on Svalbard (i.e. -32 to -30 °/oo). The isotopically heaviest values occur in the EOM fractions from the Roslagenfjellet locality (-30.0/-29.5 °/oo) of Spitsbergen. This variation in carbon isotope content appears to reflect changes in thermal maturity rather than any changes in kerogen type, the heaviest isotope values being associated with the most mature extract and vice versa. The generally light isotope values are consistent with extracts sourced from marine kerogen.

Saturated hydrocarbon gas chromatograms from rocks of the Barentsøya Formation tend to be similar in appearance and show a smooth, low molecular weight-biased n-alkane distribution (Figure 3.3.1). Similar n-alkane distributions have been reported for extracts from the Triassic succession in the Sverdrup Basin (Powell 1978; Brooks et al in press). Extract samples from the Deltadalen Member often show a secondary mode around the C_{27} n-alkane peak, which is only otherwise seen in extract samples from shales of the De Geerdalen Formation. A bias towards higher molecular weight hydrocarbons is sometimes seen in extracts from the Botneheia/Sticky Keep Members (e.g. Jinbreen, Stensiöfjellet, Vendomdalen), where it may reflect degradation or weathering.

Small "humps" of high molecular weight terpane and sterane compounds are seen in the less mature extracts from Edgeøya/Barentsøya and Dia-structure.

These are most prominent in the latter group of samples, although the n-alkane distributions are broadly similar in both groups.

Pristane and phytane isoprenoid peaks are very prominent in the extract samples from the Dia-structure succession (Figure 3.3.3). These peaks become less prominent in the extracts from Edgeøya/Barentsøya and are subordinate to the n-alkane peaks in extracts from sections in central and western Spitsbergen and the Urd Formation of Bjørnøya. There is little difference between the Botneheia and Sticky Keep Members within any one section, but differences are often observed between extracts from these two formations and those from the Deltadalen Member.

Pristane/phytane ratios for extracts from the Lower-Middle Triassic succession of Svalbard typically lie between 1.5 and 2.0, with little variation which can be attributed to variations in thermal maturity (Appendix A.1). Similar values are reported for extracts from the Triassic succession of the Sverdrup Basin (Powell 1978; Brooks et al in press). The lowest pristane/phytane ratio values are observed in extracts from the southernmost exposures of the Bravaisberget/Tvillingodden Formations and from the Triassic succession at Dia-structure (i.e. Pr/Ph = 0.9-1.5). The pristane/phytane ratio values are consistent with a source kerogen which was deposited under generally anoxic-dysoxic conditions on a marine shelf.

Variations between the isoprenoid composition of extracts from Dia-structure and Svalbard may be attributed to variations in thermal maturity, rather than variations in source kerogen depositional conditions. A change in kerogen type/depositional setting of the source kerogen may be necessary to explain the lower pristane/phytane ratios of of the more mature extracts from the southernmost exposures of the Bravaisberget/Tvillingodden Formations. The slightly lower pristane/phytane ratios from Dia-structure could reflect a higher microbial input/more anoxic conditions than occurred on Svalbard, although the kerogen data from these rocks do not really support this possibility.

The extracts from the upper Triassic succession differ in saturate composition from those of the lower-middle Triassic succession. Extracts from the Tschermaksfjellet Formation are similar to those from the immediately-underlying Botneheia Member. This is probably due to a degree of upwards migration from the Botneheia member. However, significant differences can be seen between extracts from Middle Triassic organic-rich shales and the extracts from the Ladinian/Karnian age Skuld Formation of Bjørnøya, the De

Geerdalen Formation of Svalbard and the Heiberg Formation of the Sverdrup Basin.

Although extracts from these units often show a generally low molecular weight-biased n-alkane distribution, they differ from the extracts of the underlying units in the occurrence of a "waxy" hydrocarbon component and a higher pristane/phytane ratio of greater than 2. These features probably reflect a greater terrestrial influence, which would be consistent with the depositional environment of these rocks.

Terpane and sterane biomarker data are largely confined to Svalbard and Dia-structure. Samples analysed by Bjorøy et al (1983) from Bjørnøya proved to have very low concentrations of high molecular weight compounds and the biomarker data were consequently poor.

Variations in the sterane geochemistry of the bitumens in the lower-middle Triassic succession of Svalbard/Dia-structure are largely attributable to variations in the thermal maturity of the bitumens. This is most evident in the near-absence of rearranged sterane compounds in the indigenous Dia-structure bitumens (Figure 3.3.4). These same compounds tend to dominate the more mature bitumens found on Svalbard (Figure 3.3.5).

The distribution of regular sterane compounds within the Svalbard/ Dia-structure bitumens shows relatively little variation (Figure 3.3.6). The C_{29} sterane tends to be slightly more prominent than the C_{27} sterane and is especially noticeable in the less mature Dia-structure samples. This is not inconsistent with a bitumen source in the marine phytoplankton-derived amorphous material found in these shales (Matsumoto et al 1982; Volkman 1986). The slight spread seen in the internal distribution of these compounds probably reflects a degree of cracking of the C_{29} sterane during thermal maturation. The general similarity of the sterane distributions is reflected in the near-constant value obtained for the ratio of the C_{27} and C_{29} regular steranes, which shows little variation with maturity (Figure 3.3.7).

The regular sterane compounds are thought to be directly related to the source kerogen of the bitumen (Huang and Meinschein 1979). The similarity in regular sterane composition exhibited in these samples is thought to indicate a similarity in the source kerogen of these bitumens. There is no consistent difference between the bitumen from the Botneheia Member and that from the Sticky Keep Member. Brooks et al (in press) report a similar

regular sterane distribution from Murray Harbour/Hoyle Bay Formations of the Sverdrup Basin. These authors also report the occurrence of C_{30} steranes, but these could not be recognised from the available data from Svalbard/Dia-structure.

Comparison of certain peak ratios with kerogen maturation data reveals a relationship between the maturity of the bitumen and the maturity of the kerogen in the enclosing rock (Figure 3.3.8). This correlation supports the short-range migration suggestion of Schou et al (1984), and tends to indicate that the migration pathways were very short indeed.

The distribution of terpenoid compounds in the EOM from the organic-rich shales of the Dia-structure indicates a lower thermal maturity than is evident from the EOM from any of the Triassic rocks on Svalbard (Figure 3.3.9). Moretane compounds are prominently developed in the bitumens from Dia-structure (Figure 3.3.10). These compounds are only poorly developed in all of the bitumens analysed from Svalbard. The tricyclic (C_{23}-C_{26}) diterpane compounds are either very poorly developed or absent in the bitumens from the Dia-structure succession, but are generally more prominent in the non-indigenous bitumens (Figure 3.3.10).

In contrast, tricyclic diterpane compounds are generally well-developed in the bitumens from the lower-middle Triassic succession on Svalbard (Figure 3.3.10). Tricyclic diterpane compounds are thought to be source, maturation and migration dependant (Moldowan et al 1983; Aquino Neto et al 1983). The development of these compounds in the Svalbard/Dia-structure bitumens shows a marked increase with increasing thermal maturity (Figure 3.3.11), but shows little variation within any one section, regardless of the lithology sampled. Brooks et al (in press) report significant tricyclic diterpane contents within bitumens from middle Triassic shales and oils from the Sverdrup Basin, attributing these to a microbial input but also recognising a relationship with maturation.

Bisnorhopane is recognised in indigenous bitumen from core 7323/7-U-1 and non-indigenous bitumens from cores 7323/7-U-6, U-3 and U-9 at Dia-structure. This compound is not recognised from Svalbard bitumens with the possible exception of some very poorly-developed peaks in bitumens from Veidemannen/Veidebreen on Edgeøya. In addition, the unidentified compound "X" is observed (Figure 3.3.10) in nearly all Svalbard bitumens with no apparent relation to maturity, but is absent from the Dia-structure bitumens. A tentatively-identified gammacerane peak (I) is present in all of the Sval-

bard/Dia-structure samples.

Artificial maturation of representative shale samples from Dia-structure and Blanknuten on Edgeøya produced nearly identical artificial oils, which were similar in composition to the most mature bitumens recovered from lower-middle Triassic rocks on Svalbard (Figure 3.3.6).

The biomarker data suggest that the kerogen in the MSS deposited in the western Barents Shelf and the Sverdrup Basin was largely similar in composition from Smithian to Karnian times. This kerogen was deposited under marine conditions and was probably largely derived from phytoplankton and algal material. Some contribution from microbial debris may be present.

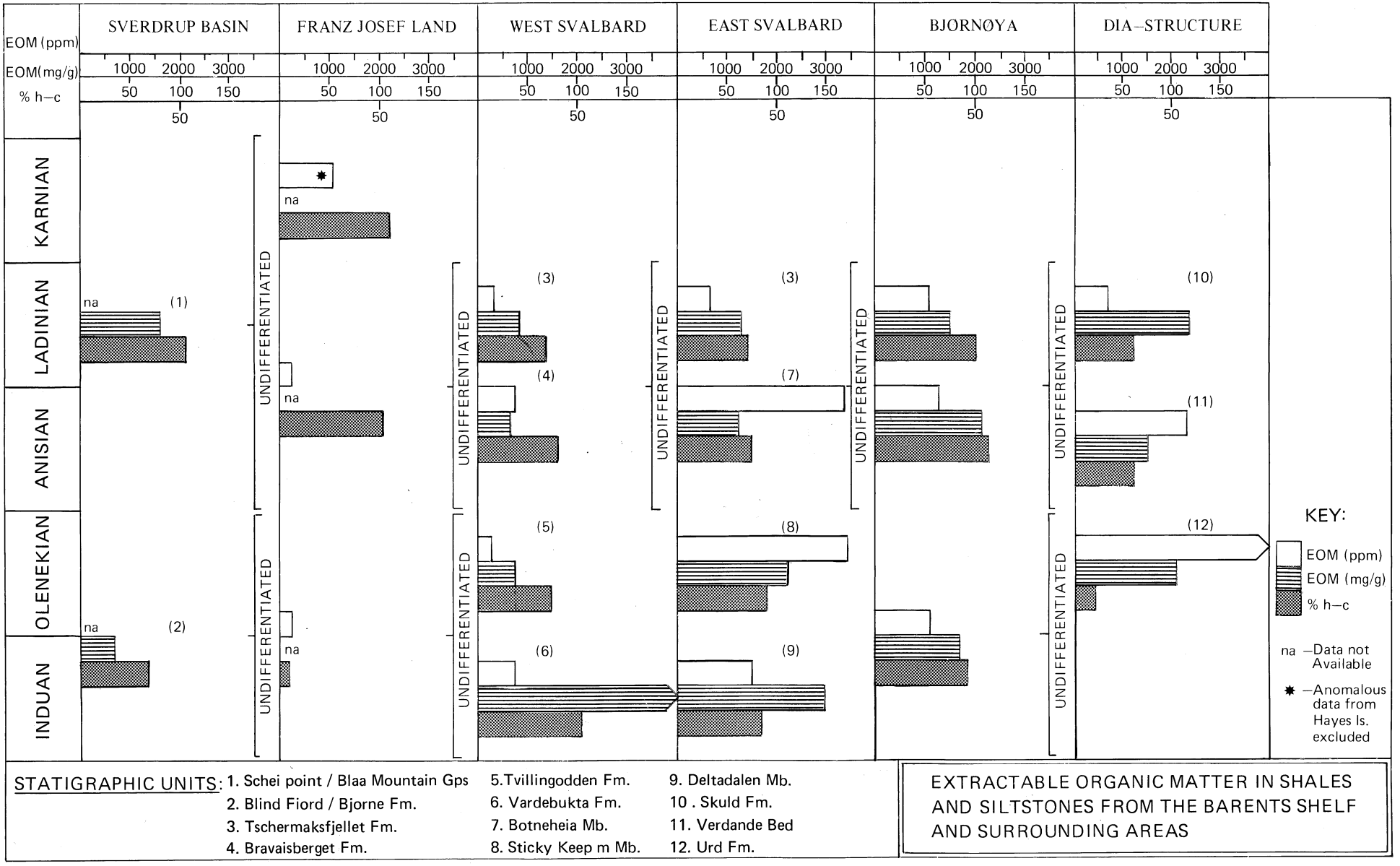

Figure 3.3.1.

IKU SINTEF-GRUPPEN

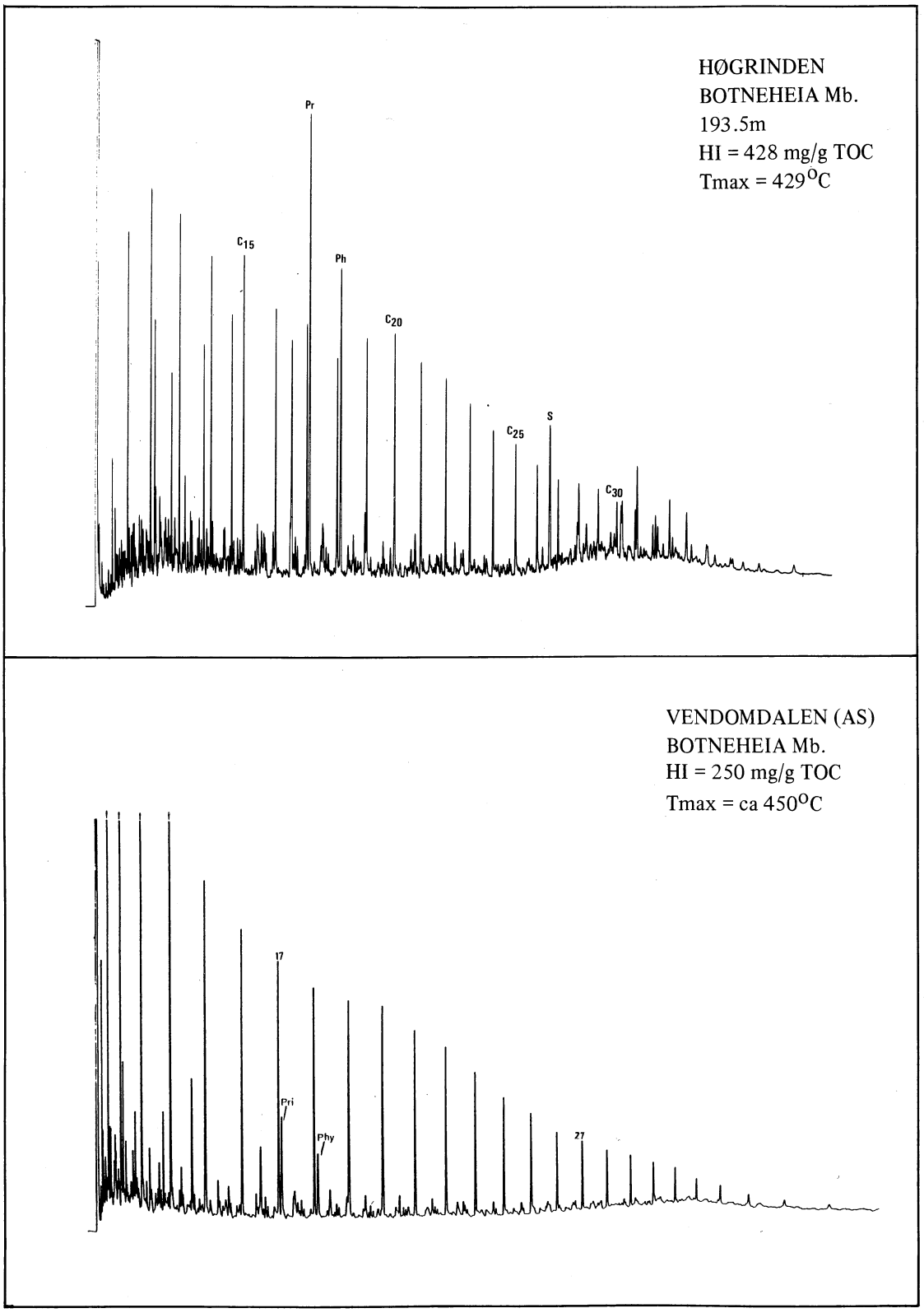

Figure 3.3.2. Typical saturated hydrocarbon gas chromatograms of bitumens from rocks of the Botneheia Member in Svalbard.

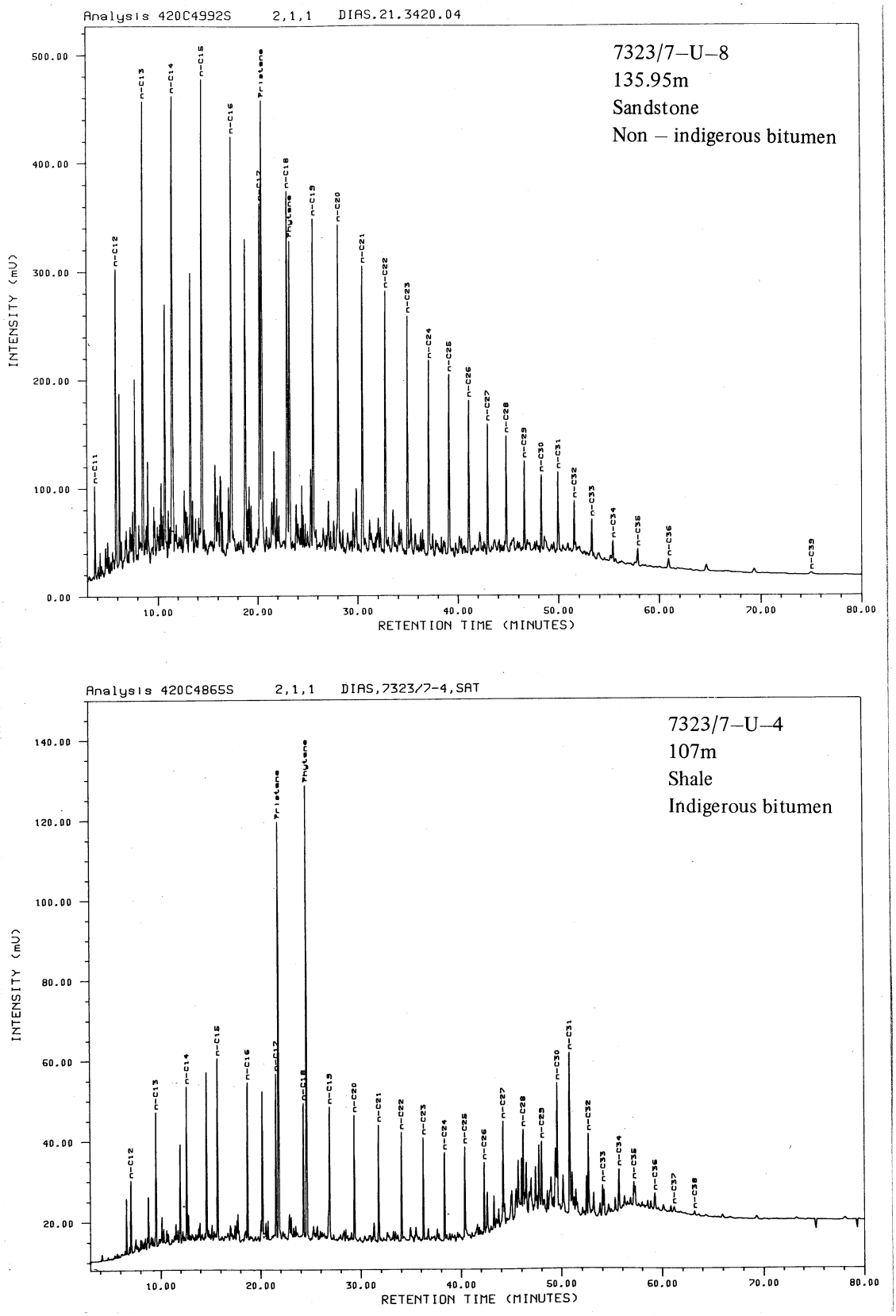

Figure 3.3.3. Typical saturated hydrocarbon gas chromatograms of indigenous and non-indigenous bitumens from rocks of the Triassic succession at Diastructure.

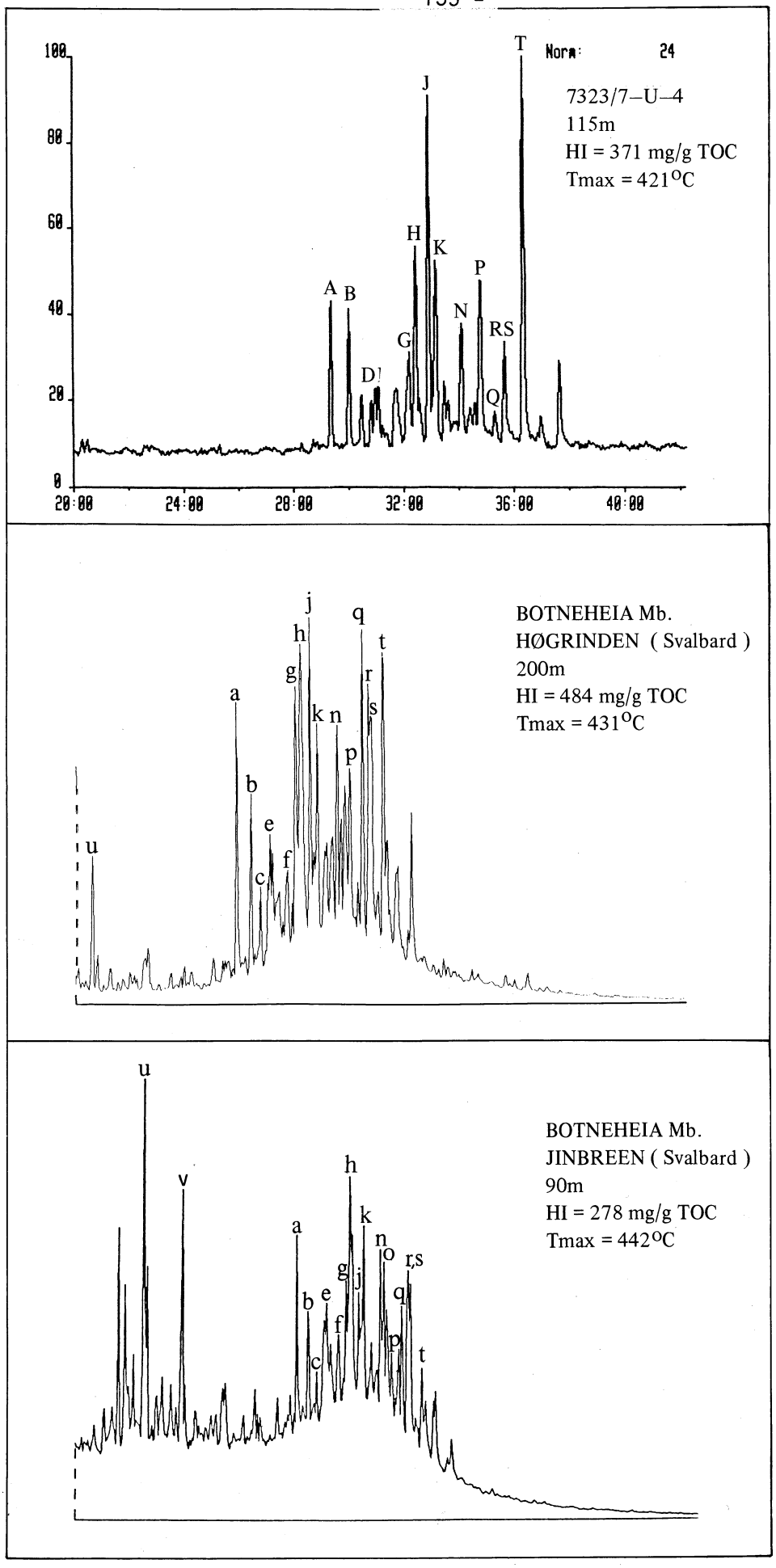

Figure 3.3.4. Typical sterane (m/z 217) mass fragmentogrmas from lower and middle Triassic strata at Dia-structure and on Svalbard.

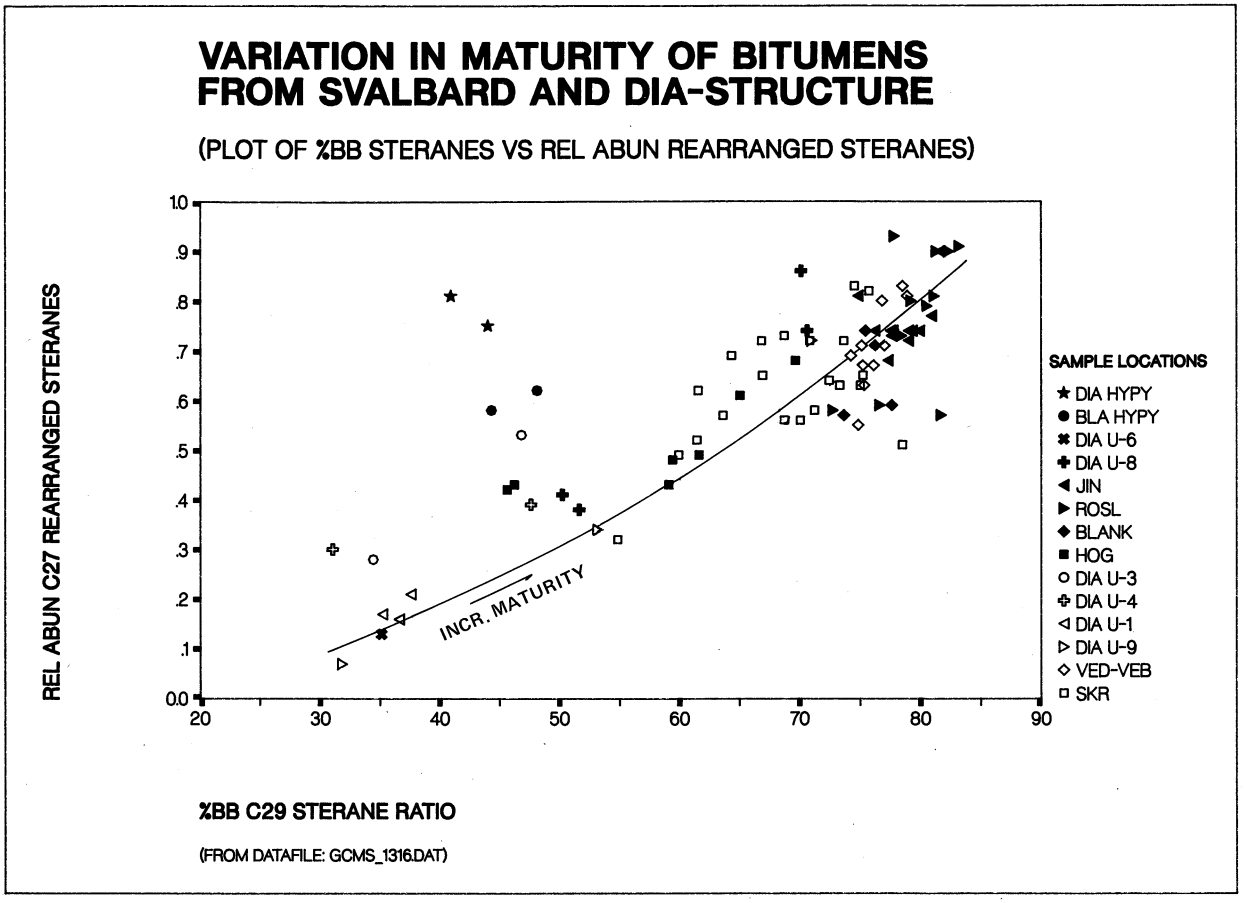

Figure 3.3.5a.

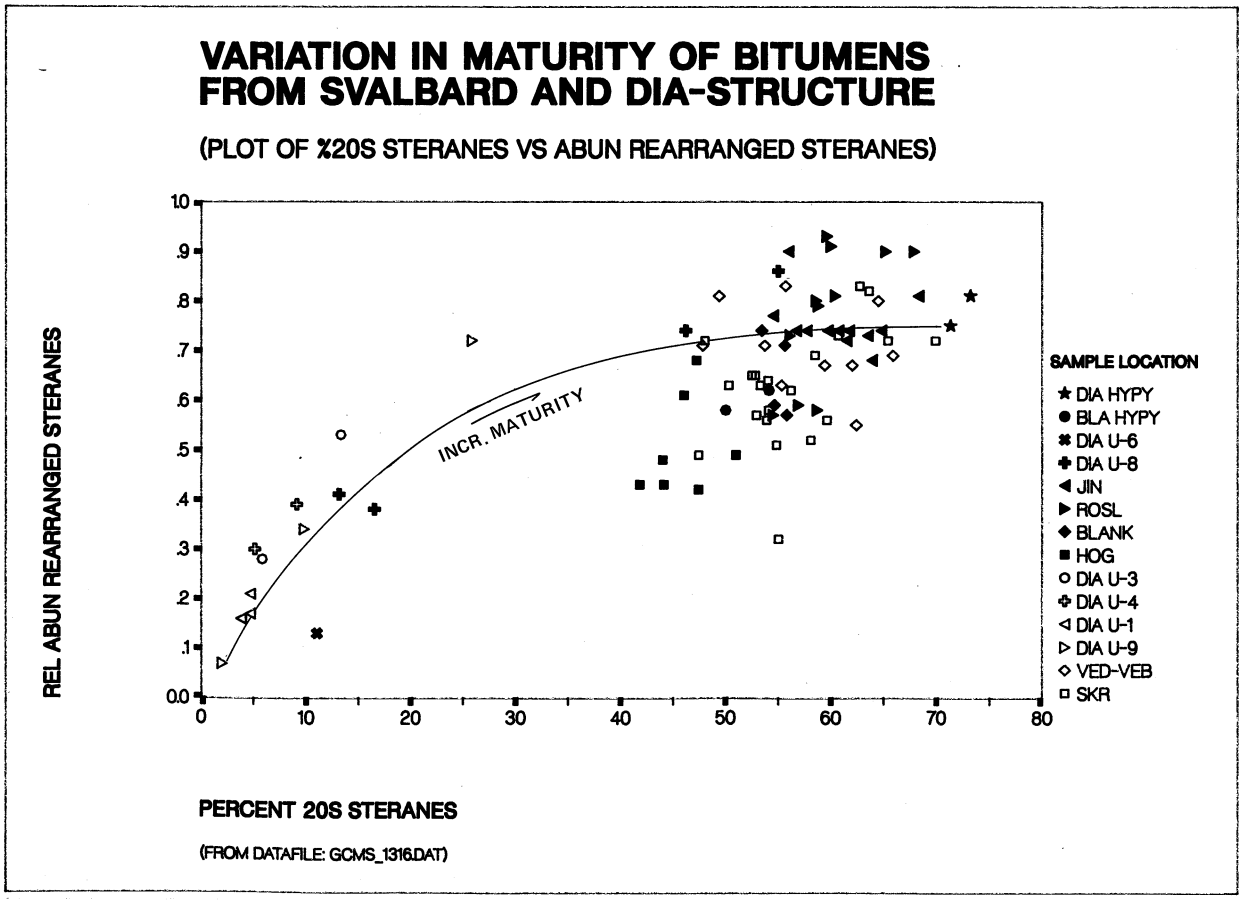

Figure 3.3.5b.

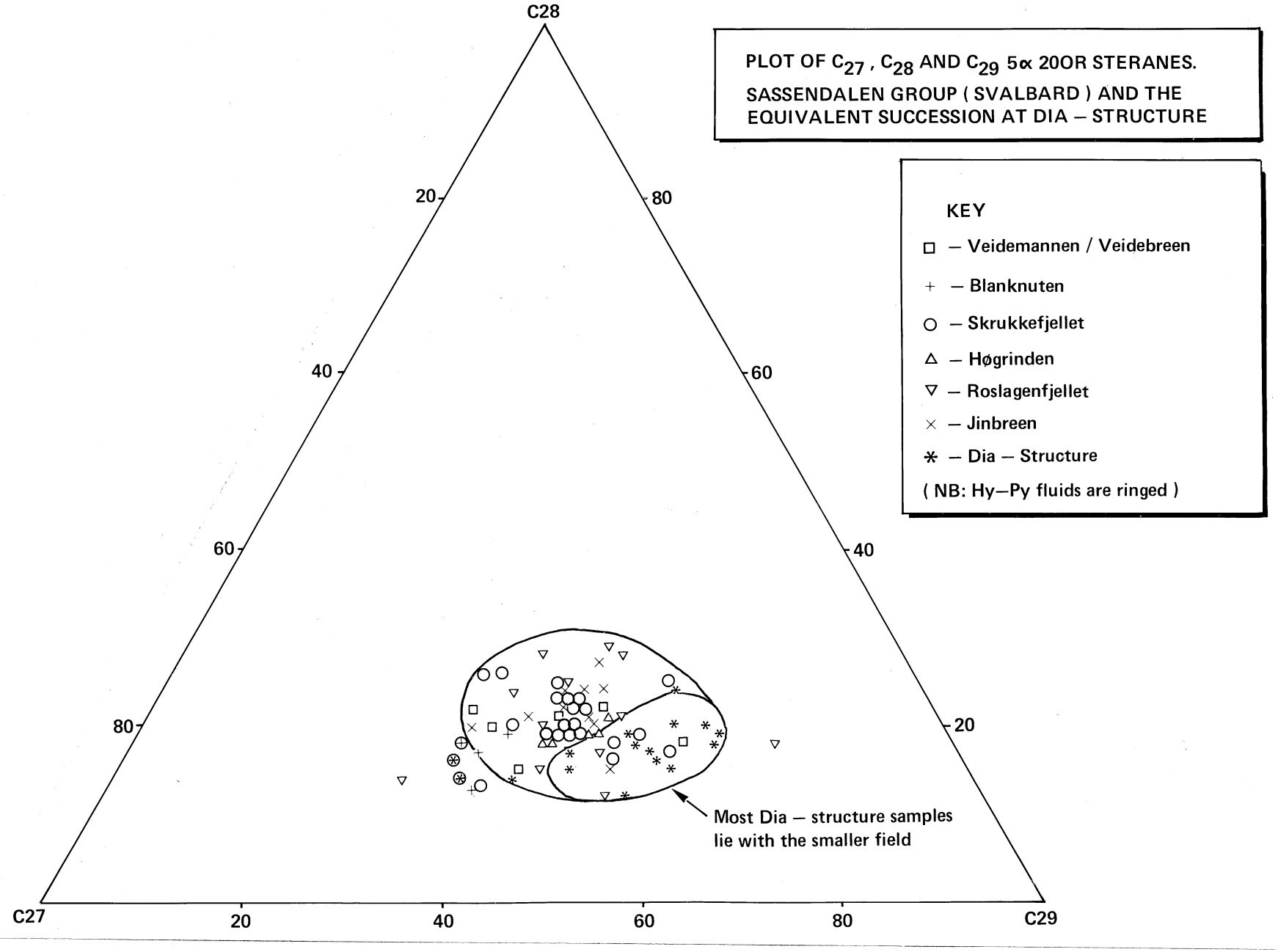

Figure 3.3.6.

IKU SINTEF-GRUPPEN

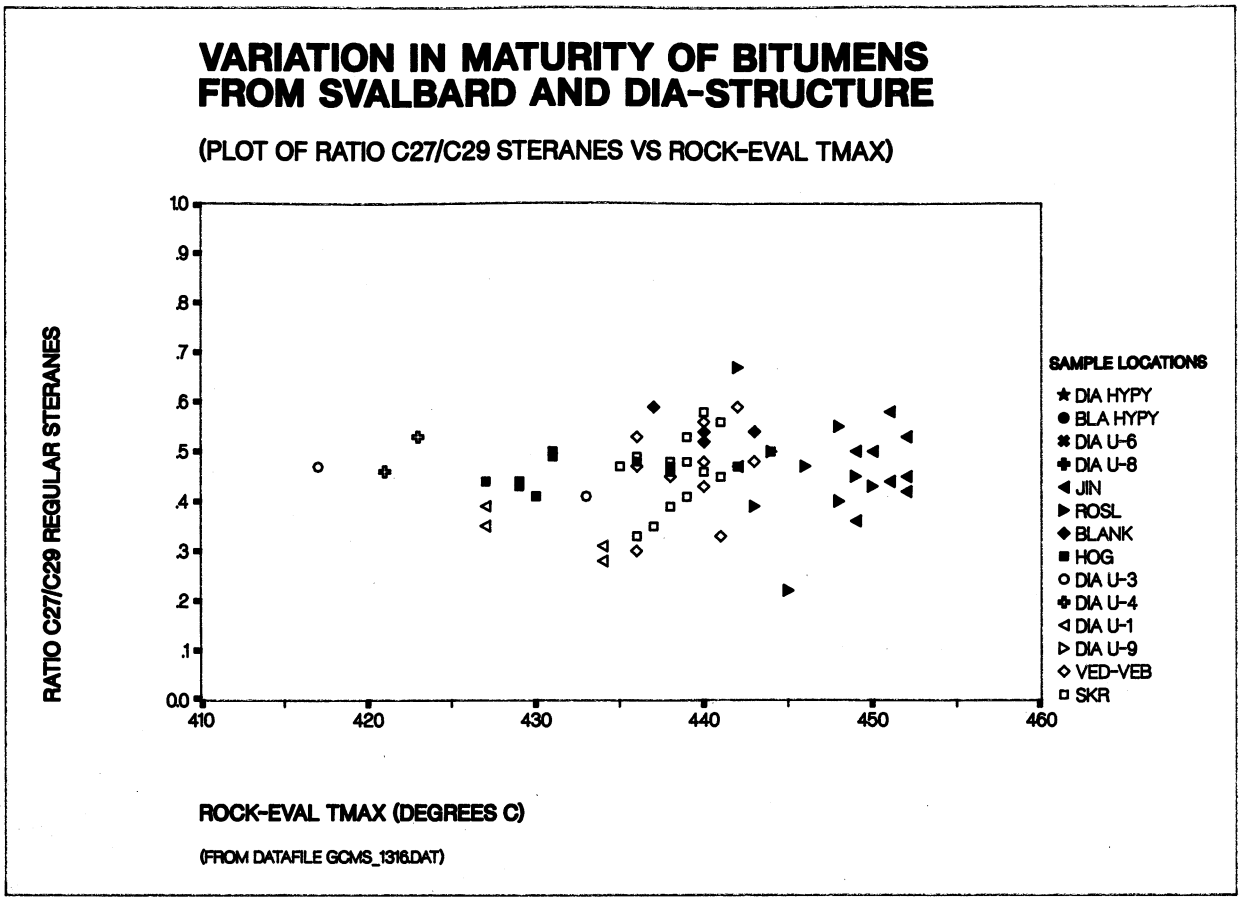
VARIATION IN MATURITY OF BITUMENS
FROM SVALBARD AND DIA-STRUCTURE
(PLOT OF RATIO C27/C29 STERANES VS ROCK-EVAL TMAX)
RATIO C27/C29 REGULAR STERANES
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
410
420
430
440
450
460
ROCK-EVAL TMAX (DEGREES C)
(FROM DATAFILE GCMS_1316.DAT)
SAMPLE LOCATIONS
DIA HYPY
BLA HYPY
DIA U-6
DIA U-8
JIN
ROSL
BLANK
HOG
DIA U-3
DIA U-4
DIA U-1
DIA U-9
VED-VEB
SKR

Figure 3.3.7.

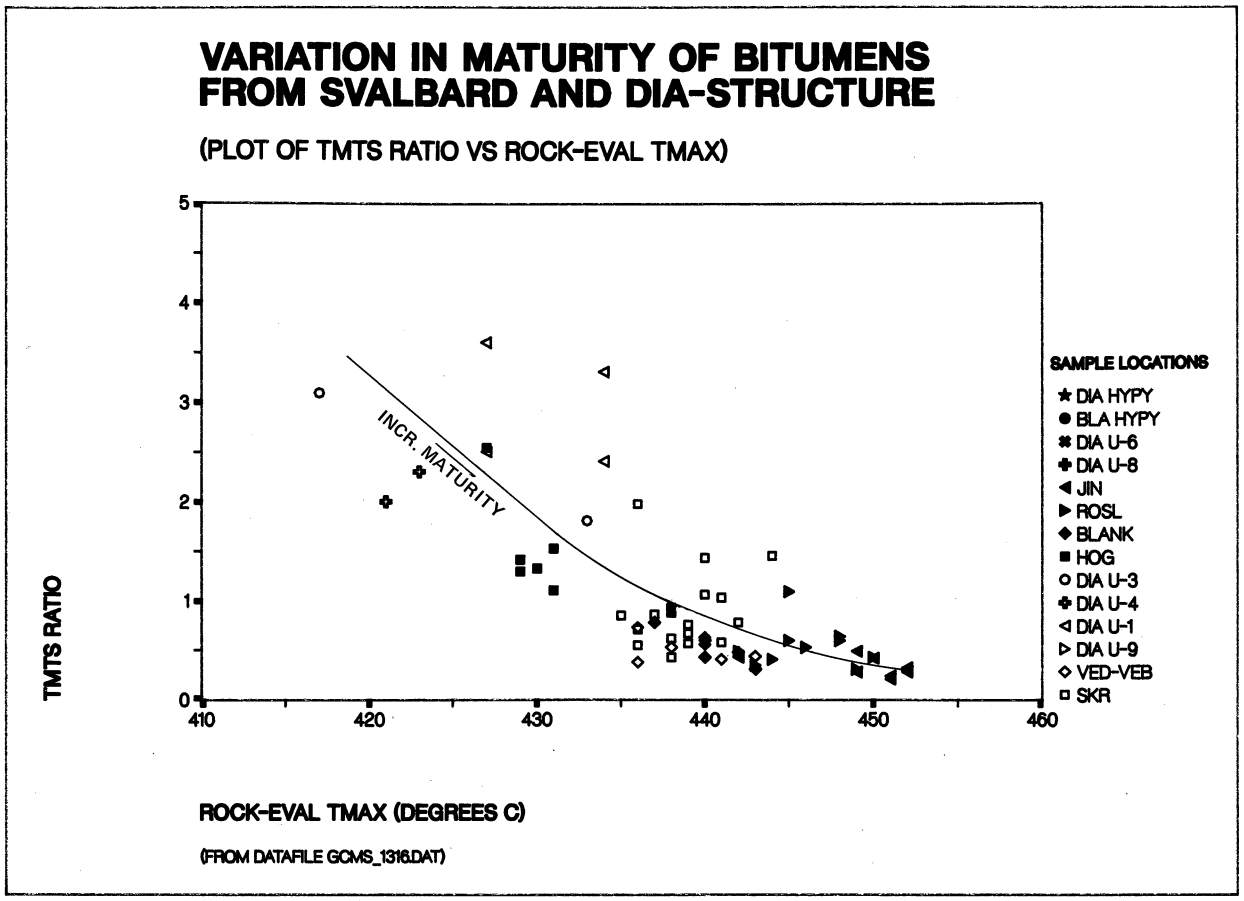

Figure 3.3.8a.

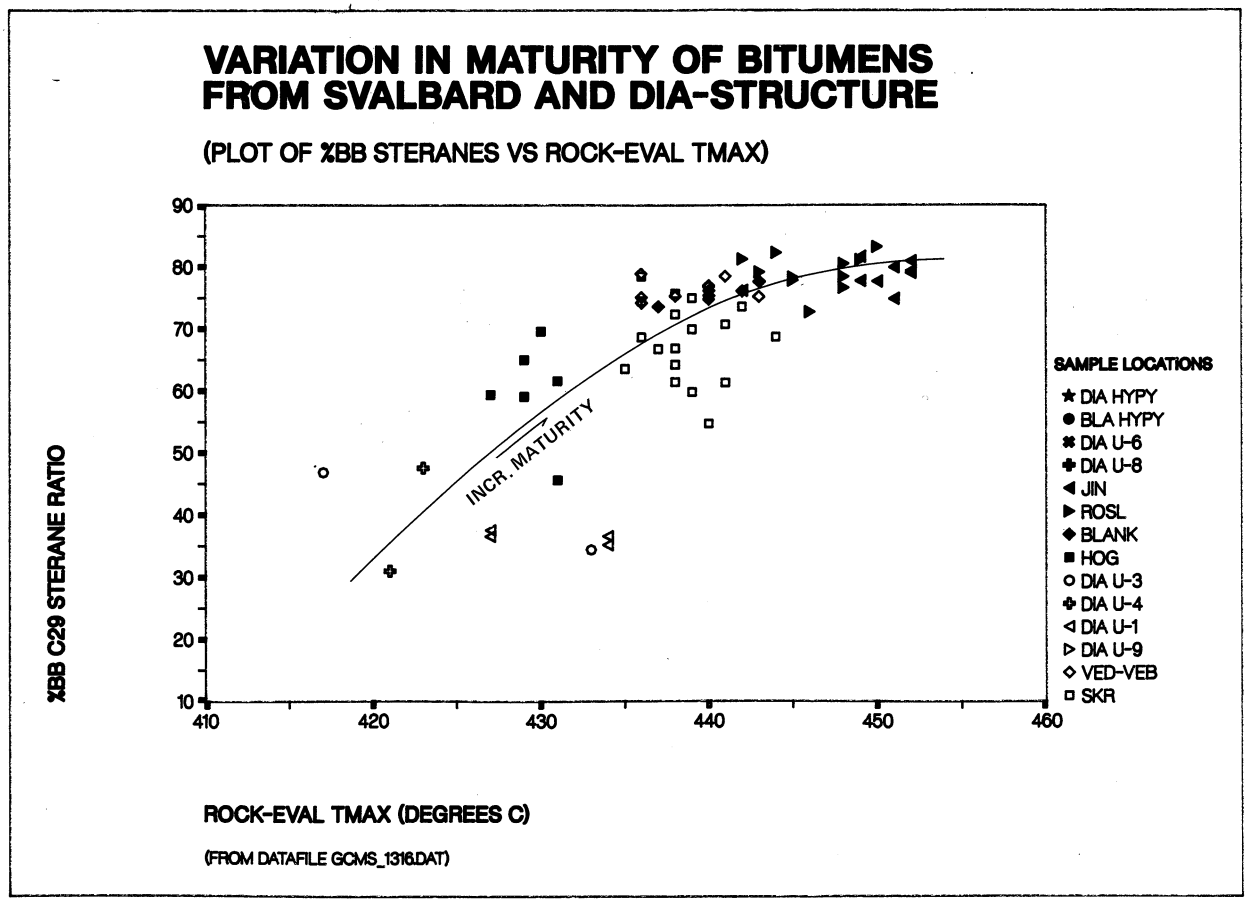

Figure 3.3.8b.

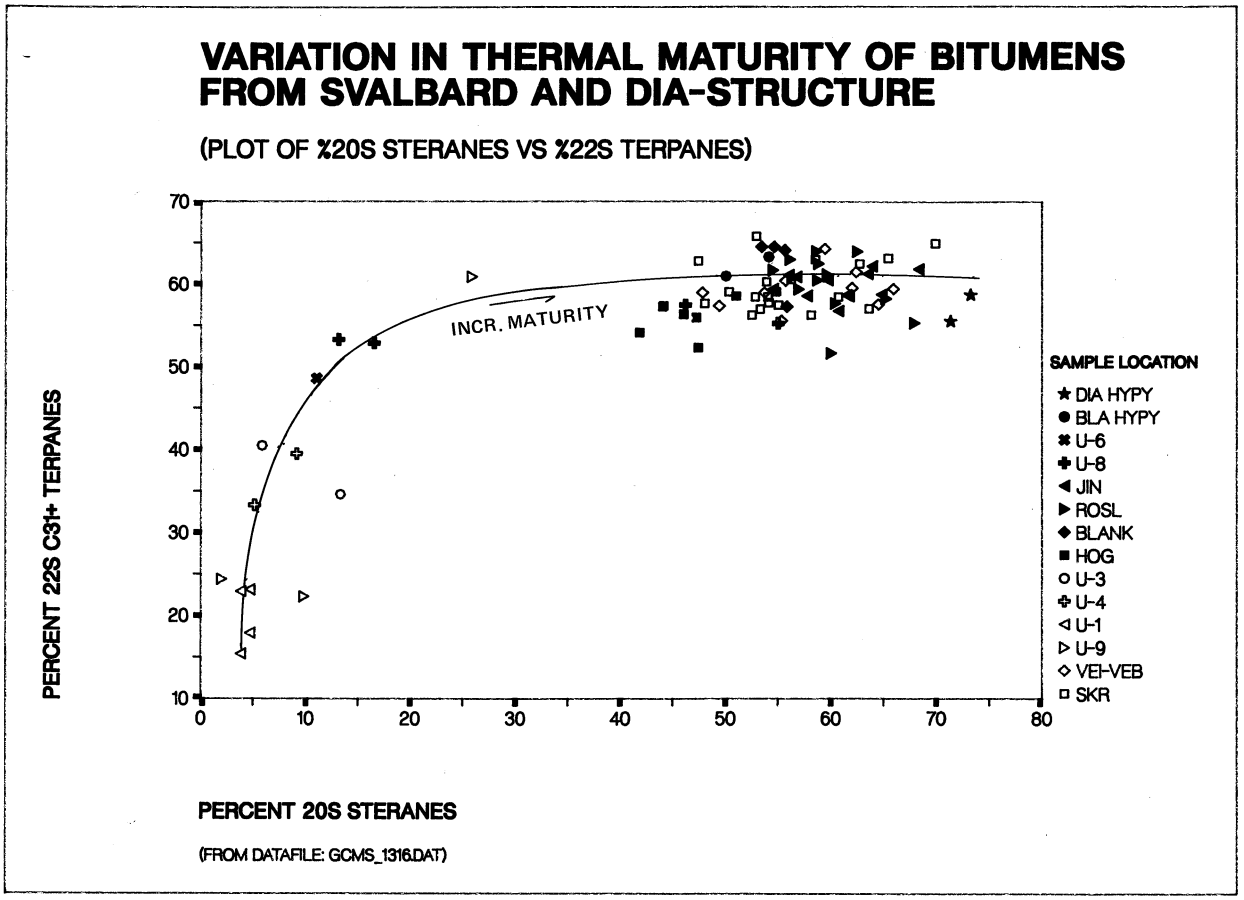
VARIATION IN THERMAL MATURITY OF BITUMENS FROM SVALBARD AND DIA-STRUCTURE
(PLOT OF %20S STERANES VS %22S TERPANES)
PERCENT 22S C31+ TERPANES
PERCENT 20S STERANES
(FROM DATAFILE: GCMS_1316.DAT)
INCR. MATURITY
SAMPLE LOCATION
DIA HYPY
BLA HYPY
U-6
U-8
JIN
ROSL
BLANK
HOG
U-3
U-4
U-1
U-9
VEI-VEB
SKR

Figure 3.3.9.

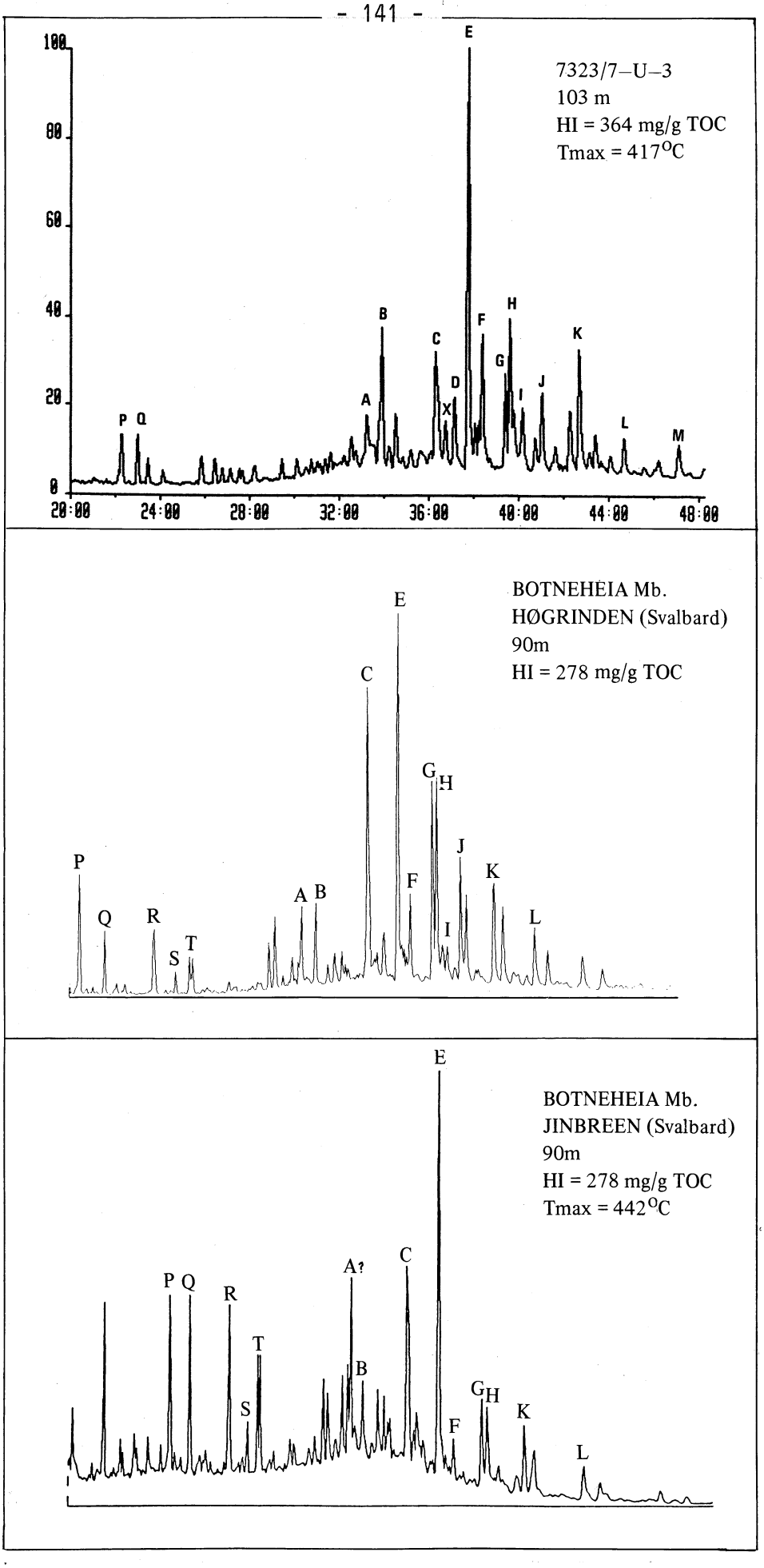

Figure 3.3.10. Typical terpane (m/z 191) mass fragmentograms from lower and middle Triassic strata at Dia-structure and on Svalbard.

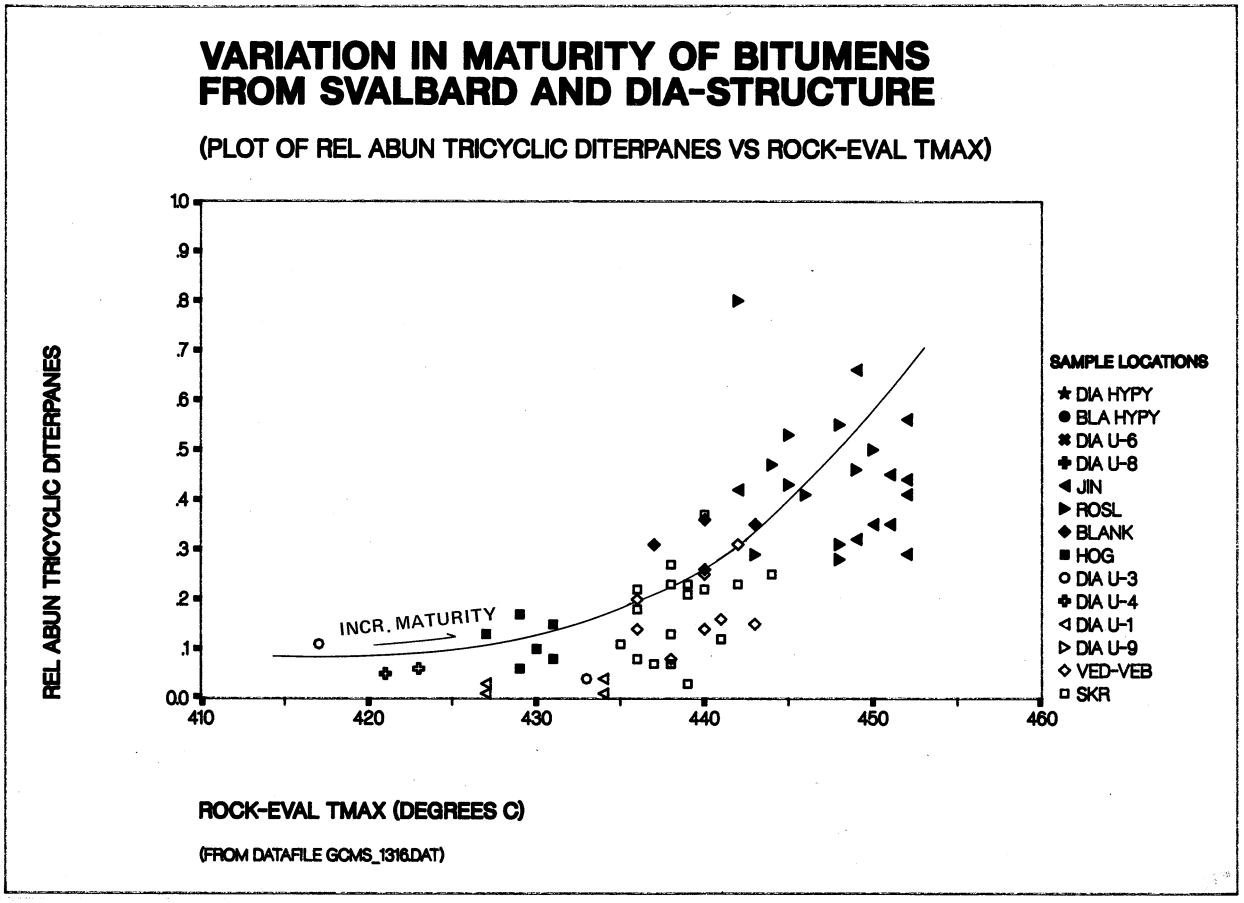

Figure 3.3.11a.

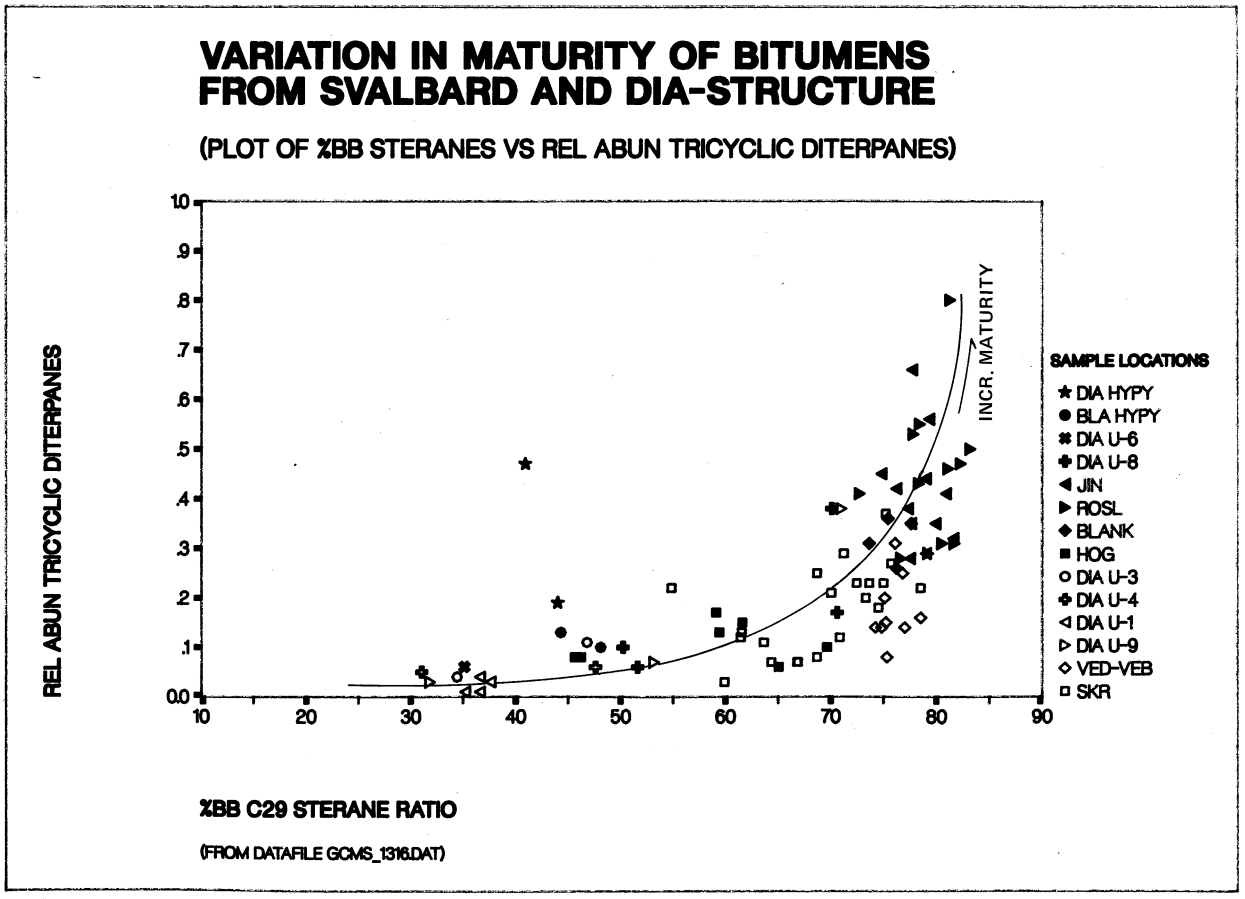

Figure 3.3.11b.

3.4 Regional Implications for Deposition of Organic-rich Shales during the Triassic

The distribution of marine shales in the study area, and especially MSS, shows a distinct pattern through the Triassic. The area affected by marine shale/mudstone deposition reaches its maximum extent in middle Triassic times and then decreases, until at the end of the Karnian, marine shale deposition effectively ceased over most of the area.

Deposition and preservation of significant quantities of organic matter seems to occur earliest in the western Barents Shelf area. The highest kerogen content and quality at this time appears to have occurred immediately to the east of the Stappen High - Loppa High area, as represented by the succession at Dia- structure, during late Early Triassic times. During the middle Triassic, deposition of MSS reached its maximum extent, and extended northwards and westwards towards Svalbard, the Sverdrup Basin and Alaska. Fluvio-deltaic clastic deposition affected the eastern areas of the Barents Shelf at this time, possibly east of a roughly north-south line 200-300 km east of Svalbard (Rønnevik 1981).

During Karnian/Norian times, there was a decrease in the area affected by deposition of MSS, such rocks only occurring in the Sverdrup Basin and the southernmost Barents Shelf. The decrease in the occurrence of these rocks in eastern parts of the study area may reflect the increasing influence of the Uralian Orogeny as a clastic sediment source. By Norian-Rhaetian times, fluvio-deltaic sedimentation had become established over most of the study area.

Organic geochemical data suggest that the kerogen present in the organic-rich rocks (MSS) deposited during Smithian to Karnian times in the western Barents Shelf and the Sverdrup Basin is basically similar in composition. This kerogen consists predominantly of sapropelised marine phytoplankton and algal debris. Small amounts of terrestrial debris only occur in more proximal locations (e.g. Dia-structure, western Spitsbergen). The organic-rich shales of the Sverdrup Basin tend to show more evidence of terrestrial influence than is seen in the organic-rich shales of the Barents Shelf.

Some minor differences are observed between the kerogen in the Dia-structure succession and that in the equivalent Svalbard succession which do not appear to be due to variations in thermal maturity. This is reflected in the higher aliphaticity of the kerogen in the eastern part of Svalbard

(Edgeøya and Barentsøya). This increased aliphaticity may reflect the presence of larger amounts of algal material in the eastern Svalbard succession. Alternatively, it could reflect the slightly higher content of terrestrial kerogen in the Dia-structure shales. Bulk organic geochemical data suggest that the Smithian-Anisian age shales of the Dia-structure area are more similar to the shales of the Sticky Keep Member than the shales of the Botneheia Member.

The higher degree of variability in the organic richness/kerogen type of the Anisian-age Dia-structure shales suggests that conditions conducive to the accumulation of hydrogen-rich kerogen were less firmly established than in Svalbard over this period of time. There is no evidence for connection of the various organic-rich shale occurrences during deposition, although there is strong evidence from Svalbard that local shelf-floor topographic features were important for organic matter preservation. Sedimentological evidence suggests a tendency for anoxic/dysoxic conditions to become less common in the Dia-structure area towards Ladinian times. The opposite is seen in Svalbard where anoxia/dysoxia seems to have become more firmly developed during late Anisian-Ladinian times in central and eastern Svalbard. This observation could also reflect the less complete sampling of the Dia-structure succession.

The occurrence of periodic ventilation events during the deposition of the organic-rich middle Triassic shales is suggested by the presence of thin siltstone beds with evidence of storm-influence and the presence of Thalassinoides trace-fossils (Mørk pers comm; Vigran et al 1986). During these events, oxygenated waters would have been supplied to the previously anoxic/dysoxic areas of the sea-floor, and preservation of organic debris would be consequently reduced. In addition, these events may have lead to the disruption of any upwelling currents which existed. The presence of certain trace fossils under apparently anoxic conditions can also be explained by the "exaerobic zone" of Savrda and Bottjer (1987). This zone may become established when the anaerobic/aerobic interface coincides with the sediment/water interface.

Comparison of models for the deposition of organic-rich rocks proposed by Demaison and Moore (1980), Stein (1986) and Hallam (1987) indicate an epicontinental sea model for the Western Barents Shelf. Isotopic data suggests that this sea was unlikely to have exceeded 200 m depth and had probably developed a stratified water column which would have permitted the operation of upwelling currents. Hallam (1987) has suggested that in shallow

epicontinental seas, slight topographic features can have a disproportionate effect on restriction of water circulation. Therefore, the topographic features postulated on Svalbard need only have been of the order of 10-50 m. Parrish (1982) has suggested that upwelling currents can be established in relatively shallow waters, a minimum depth of 50 m being suggested.

Parrish and Curtis (1982) have postulated a seasonal oceanic-divergence upwelling current in the Arctic basin area during Early Triassic times, based on palaeo-climatology. This would not have influenced the organic matter content of the shales deposited at this time as the organic matter produced in these currents does not generally survive long transport. A coastal upwelling current is postulated to have developed in the North American-Barents Shelf area by Pliensbachian times, although it is not certain if this was established during middle Triassic times. Geological evidence suggests that it may have been. Widespread deltaic progradation during late Triassic times would tend to disrupt any upwelling current system during this period.

Preliminary palaeo-productivity calculations based on the method of Stein (1986) yielded values of between 200 and 400 gC m^{-2} y^{-1} for the Smithian-Spathian age shales of the Dia-structure and the Sticky Keep Member. Similar values are typical of areas affected by upwelling current systems at the present day (Brooks et al 1987).

It is unlikely that anoxia/dysoxia in the Barents Shelf area became established due to a high input of terrestrial organic matter from the flanking deltaic systems. If such a mechanism had operated, then evidence of significant terrestrial organic matter input would be expected. This is not seen in the shales of the Sticky Keep and Botneheia Members and their equivalents. This mechanism may, however, be partially applicable to the Sverdup Basin.

It is difficult to make any detailed organic geochemical comparisons for the organic-rich Triassic shales, between the Sverdrup Basin and the Barents Shelf due to a lack of data. An epicontinental sea model may not be applicable to the Sverdrup Basin, as this basin is thought to have been quite deep during most of the Triassic (Balkwill and Fox 1982). The occurrence of organic-rich rocks in the Hoyle Bay Formation suggests that organic matter was being preserved up to the end of the Karnian. Whether this occurrence suggests that upwelling currents persisted in this area later than in the Barents Shelf, or that conditions conducive to organic matter

preservation were obtained by the input of organic matter from marginal delta systems cannot be resolved at this time. The lack of organic-rich rocks of this age in the western Barents Shelf probably reflects the increasing influence of eastern sediment sources during this time.

Accumulation of the organic-rich Smithian-Ladinian age shales of the Barents Shelf is thought to have occurred in a shallow epicontinental sea. The accumulation and preservation of organic matter was probably influenced by juxta-position of an upwelling current system, sea-floor topography and a relatively low sediment supply. Conditions conductive to the preservation of organic matter were maintained in the Sverdrup Basin until Karnian times.

4. CONCLUSIONS

* Deposition of marine shales (MSS) containing ca. 2-10% organic carbon began during Late Early Triassic times in the western Barents Shelf. The area affected by the deposition of these organic-rich marine shales reached a maximum in Middle Triassic times. By Early Late Triassic times, MSS were only being deposited in the Sverdrup Basin.

* Shales (MSS) deposited during Late Early Triassic times appear to be less organic-rich than those deposited during Middle Triassic times.

* The early and middle Triassic organic-rich shales of the Barents Shelf contain kerogen which shows little variation in physical and chemical characteristics. Variations in maturation level account for most of the variations observed in the chemical character of the kerogen. A slightly higher input of terrestrial material in the Dia-structure shales explains the slight difference between the kerogen in these shales and that from rocks of the equivalent Barentsøya Formation of Svalbard.

* The organic matter in the organic-rich shales of the Sverdrup Basin appears to be more terrestrially-influenced than that in the equivalent shales of the Barents Shelf.

* Deposition of organic-rich marine shales during the Triassic in the Barents Shelf area seems to have occurred in a shallow epi-continental sea (<200 m deep). Accumulation of organic matter was probably controlled by a juxta-position of an upwelling current system and sea-floor topography, the most organic-rich rocks being deposited in shallow depressions.

* Bitumen from organic-rich Triassic shales appears to be rather similar in composition and variations in composition may be explained by variations in thermal maturity. This bitumen has most probably been sourced from marine organic matter such as is found in the organic-rich shales.

* Evidence of both short-distance and longer-distance migration is seen both on Svalbard and at the Dia-structure.

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APPENDIX A.1
SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR THE SASSENDALEN GROUP AND KAPP TOSCANA GROUP

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ARGILLACEOUS ROCKS OF THE SASSENDALEN GROUP OF SVALBARD

(A.1.1: Botneheia Mbr/Bravaisberget Fm.)

	ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
	MEAN	MEAN	MEAN	MEAN	MEAN	Mean		MEAN	MEAN	MEAN
LOCALITY	TOC	H.I.	O.I.	TMAX	V.R.	Concentration		HC	PrPh	$PrnC_{17}$
NAME	(wt%)	(mg/g TOC)	(mg/g TOC)	(°C)	(%)	(ppm)	(mg/g TOC)	(%)		
Veidemannen	4.8	391	17	439	0.45	4300	78.7	59.4	1.9	0.8
Blanknuten	4.5	282	29	439	na	2245	58.0	47.7	1.9	0.8
Pistra	4.4	288	36	437	na	3761	88.9	35.1	na	na
K Peuchel Löche	1.2	104	44	440	na	na	na	na	na	na
Skrukkefjellet	6.6	402	17	438	0.53	4606	69.7	37.4	1.9	1.1
Høgrinden	6.0	434	19	434	0.46	3420	61.4	30.4	1.9	1.3
Lomberget	4.3	397	25	434	0.41	2940	54.3	30.5	1.6	1.4
Kvitberget	4.3	384	27	434	na	na	na	na	na	na
Torellnesfj.	4.1	628	8	446	na	na	na	na	na	na
Teistberget	7.0	471	31	435	0.45	5993	59.3	27.9	2.1	1.1
Roslagenfjellet	5.7	268	32	445	0.53	3205	61.8	43.4	1.7	0.9
Krapotkinfj.	5.7	253	13	449	0.72	3261	69.5	44.4	2.1	0.4

na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ARGILLACEOUS ROCKS OF THE SASSENDALEN GROUP OF SVALBARD

(A.1.1: Botneheia Mbr/Bravaisberget Fm.)

(Cont'd)

	ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
LOCALITY NAME	MEAN TOC (wt%)	MEAN H.I. (mg/g TOC)	MEAN O.I. (mg/g TOC)	MEAN TMAX (°C)	MEAN V.R. (%)	Mean Concentration (ppm)	Mean Concentration (mg/g TOC)	MEAN HC (%)	MEAN PrPh	MEAN $PrnC_{17}$
Stensiöfjellet	4.3	339	72	438	0.49	3113	75.7	41.5	1.8	1.2
Jinbreen	4.7	302	10	450	0.57	3293	73.4	41.2	1.8	0.5
Vendomdalen	4.6	251	31	443	0.60	3049	65.7	44.1	1.7	0.6
Sticky Keep	4.1	259	192	440	na	2934	70.9	47.5	1.9	1.1
Vikinghøgda	6.5	343	70	438	na	3727	56.6	39.5	2.0	0.8
Botneheia	5.1	247	22	443	0.57	2701	49.9	23.8	1.8	0.4
Tschermaksfj.	4.1	291	54	438	0.52	2065	51.0	16.8	1.9	1.1
Bertilryggen	4.8	428	16	438	na	2386	57.8	48.8	na	na
Labben	2.3	143	27	446	na	1371	59.2	54.7	na	na
Selmaneset	4.4	93	48	444	na	1458	36.5	24.9	1.7	0.6
Festningen	2.1	158	47	451	0.89	1520	77.7	53.6	1.6	0.5
Bravaisberget	1.9	54	70	457	0.87	1164	64.2	51.5	1.7	0.3

na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ARGILLACEOUS ROCKS OF THE SASSENDALEN GROUP OF SVALBARD

(A.1.1: Botneheia Mbr/Bravaisberget Fm.)

(Cont'd)

	ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
LOCALITY NAME	MEAN TOC (wt%)	MEAN H.I. (mg/g TOC)	MEAN O.I. (mg/g TOC)	MEAN TMAX (°C)	MEAN V.R. (%)	Mean Concentration (ppm)	Mean Concentration (mg/g TOC)	MEAN HC (%)	MEAN PrPh	MEAN $PrnC_{17}$
Wallisberget	1.9	0	110	nr	nr	119	6.3	51.3	1.5	0.2
Treskelen	1.9	0	77	nr	2.36	209	11.3	22.9	1.3	0.5
Austjøkelen	1.9	28	91	nr	1.32	200	7.1	36.0	1.1	0.4
Liddalen	1.0	34	51	nr	na	na	na	na	na	na
Karentoppen	1.5	18	73	nr	nr	436	25.6	41.3	1.2	0.4

na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ARGILLACEOUS ROCKS OF THE SASSENDALEN GROUP OF SVALBARD

(A.1.2: Sticky keep Mbr/Tvillingodden Fm.)

	ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
LOCALITY NAME	MEAN TOC (wt%)	MEAN H.I. (mg/g TOC)	MEAN O.I. (mg/g TOC)	MEAN TMAX (°C)	MEAN V.R. (%)	Mean Concentration (ppm)	Mean Concentration (mg/g TOC)	MEAN HC (%)	MEAN PrPh	MEAN $PrnC_{17}$
Veidemannen	3.2	275	25	439	0.45	4469	133.2	65.4	1.6	1.5
Blanknuten	3.2	210	32	439	na	3185	109.8	52.5	1.8	1.1
Kråka	3.0	326	12	444	na	5891	170.3	61.0	na	na
Skrukkefjellet	3.1	242	30	438	0.53	3901	126.6	30.1	1.6	1.4
Høgrinden	3.2	335	22	433	0.46	2903	91.3	44.4	1.7	2.1
Lomberget	4.2	373	22	432	0.41	4349	86.8	32.2	1.5	2.1
Teistberget	3.3	259	43	435	0.45	6456	124.2	37.6	1.6	1.8
Roslagenfjellet	2.6	198	42	445	0.53	4313	154.0	37.1	1.6	1.6
Stensiöfjellet	3.3	244	64	437	0.49	1994	57.8	24.5	1.6	1.8
Vendomdalen	2.0	111	111	440	0.60	2438	105.5	49.6	1.6	1.7
Sticky Keep	2.3	272	38	440	na	3523	132.9	63.6	1.6	2.0
Vikinghøgda	2.0	140	39	437	na	2971	126.3	54.0	1.6	1.9

na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ARGILLACEOUS ROCKS OF THE SASSENDALEN GROUP OF SVALBARD

(A.1.2: Sticky Keep Mbr/Tvillingodden Fm.)

(Cont'd)

	ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
	MEAN	MEAN	MEAN	MEAN	MEAN	Mean		MEAN	MEAN	MEAN
LOCALITY	TOC	H.I.	O.I.	TMAX	V.R.	Concentration		HC	PrPh	$PrnC_{17}$
NAME	(wt%)	(mg/g TOC)	(mg/g TOC)	(°C)	(%)	(ppm)	(mg/g TOC)	(%)		
Botneheia	2.3	189	28	443	0.57	1859	98.6	51.0	1.9	1.2
Tcshermaksfj.	2.1	166	59	443	0.52	2183	102.9	37.3	1.6	1.7
Bertilryggen	2.1	279	17	438	na	2418	135.5	61.0	na	na
Wittenburgfj.	0.6	11	53	nr	na	na	na	na	na	na
Labben	0.5	60	55	452	na	500	86.3	75.0	na	na
Festningen	0.7	57	105	446	na	570	59.5	45.6	na	na
Bravaisberget	0.6	38	432	448	na	na	na	na	na	na
Treskelen	0.7	nr	nr	nr	nr	106	12.0	27.1	1.7	0.9
Austjøkelen	0.4	29	170	nr	na	64	12.8	38.4	1.0	0.3

na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ARGILLACEOUS ROCKS OF THE SASSENDALEN GROUP OF SVALBARD

(A.1.3: Deltadalen Mbr/Vardebukta Fm.)

	ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
LOCALITY NAME	MEAN TOC (wt%)	MEAN H.I. (mg/g TOC)	MEAN O.I. (mg/g TOC)	MEAN TMAX (°C)	MEAN V.R. (%)	Mean Concentration (ppm)	Concentration (mg/g TOC)	MEAN HC (%)	MEAN PrPh	MEAN $PrnC_{17}$
Veidemannen	0.7	114	72	439	0.45	2584	215.3	45.3	0.7	0.4
Kråka	0.8	164	44	440	na	1326	181.1	51.3	na	na
Høgrinden	0.7	58	104	434	0.46	1070	148.6	36.3	1.1	0.7
Stensiöfjellet	1.0	97	151	438	0.49	1454	110.9	40.9	1.5	1.2
Vikinghøgda	1.0	51	74	439	na	1930	174.5	49.9	1.3	0.9
Tschermaksfj.	0.3	29	197	438	0.52	694	99.1	44.1	1.4	0.7
Bertilryggen	0.3	109	53	438	na	593	116.7	77.4	na	na
Wittenburgfj.	0.2	nr	nr	nr	na	na	na	na	na	na
Labben	0.3	24	103	nr	na	377	89.0	74.0	na	na
Festningen	1.7	41	122	nr	na	577	33.9	51.2	na	na
Bravaisberget	0.3	41	348	nr	na	na	na	na	na	na

na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ARGILLACEOUS ROCKS OF THE SASSENDALEN GROUP OF SVALBARD

(A.1.3: Deltadalen Mbr/Vardebukta Fm.)

(Cont'd)

	ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
	MEAN	MEAN	MEAN	MEAN	MEAN	Mean		MEAN	MEAN	MEAN
LOCALITY	TOC	H.I.	O.I.	TMAX	V.R.	Concentration		HC	PrPh	$PrnC_{17}$
NAME	(wt%)	(mg/g TOC)	(mg/g TOC)	(°C)	(%)	(ppm)	(mg/g TOC)	(%)		
Treskelen	0.2	na	na	na	na	na	na	na	na	na
Austjøkelen	0.3	22	326	nr	na	764	254.5	52.9	1.0	0.4

na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ROCKS OF THE KAPP TOSCANA GROUP
(A.1.4: Tschermaksfjellet Formation)

		ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
		MEAN	MEAN	MEAN	MEAN	MEAN	Mean		MEAN	MEAN	MEAN
LOCALITY	MAIN	TOC	H.I.	O.I.	TMAX	V.R.	Concentration		HC	PrPh	$PrnC_{17}$
NAME	LITH.	(wt%)	(mg/g TOC)	(mg/g TOC)	(°C)	(%)	(ppm)	(mg/g TOC)	(%)		
Veidemannen	Shale	2.0	70	50	433	na	na	na	na	na	na
Blanknuten	Shale	2.6	na	na	na	na	na	na	na	na	na
K. Peu. Löche	Shale	1.3	67	30	444	na	na	na	na	na	na
Skrukkefj.	Shale	2.6	127	38	439	na	1200	46.2	51.2	2.4	1.0
Høgrinden	Shale	4.7	417	25	433	0.46	2145	40.1	33.1	2.3	1.2
Lomberget	Shale	1.6	84	51	441	0.41	366	22.3	21.3	1.9	1.3
Teistberget	Sh/Silt	1.0	19	68	nr	0.56	na	na	na	na	na
Storfjellet	Shale	0.8	12	217	nr	0.61	417	50.3	11.4	2.5	0.3
Vendomdalen	Silt.	1.4	na	na	na	na	78	5.5	51.3	1.4	0.7
Sticky Keep	Shale	0.9	25	639	nr	na	350	36.1	51.9	3.4	0.6
Vikinghøgda	Shale	0.9	na	na	na	na	na	na	na	na	na
Botneheia	Shale	1.1	na	na	na	nr	410	34.2	35.1	2.1	0.4
Tschermaksfj.	Shale	0.9	8	98	nr	0.56	442	26.0	42.1	3.4	0.7
Treskelen	Shale	0.8	0	124	nr	1.53	254	42.3	60.6	nr	nr
Austjøkelen	Mudst.	1.0	40	149	nr	1.10	444	45.3	7.0	1.9	0.3

Silt = Siltstone; Mudst = Mudstone; Sh = Shale; na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ROCKS OF THE KAPP TOSCANA GROUP
(A.1.5: De Geerdalen Formation)

		ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
		MEAN	MEAN	MEAN	MEAN	MEAN	Mean		MEAN	MEAN	MEAN
LOCALITY	MAIN	TOC	H.I.	O.I.	TMAX	V.R.	Concentration		HC	PrPh	$PrnC_{17}$
NAME	LITH.	(wt%)	(mg/g TOC)	(mg/g TOC)	(°C)	(%)	(ppm)	(mg/g TOC)	(%)		
Klementievfj.	Shale	0.8	33	149	449	0.60	754	56.6	37.4	2.5	0.3
Prospektrygg.	Shale	1.0	29	88	446	0.63	321	23.5	20.4	3.8	0.5
Storfjellet	Shale	1.4	54	95	454	0.61	468	33.8	43.1	3.2	0.5
Botneheia	Shale	1.0	10	131	nr	nr	254	24.8	44.9	1.9	0.2
Festningen	Silt/sst	0.7	64	130	458	0.74	356	28.4	53.7	2.6	0.3
Bravaisberget	Shale	0.9	65	147	nr	1.00	714	67.4	49.7	1.6	0.4
Treskelen	?	0.6	na	na	na	nr	na	na	na	na	na
Austjøkelen	Mud/Silt	0.7	na	na	na	1.13	na	na	na	na	na

Silt = Siltstone; Sst = Sandstone; Mud = Mudstone; na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

SUMMARY OF ORGANIC GEOCHEMICAL DATA FOR ROCKS OF THE KAPP TOSCANA GROUP
(A.1.6: Undifferentiated Kapp Toscana Group)

		ROCK-EVAL DATA					EXTRACTABLE ORGANIC MATTER				
		MEAN	MEAN	MEAN	MEAN	MEAN	Mean		MEAN	MEAN	MEAN
LOCALITY	MAIN	TOC	H.I.	O.I.	TMAX	V.R.	Concentration		HC	PrPh	$PrnC_{17}$
NAME	LITH.	(wt%)	(mg/g TOC)	(mg/g TOC)	(°C)	(%)	(ppm)	(mg/g TOC)	(%)		
Klementievfj.	Shale	1.4	nr	nr	nr	0.62	107	6.1	44.4	1.9	0.5
Dalsnuten	Shale	1.1	49	172	463	0.60	487	44.2	30.2	3.4	0.8
Selmaneset	?	1.6	10	84	nr	na	192	55.7	25.1	1.6	0.3

na = data not available; nr = data not reliable.

IKU SINTEF-GRUPPEN

APPENDIX A.2

KEROGEN COMPOSITION AND MATURITY VARIATION IN THE SASSENDALEN GROUP AND KAPP TOSCANA GROUP

IKU SINTEF-GRUPPEN

KEROGEN COMPOSITION AND MATURITY VARIATION IN THE SASSENDALEN GROUP

(A.2.1: Botneheia Mb./Bravaisberget Fm.)

LOCALITY NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Veidemannen/ Veidebreen	197	--	50	50	--	--	3.0-3.5	0.43	6-7
	177	--	50	50	--	--	3.5	0.41	6
	157	--	50	50	--	--	3.5-4.0	0.44	5
	143	Tr	90	10	--	--	3.5-4.0	0.41	5-6
	123	Tr	95	5	--	--	3.0-3.5	0.50	5-6
Blanknuten	146.3	--	90	Tr	10	Tr	3.0	na	na
	135	Tr	90	Tr	Tr	Tr	3.0	na	na
	131	Tr	95	5	--	--	3.0	na	na
	111	Tr	95	5	--	--	3.0	na	na
	93	Tr	95	5	--	--	3.0	na	na
	78	Tr	85	15	--	--	3.0	na	na
Skrukkefj.	149.5	--	50	40	10	--	4.0	nr	na
	143	--	95	5	--	--	4.0	0.50	4-5
	127	--	65	25	5	--	4.0	0.33	5
	117	Tr	80	20	--	--	4.0	0.51	4-5
	114.4	Tr	50	50	--	--	3.5	0.58	4-5
	100	Tr	70	30	--	--	3.5	0.36	3-4
	73	Tr	45	55	--	--	3.5	0.55	5
Høgrinden	185	--	75	25	--	--	3.5-4.0	0.33	5
	167	--	70	20	10	--	3.5-4.0	0.49	4
	159.5	--	75	20	5	--	3.5-4.0	nr	5
Lomberget	148	--	75	25	Tr	--	3.5-4.0	nr	5
	135	Tr	75	25	Tr	--	na	na	na

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

KEROGEN COMPOSITION AND MATURITY VARIATION IN THE SASSENDALEN GROUP

(A.2.1: Botneheia Mb./Bravaisberget Fm.)

LOCALITY NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Lomberget (cont'd)	127	Tr	75	20	5	--	na	0.42	4
	107	--	75	25	--	--	3.5-4.0	0.40	4
	96	--	75	25	--	--	3.5-4.0	na	na
Teistberget	157	--	85	15	--	--	3.5-4.0	na	na
	146	--	75	20	5	--	3.5-4.0	nr	4-5
	128	--	80	10	10	--	na	0.39	3-4
	109	--	80	10	10	--	3.0-3.5	0.39	5
	92	--	50	50	--	--	3.5-4.0	0.32	4-5
	78	--	60	40	--	--	3.5-4.0	0.36	4
Botneheia	195	--	85	15	--	--	na	nr	6-7
	179	--	75	25	--	--	na	0.63	4-6
	159	--	80	20	--	--	5.5	0.52	6-7
Tschermaksfj.	266	--	50	50	--	--	3.5-5.5	0.43	5
	248	--	65	35	--	--	3.5-6.0	0.51	5-6
	225	--	30	70	--	--	3.5-4.0	0.34	5-6
	209	--	50	50	--	--	na	0.38	4-5
	185	--	80	20	Tr	Tr	na	0.34	4-5
	161	--	60	40	--	--	na	nr	5
Festningen	720	--	70	15	10	5	4.0-5.0	nr	7
	705	--	85	10	5	--	4.0-5.0	0.60	3-6
	675	5	80	15	--	--	5.5	na	na
	673	--	70	30	--	--	5.0	na	na

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

IKU SINTEF-GRUPPEN

KEROGEN COMPOSITION AND MATURITY VARIATION IN THE SASSENDALEN GROUP

(A.2.1: Botneheia Mb./Bravaisberget Fm.)

LOCALITY NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Festningen (cont'd)	662	10	80	--	10	--	5.0	na	na
	643	--	45	55	--	--	5.5-6.0	1.23	6-7
	626	Tr	50	45	5	--	5.0	0.54	7
	571	--	80	10	--	--	5.0	na	na
	562	--	55	45	--	--	5.0	na	na
	547	--	55	45	--	--	5.0	na	na
	541	--	50	50	--	--	5.0-5.5	na	na
	537	--	60	40	--	--	5.0	0.87	7
	531	--	75	20	5	--	5.0-5.5	na	na
	528	10	75	10	5	--	5.0	0.99	7-8
	517	5	85	10	--	--	5.0	na	na
	513.5	--	45	40	10	5	5.0	0.82	7
Bravaisberget	682	--	70	25	--	--	5.5-6.0	1.24	7
	642	--	70	25	--	--	5.5-6.0	nr	7
	629	--	95	5	--	--	5.5-6.0	1.28	7
	593	--	70	30	--	--	5.0	0.85	6
	566	--	70	30	--	--	5.0	na	na
	526	--	70	30	--	--	5.0	na	na
	504.5	--	70	30	--	--	5.0	na	na
	492	--	70	30	--	--	5.0-5.5	na	na
Treskelen	274	--	70	--	25	5	5.5-6.0	na	na
	222.5	--	100	--	--	Tr	3.5-6.0	2.43	---

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

IKU SINTEF-GRUPPEN

KEROGEN COMPOSITION AND MATURITY VARIATION IN THE SASSENDALEN GROUP

(A.2.1: Botneheia Mb./Bravaisberget Fm.)

LOCALITY NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Treskelen (cont'd)	212.5	10	85	5	--	--	5.5-6.0	2.34	---
	208	10	85	5	--	--	5.5-6.0	2.57	---
	194	10	85	5	--	--	5.5-6.0	1.96	---
Karentoppen	79.5	--	85	5	5	5	5.5	na	na
	74.3	--	85	5	10	Tr	na	nr	6
	60.5	--	80	Tr	10	10	na	nr	6

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

KEROGEN COMPOSITION AND MATURITY VARIATION IN THE SASSENDALEN GROUP

(A.2.2: Sticky Keep Mb./Tvillingodden Fm.)

LOCALITY NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Veidemannen/ Veidebreen	118	10	45	20	25	--	3.0	na	na
Blanknuten	68.5	--	50	50	--	--	3.0	na	na
	1.0	--	50	50	--	--	3.0	na	na
Skrukkefj.	66	Tr	50	50	--	--	3.5	nr	4
	54	Tr	55	45	--	--	3.5	0.58	5-6
	25.4	--	30	70	--	--	3.5	nr	4
	5	--	50	45	--	5	3.5	nr	5-6
Høgrinden	113	--	60	20	20	--	4.0	0.46	4-6
	82	--	85	15	--	--	4.0	0.41	5
	62	--	70	25	5	--	3.5-4.0	0.44	5
	45	--	75	15	10	--	4.0	0.48	3-4
Lomberget	90	--	75	25	--	--	na	0.43	4
	65	--	75	25	--	--	na	0.35	4-6
	46	Tr	20	80	--	--	na	na	na
	32	Tr	60	35	5	--	3.5-4.0	0.40	4-5
Teistberget	1	--	50	50	--	--	na	0.38	6
Botneheia	65	--	45	55	--	--	6.0-6.5	nr	7
	48	--	85	15	--	--	na	0.58	6-7
	12	--	85	15	--	--	5.5-6.0	nr	6
	3	--	85	15	--	--	6.0-6.5	nr	6
Tschermaksfj.	154	--	90	10	--	--	na	na	na
	134	--	60	35	--	5	3.5	na	na

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

KEROGEN COMPOSITION AND MATURITY VARIATION IN THE SASSENDALEN GROUP

(A.2.2: Sticky Keep Mb./Tvillingodden Fm.)

LOCALITY NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Tschermaksfj. (cont'd)	111	--	60	35	Tr	Tr	na	na	na
	92	--	35	60	Tr	Tr	nr	nr	5-6
	75	--	35	60	--	Tr	4.0-5.5	0.41	5

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

IKU SINTEF-GRUPPEN

KEROGEN COMPOSITION AND MATURITY VARIATION IN THE SASSENDALEN GROUP

(A.2.3: Deltadalen Mb./Vardebukta Fm.)

LOCALITY NAME	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Veidemannen/ Veidebreen	47	--	60	40	--	--	na	na	na
	21	--	75	25	--	--	5.5-6.0	na	na
	14	--	5	95	--	--	na	na	na
	7	Tr	80	20	--	--	na	na	na
Høgrinden	2	--	80	10	10	--	4.0	na	na
Tschermaksfj.	43	Tr	50	50	--	--	4.0-5.0	nr	4-5
	0.5	Tr	90	10	--	--	3.5-4.0	0.40	5-6
Austjøkelen	16	--	35	40	25	--	na	na	na
	6	--	85	15	Tr	--	5.5	na	na
	2.7	--	45	25	10	20	na	na	na

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

A.2.4: KEROGEN COMPOSITION AND MATURITY VARIATION IN THE KAPP TOSCANA GROUP

LOCALITY NAME (Formation)	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Skrukkefj. (Tschermaks.)	152	--	50	40	10	--	4.0	na	na
Høgrinden (Tschermaks.)	208	--	90	10	--	--	3.5-4.0	0.46	4
Lomberget (Tschermaks.)	154	--	90	10	--	--	na	0.41	5
Teistberget (Kapp Tosc.)	234	--	50	50	--	--	3.5-4.0	0.55	4
Klementievfj. (Kapp Tosc.)	370	--	55	--	10	35	5.5	0.99	na
	350	--	30	35	5	30	5.5	0.62	na
(Wilhelmøya)	315	--	25	40	35	--	na	0.79	na
	297	--	70	--	30	--	5.5	na	6
(De Geerdal.)	236	--	20	55	15	10	na	nr	na
	223	--	30	40	10	20	5.0	0.73	7
	202.8	--	20	55	25	--	na	na	na
	187.5	--	85	10	Tr	Tr	na	nr	na
	157	--	80	10	10	Tr	5.5	0.78	7
Storfjellet (De Geerdal.)	393	--	Tr	80	20	--	4.0-4.5	0.54	na
	265	Tr	25	50	--	25	5.0	0.68	7
(Tschermaks.)	175	--	15	70	--	15	5.0	0.80	na
Dalsnuten (Kapp Tosc.)	411	--	15	80	5	Tr	4.0	0.55	6-7
	373	--	25	40	15	20	4.0	0.59	6
	338	--	25	50	25	--	4.0	0.61	6

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

A.2.4: KEROGEN COMPOSITION AND MATURITY VARIATION IN THE KAPP TOSCANA GROUP

LOCALITY NAME (Formation)	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Dalsnuten	305	--	90	10	--	--	4.0-4.5	0.66	na
(Kapp Tosc.-cont'd)	289	--	90	10	--	--	5.0	nr	6
Botneheia (De Geerdal.)	417.5	--	10	30	60	--	4.0-4.5	nr	na
	375	--	45	30	10	15	4.5	nr	na
	298	--	80	Tr	5	15	4.0-4.5	na	na
(Tschermaks.)	200	--	100	Tr	--	--	4.0-4.5	0.86	6-7
Selmaneset (Kapp Tosc.)	79	--	45	55	--	--	5.5	na	na
Festningen (Wilhelmøya)	329.3	--	50	40	10	--	5.5-6.0	na	na
(De Geerdal.)	319.8	--	85	--	15	--	na	na	na
	240	--	70	--	20	10	4.5	0.79	na
	143	Tr	45	5	40	10	5.0	0.73	7
	78	--	25	35	20	20	5.0	na	na
	74.5	--	35	45	10	10	5.5-6.0	na	na
	42	--	40	30	15	15	5.0	na	na
	29.2	--	45	35	10	10	5.0	na	na
Bravaisberget (De Geerdal.)	130	--	30	10	--	60	5.5-6.0	na	na
	107	--	20	15	65	--	na	na	na
	87.5	--	20	50	10	20	5.5-6.0	1.30	na
	31	--	30	45	10	15	na	na	na
	20	--	15	55	10	15	5.5-6.0	1.58	na
	17.3	--	50	50	--	--	na	1.00	8-9

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

A.2.4: KEROGEN COMPOSITION AND MATURITY VARIATION IN THE KAPP TOSCANA GROUP

LOCALITY NAME (Formation)	LEVEL (m)	% KEROGEN COMPOSITION AL	AM	HE	WO	CO	MATURITY TAI*	V.R. (%)	SPOR
Bravaisberget (De Geerdal.-	10.2	--	45	20	10	25	5.5-6.0	na	na
cont'd)	4.4	--	45	15	15	15	5.5-6.0	1.22	na
Treskelen (De Geerdal.)	332	--	5	85	10	--	5.5-6.0	1.39	na

(* - TAI data upgraded to current IKU usage).

Al=Algal debris; Am=Amorphous debris; He=Herbaceous debris; Wo=Woody particles; Co=Coaly Particles; na=data not available; nr=data not reliable.

APPENDIX A.3

DATA FROM SAMPLES SELECTED FOR ROCK-EVAL ANALYSIS OF KEROGEN CONCENTRATES

TABLE A.3.1. ROCK-EVAL DATA FROM WHOLE-ROCK SAMPLES

Dia-Structure:

LOC	AGE	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET	PI	TMAX (°C)
U-3	Smith	107.00	0.41	8.55	0.11	2.39	358	5	8.96	0.05	429
U-3	Smith	103.00	0.79	15.55	0.76	4.27	364	18	16.34	0.05	417
U-3	Smith	99.00	0.87	10.81	0.57	3.36	322	17	11.68	0.07	422
U-4	Smith	138.52	0.64	10.18	0.66	3.09	329	21	10.82	0.06	423
U-4	Smith	136.00	0.73	13.63	1.14	3.68	370	31	14.36	0.05	421
U-4	Smith	132.00	0.50	9.74	0.83	3.01	324	28	10.24	0.05	421
U-4	Smith	127.00	0.38	5.72	0.42	2.19	261	19	6.10	0.06	425
U-4	Smith	123.00	0.34	4.88	0.54	2.12	230	25	5.22	0.07	429
U-4	Smith	119.00	0.79	11.33	0.46	3.33	340	14	12.12	0.07	426
U-4	Smith	115.00	0.64	13.31	0.34	3.59	371	9	13.95	0.05	421
U-4	Smith	112.00	0.40	9.49	0.89	3.02	314	29	9.89	0.04	422
U-4	Smith	107.00	1.14	21.40	0.92	8.81	243	10	22.54	0.05	422
U-4	Anis	103.00	0.63	12.20	0.62	3.32	367	19	12.83	0.05	428
U-4	Anis	99.00	0.67	18.10	0.26	4.57	396	6	18.77	0.04	429
U-1	Anis	125.00	0.30	11.72	1.10	3.29	356	33	12.02	0.02	429
U-1	Anis	121.00	0.14	3.08	1.09	1.38	223	79	3.22	0.04	428
U-1	Anis	118.00	0.28	8.78	0.15	2.91	302	5	9.06	0.03	434
U-1	Anis	114.00	0.23	5.87	0.13	2.18	269	6	6.10	0.04	433
U-1	Anis	110.00	0.95	40.72	0.20	7.72	527	3	41.67	0.02	427
U-1	Anis	107.00	0.78	18.24	0.75	5.63	324	13	19.02	0.04	423
U-9	Anis	111.08	0.50	9.08	0.50	2.57	353	19	9.58	0.05	425
U-9	Anis	107.80	0.57	10.81	0.46	2.99	362	15	11.38	0.05	425
U-9	Anis	103.50	0.39	12.14	0.79	3.30	368	24	12.53	0.03	426
U-9	Anis	99.65	0.30	10.09	0.52	2.62	385	20	10.39	0.03	427
U-9	Anis	93.90	0.38	12.47	0.89	4.36	286	20	12.85	0.03	431

SVALBARD
Veidemannen/Veidebreen:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET	PI	TMAX (°C)
Sticky Keep	64.00	1.40	10.92	0.59	3.33	328	18	12.32	0.11	441
Sticky Keep	98.00	2.00	7.55	1.26	3.34	226	38	9.55	0.20	436
Sticky Keep	113.00	2.84	12.80	0.57	4.26	300	13	15.64	0.18	436
Sticky Keep	119.00	1.49	6.65	0.86	2.73	244	32	8.14	0.18	440
Botneheia	131.00	1.20	19.77	0.82	4.53	436	18	20.97	0.05	443
Botneheia	143.00	1.18	9.12	0.88	3.24	281	27	10.30	0.11	431
Botneheia	149.00	1.39	19.62	0.73	5.16	380	14	21.01	0.06	440
Botneheia	157.00	0.67	21.16	0.69	4.50	470	15	21.83	0.03	440
Botneheia	177.00	2.08	31.47	0.97	7.33	429	13	33.55	0.06	438
Botneheia	189.00	0.75	13.32	0.98	4.94	269	20	14.07	0.05	436
Botneheia	197.00	0.62	32.50	0.82	6.91	470	12	33.12	0.01	442

Skrukkefjellet:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET	PI	TMAX (°C)
Sticky Keep	13.00	1.14	5.63	0.54	2.27	248	24	6.77	0.16	438
Sticky Keep	37.00	0.72	4.53	0.96	2.23	203	43	5.25	0.13	436
Sticky Keep	66.00	0.44	10.86	0.94	3.93	276	24	11.30	0.03	439
Botneheia	85.00	0.83	9.90	0.82	3.48	285	24	10.73	0.07	439
Botneheia	100.00	0.48	6.41	0.52	2.35	273	22	6.89	0.06	438
Botneheia	110.00	1.27	37.45	1.36	8.28	452	16	38.72	0.03	438
Botneheia	118.00	1.47	15.13	0.69	3.66	413	19	16.60	0.08	442
Botneheia	127.00	2.25	48.75	0.80	11.22	434	7	51.00	0.04	436
Botneheia	136.00	1.76	38.36	0.69	7.10	540	10	40.12	0.04	438
Botneheia	149.50	1.74	43.38	1.82	10.38	418	18	45.12	0.03	440

Lomberget:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET	PI	TMAX (°C)
Sticky Keep	38.00	2.08	16.16	1.12	4.95	326	23	51.00	0.11	432
Sticky Keep	46.00	1.29	9.48	0.87	3.35	283	26	10.77	0.11	429
Sticky Keep	65.00	2.59	21.74	0.85	5.54	392	15	24.33	0.10	430
Sticky Keep	82.00	2.68	37.04	0.87	5.90	628	15	39.72	0.06	438
Botneheia	96.00	1.01	11.36	0.37	3.16	359	12	12.37	0.08	434
Botneheia	103.00	0.37	3.82	0.80	1.79	213	45	4.19	0.08	434
Botneheia	114.00	2.07	32.69	0.88	6.36	514	14	34.76	0.05	436
Botneheia	127.00	2.94	48.60	0.98	8.90	552	11	51.54	0.05	435
Botneheia	135.00	1.13	16.95	1.70	5.12	331	33	18.08	0.06	433
Botneheia	148.00	0.96	17.06	1.49	4.15	411	36	18.02	0.05	434

Teistberget:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET	PI	TMAX (°C)
Sticky Keep	1.00	0.74	4.61	0.84	2.24	206	38	5.35	0.13	433
Sticky Keep	23.00	3.02	19.57	1.67	5.21	376	32	22.59	0.13	437
Sticky Keep	47.00	0.75	5.01	1.51	2.58	194	59	5.76	0.13	432
Botneheia	78.00	1.26	14.85	2.25	4.49	331	50	16.11	0.07	436
Botneheia	92.00	3.18	32.24	2.82	6.96	463	41	35.82	0.08	432
Botneheia	99.00	3.80	59.17	2.11	10.25	577	21	62.97	0.06	435
Botneheia	105.00	5.03	53.60	1.64	8.81	608	19	58.63	0.08	438
Botneheia	109.00	3.23	48.63	2.52	9.79	497	26	51.86	0.06	436
Botneheia	114.00	1.94	27.84	1.66	8.33	334	20	29.78	0.06	434
Botneheia	124.00	3.53	42.08	0.98	5.90	713	17	45.61	0.07	439
Botneheia	128.00	0.78	5.69	1.08	2.17	262	50	6.47	0.12	429
Botneheia	132.00	2.08	36.40	2.45	7.49	486	33	38.48	0.05	433
Botneheia	139.00	1.68	25.90	2.03	5.87	441	28	27.58	0.06	435

Krapotkinfjellet:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET	PI	TMAX (°C)
Botneheia	2.75	2.64	16.74	0.51	5.99	279	9	19.38	0.14	454
Botneheia	3.70	2.15	18.83	0.50	6.92	272	7	20.98	0.10	451
Botneheia	5.05	2.94	22.28	1.09	8.64	258	13	25.22	0.12	453
Botneheia	5.55	2.35	17.98	0.75	7.95	226	9	20.33	0.12	455
Botneheia	6.70	2.05	14.35	0.53	6.60	217	8	16.40	0.13	452
Botneheia	7.90	2.45	27.64	0.61	9.43	293	6	30.09	0.08	456
Botneheia	8.50	3.20	24.11	0.50	9.44	255	5	27.31	0.12	451
Botneheia	9.20	1.93	15.24	0.51	7.27	210	7	17.17	0.11	453

Vendomdalen:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET	PI	TMAX (°C)
Botneheia	72.00	1.01	19.37	3.19	6.87	282	46	20.38	0.04	444
Botneheia	88.00	1.40	10.04	1.82	4.82	208	38	11.44	0.12	441
Botneheia	98.00	1.95	17.30	3.02	7.09	244	43	19.25	0.10	443
Botneheia	117.30	2.30	16.10	0.60	6.02	267	10	18.40	0.13	446
Botneheia	123.50	2.10	14.80	0.65	5.43	273	12	16.90	0.12	443
Botneheia	139.00	1.15	9.27	2.18	4.24	219	51	10.42	0.11	443
Botneheia	158.00	2.13	16.66	2.69	6.39	261	19	18.79	0.11	441
Botneheia	168.00	1.11	6.48	3.62	6.52	99	56	7.59	0.14	439

Botneheia:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET	PI	TMAX (°C)
Sticky Keep	10.00	1.46	4.20	0.60	2.30	183	26	5.66	0.25	441
Sticky Keep	30.00	0.47	2.97	0.53	1.80	165	29	3.44	0.13	442
Sticky Keep	40.00	0.58	2.08	0.52	1.40	149	37	2.66	0.21	442

Sticky Keep	52.00	0.27	7.06	0.79	3.00	235	26	7.33	0.03	444
Sticky Keep	62.00	0.62	9.42	0.86	4.40	214	20	10.04	0.06	442
Botneheia	78.00	1.24	13.32	0.84	5.60	238	15	14.56	0.08	445
Botneheia	88.00	0.80	28.60	0.79	9.40	304	8	29.40	0.02	440
Botneheia	98.00	0.40	8.70	0.57	3.50	249	16	9.10	0.04	443
Botneheia	109.00	0.88	9.94	1.62	5.74	173	28	10.82	0.08	440
Botneheia	118.00	0.45	14.98	1.17	6.90	217	17	15.43	0.02	441
Botneheia	149.00	1.69	12.55	1.45	5.35	235	27	14.24	0.11	443
Botneheia	159.00	1.39	19.76	1.61	6.54	302	25	21.15	0.06	448
Botneheia	174.00	1.26	11.75	1.61	4.97	236	32	13.01	0.09	443
Botneheia	183.00	1.51	14.07	1.73	5.64	250	31	15.58	0.09	444
Botneheia	194.00	1.54	16.82	1.84	7.65	220	24	18.36	0.08	443

TOC = Total Organic Carbon; HI = Hydrogen Index; OI = Oxygen Index; PET POT = Petroleum Potential (S1+S2); PI = Petroleum Potential (S1/S1+S2); nr = data not reliable.

TABLE A.3.2. ROCK-EVAL DATA FOR KEROGEN CONCENTRATE SAMPLES

Dia-structure:

LOC	AGE	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET POT	PI	TMAX (°C)
U-3	Smith	107.00	8.18	127.52	4.86	23.48	543	21	135.70	0.06	424
U-3	Smith	103.00	2.60	147.03	7.39	35.75	411	21	149.63	0.02	421
U-4	Smith	138.52	7.62	86.78	2.63	20.96	414	13	94.40	0.08	422
U-4	Smith	136.00	6.67	77.77	2.73	18.07	430	15	84.44	0.08	422
U-4	Smith	132.00	5.82	59.57	2.40	16.40	363	15	65.39	0.09	419
U-4	Smith	127.00	1.92	31.57	1.91	7.68	411	25	33.49	0.06	421
U-4	Smith	123.00	4.84	96.94	5.58	15.56	623	36	101.78	0.05	421
U-4	Smith	119.00	8.93	139.79	5.00	34.13	410	15	148.72	0.06	421
U-4	Smith	115.00	2.56	161.41	15.12	33.48	482	45	163.97	0.02	425
U-4	Smith	112.00	7.45	112.75	4.30	21.82	517	20	120.20	0.06	423
U-4	Smith	107.00	2.63	210.87	6.78	36.21	582	19	213.50	0.01	426
U-4	Anis	103.00	2.21	46.07	1.97	10.74	429	18	48.28	0.05	425
U-4	Anis	99.00	19.34	299.12	8.35	45.35	660	18	318.46	0.06	nr
U-1	Anis	125.00	3.87	72.49	2.25	17.16	422	13	76.36	0.05	421
U-1	Anis	121.00	3.15	65.80	3.61	20.86	315	17	68.95	0.05	424
U-1	Anis	118.00	4.18	124.00	3.81	30.39	408	13	128.18	0.03	428
U-1	Anis	114.00	3.22	55.30	1.41	11.73	471	12	58.52	0.06	424
U-1	Anis	110.00	5.03	251.50	9.80	47.52	529	21	256.53	0.02	425
U-1	Anis	107.00	4.90	85.82	2.70	17.14	501	16	90.72	0.05	426
U-9	Anis	99.65	2.10	160.40	16.40	37.19	431	44	162.50	0.01	428
U-9	Anis	93.90	4.47	194.47	7.86	34.42	565	23	198.94	0.02	423

SVALBARD
Veidemannen/Veidebreen:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET POT	PI	TMAX (°C)
Sticky Keep	64.00	22.94	179.42	3.18	40.36	445	8	202.36	0.11	444
Sticky Keep	113.00	12.25	52.17	1.48	16.45	317	9	64.42	0.19	440
Sticky Keep	119.00	6.98	91.32	2.31	28.99	315	8	98.30	0.07	438
Botneheia	131.00	12.64	115.98	2.20	41.14	282	5	128.62	0.10	445
Botneheia	143.00	10.00	175.78	3.75	40.51	434	9	185.78	0.05	443
Botneheia	157.00	8.61	210.49	4.15	47.66	442	9	219.10	0.04	440
Botneheia	177.00	15.58	148.26	2.12	50.94	291	4	163.84	0.10	442
Botneheia	189.00	22.22	170.76	3.58	40.93	417	9	192.98	0.12	449
Botneheia	197.00	8.92	267.12	3.26	57.65	463	6	276.04	0.03	442

Skrukkefjellet:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET POT	PI	TMAX (°C)
Sticky Keep	66.00	6.68	174.11	4.39	41.44	420	11	180.79	0.04	440
Botneheia	100.00	8.25	88.17	1.63	24.16	365	7	96.42	0.09	439
Botneheia	110.00	20.00	213.75	6.60	47.02	455	14	233.75	0.09	442
Botneheia	118.00	11.62	291.75	7.25	57.44	508	13	303.37	0.04	443
Botneheia	127.00	13.77	290.07	3.33	63.37	458	5	303.84	0.05	444
Botneheia	136.00	30.40	274.32	5.74	58.35	470	10	304.72	0.10	444
Botneheia	149.50	12.42	180.53	4.55	56.94	317	8	192.95	0.06	437

Lomberget:

UNIT	DEPTH (m)	S1 (mg/g rock)	S2 (mg/g rock)	S3 (mg/g rock)	TOC (%)	HI (mg/g TOC)	OI (mg/g TOC)	PET POT	PI	TMAX (°C)
Sticky Keep	65.00	12.16	199.27	3.87	41.77	477	9	211.43	0.06	438
Botneheia	96.00	10.12	219.39	5.78	44.12	497	13	229.51	0.04	438
Botneheia	127.00	11.47	265.75	5.46	45.72	581	12	277.22	0.04	436
Botneheia	135.00	9.93	196.35	6.77	45.22	434	15	206.28	0.05	432
Botneheia	148.00	17.24	222.65	10.03	54.50	409	18	239.89	0.07	438

Teistberget:

UNIT	DEPTH (m)	S1	S2	S3	TOC (%)	HI (mg/g TOC)	OI	PET POT	PI	TMAX (°C)
		(mg/g rock)								
Sticky Keep	1.00	5.80	96.23	22.79	33.88	284	67	102.03	0.06	438
Sticky Keep	23.00	31.37	290.57	3.90	57.87	502	7	321.94	0.10	443
Botneheia	78.00	6.25	179.42	29.23	53.47	336	55	185.67	0.03	439
Botneheia	92.00	16.55	199.48	5.24	39.98	499	13	216.03	0.08	435
Botneheia	99.00	5.58	91.91	3.52	20.81	442	17	97.49	0.06	nr
Botneheia	105.00	20.42	237.11	4.87	50.41	470	10	257.53	0.08	440
Botneheia	114.00	7.75	224.59	4.34	45.98	488	9	232.34	0.03	440
Botneheia	124.00	4.02	270.26	6.28	62.68	431	10	274.28	0.01	440
Botneheia	132.00	15.13	251.56	6.39	54.24	464	12	266.69	0.06	436
Botneheia	139.00	10.20	191.75	4.94	39.51	485	13	201.95	0.05	436

Krapotkinfjellet:

UNIT	DEPTH (m)	S1	S2	S3	TOC (%)	HI (mg/g TOC)	OI	PET POT	PI	TMAX (°C)
		(mg/g rock)								
Botneheia	2.75	14.53	157.83	1.64	40.26	392	4	172.36	0.08	454
Botneheia	3.70	23.90	114.14	2.80	51.95	220	5	138.04	0.17	444
Botneheia	5.05	16.55	107.00	3.22	47.85	224	7	123.55	0.13	445
Botneheia	5.55	10.30	48.86	0.00	26.93	181	0	59.16	0.17	445
Botneheia	6.70	9.48	39.69	1.03	20.17	197	5	49.17	0.19	444
Botneheia	7.90	20.22	113.55	0.66	49.17	231	1	133.77	0.15	448
Botneheia	8.50	16.21	64.24	0.60	37.42	172	2	80.45	0.20	445
Botneheia	9.20	42.40	222.70	1.42	45.59	488	3	265.10	0.16	444

Vendomdalen:

UNIT	DEPTH (m)	S1	S2	S3	TOC (%)	HI (mg/g TOC)	OI	PET POT	PI	TMAX (°C)
		(mg/g rock)								
Botneheia	72.00	9.33	161.77	5.55	50.48	320	11	171.10	0.05	448
Botneheia	88.00	20.15	145.71	4.55	52.19	279	9	165.86	0.12	447
Botneheia	98.00	28.84	198.53	5.96	62.31	319	10	227.37	0.13	446
Botneheia	139.00	7.90	132.67	3.95	50.60	262	8	140.57	0.06	444
Botneheia	168.00	23.10	179.10	10.00	66.39	270	15	202.20	0.11	444

Botneheia:

UNIT	DEPTH (m)	S1	S2	S3	TOC (%)	HI (mg/g TOC)	OI	PET POT	PI	TMAX (°C)
		(mg/g rock)								
Botneheia	159.00	9.97	130.48	2.93	52.55	248	6	140.45	0.07	442
Botneheia	174.00	22.41	167.14	7.85	66.72	251	12	189.55	0.12	445
Botneheia	183.00	20.80	166.58	9.19	52.45	318	18	187.38	0.11	442
Botneheia	194.00	11.13	126.52	4.34	54.89	230	8	137.65	0.08	439

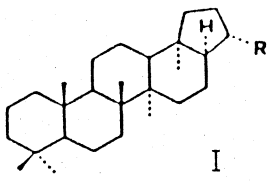
TOC = Total Organic Carbon; HI = Hydrogen Index; OI = Oxygen Index; PET POT = Petroleum Potential (S1+S2); PI = Production Index (S1/S1+S2); nr = data not reliable.

APPENDIX A.4

GC-MS PEAK IDENTIFICATIONS USED AT IKU

Mass chromatograms representing terpanes (m/z 191)

P	tricyclic terpane	$C_{23}H_{42}$	(IV,R=C_4H_9)
Q	tricyclic terpane	$C_{24}H_{44}$	(IV,R=C_5H_{11})
R	tricyclic terpane (17R,17S)	$C_{25}H_{46}$	(IV,R=C_6H_{13})
S	tetracyclic terpane	$C_{24}H_{42}$	(V)
T	tricyclic terpane (17R,17S)	$C_{26}H_{48}$	(IV,R=C_7H_{15})
A	T_s, 18α(H)-trisnorneohopane	$C_{27}H_{46}$	(III)
B	T_m, 17α(H)-trisnorhopane	$C_{27}H_{46}$	(I,R=H)
Z	bisnorhopane	$C_{28}H_{48}$	
C	17α(H)-norhopane	$C_{29}H_{50}$	(I,R=C_2H_5)
X	unknown triterpane	$C_{30}H_{52}$	
D	17β(H)-normoretane	$C_{29}H_{50}$	(II,R=C_2H_5)
E	17α(H)-hopane	$C_{30}H_{52}$	(I,R=C_3H_7)
F	17β(H)-moretane	$C_{30}H_{52}$	(II,R=C_3H_7)
G	17α(H)-homohopane (22S)	$C_{31}H_{54}$	(I,R=C_4H_9)
H	17α(H)-homohopane (22R)	$C_{31}H_{54}$	(I,R=C_4H_9)
	+ unknown triterpane (gammacerane?)		
I	17β(H)-homomoretane	$C_{31}H_{54}$	(II,R=C_4H_9)
J	17α(H)-bishomohopane (22S,22R)	$C_{32}H_{56}$	(I,R=C_5H_{11})
K	17α(H)-trishomohopane (22S,22R)	$C_{33}H_{58}$	(I,R=C_6H_{13})
L	17α(H)-tetrakishomohopane (22S,22R)	$C_{34}H_{60}$	(I,R=C_7H_{15})
M	17α(H)-pentakishomohopane (22S,22R)	$C_{35}H_{62}$	(I,R=C_8H_{17})



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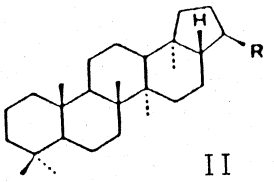
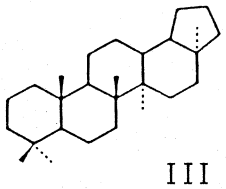


II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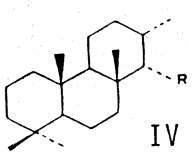

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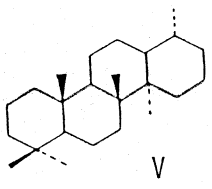
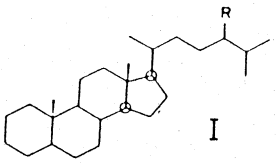

V

Mass chromatograms representing steranes (m/z 217 and 218)

u	5α(H)-sterane	$C_{21}H_{36}$	(V,R=C_2H_5)
v	5α(H)-sterane	$C_{22}H_{38}$	(V,R=C_3H_7)
a	13β(H),17α(H)-diasterane (20S)	$C_{27}H_{48}$	(III,R=H)
b	13β(H),17α(H)-diasterane (20R)	$C_{27}H_{48}$	(III,R=H)
c	13α(H),17β(H)-diasterane (20S)	$C_{27}H_{48}$	(IV,R=H)
d	13α(H),17β(H)-diasterane (20R)	$C_{27}H_{48}$	(IV,R=H)
e	13β(H),17α(H)-diasterane (20S)	$C_{28}H_{50}$	(III,R=CH_3)
f	13β(H),17α(H)-diasterane (20R)	$C_{28}H_{50}$	(III,R=CH_3)
g	13α(H),17β(H)-diasterane (20S)	$C_{28}H_{50}$	(IV,R=CH_3)
	+ 14α(H),17α(H)-sterane (20S)	$C_{27}H_{48}$	(I,R=H)
h	13β(H),17α(H)-diasterane (20S)	$C_{29}H_{52}$	(III,R=C_2H_5)
	+ 14β(H),17β(H)-sterane (20R)	$C_{27}H_{48}$	(II,R=H)
i	14β(H),17β(H)-sterane (20S)	$C_{27}H_{48}$	(II,R=H)
	+ 13α(H),17β(H)-diasterane (20R)	$C_{28}H_{50}$	(IV,R=CH_3)
j	14α(H),17α(H)-sterane (20R)	$C_{27}H_{48}$	(I,R=H)
k	13β(H),17α(H)-diasterane (20R)	$C_{29}H_{52}$	(III,R=C_2H_5)
l	13α(H),17β(H)-diasterane (20S)	$C_{29}H_{52}$	(IV,R=C_2H_5)
m	14α(H),17α(H)-sterane (20S)	$C_{28}H_{50}$	(I,R=CH_3)
n	13α(H),17β(H)-diasterane (20R)	$C_{29}H_{52}$	(IV,R=C_2H_5)
	+ 14β(H),17β(H)-sterane (20R)	$C_{28}H_{50}$	(II,R=CH_3)
o	14β(H),17β(H)-sterane (20S)	$C_{28}H_{50}$	(II,R=CH_3)
p	14α(H),17α(H)-sterane (20R)	$C_{28}H_{50}$	(I,R=CH_3)
q	14α(H),17α(H)-sterane (20S)	$C_{29}H_{52}$	(I,R=C_2H_5)
r	14β(H),17β(H)-sterane (20R)	$C_{29}H_{52}$	(II,R=C_2H_5)
	+ unknown sterane		
s	14β(H),17β(H)-sterane (20S)	$C_{29}H_{52}$	(II,R=C_2H_5)
t	14α(H),17α(H)-sterane (20R)	$C_{29}H_{52}$	(I,R=C_2H_5)



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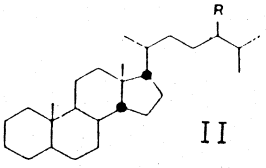

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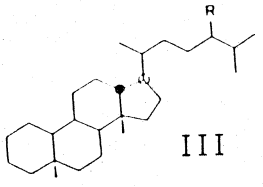

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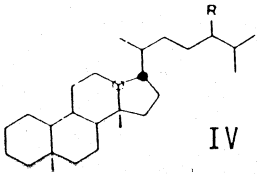

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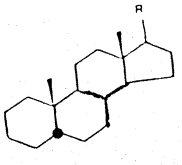

V

MOLECULAR RATIOS FROM TERPANE AND STERANE MASS CHROMATOGRAMS APPLIED AS MATURITY AND SOURCE CHARACTERISTIC PARAMETERS

Geochemical fossils or biological marker components are characteristic of the type of organic matter present at the time the sediments were deposited. The biological isomers of these components undergo changes due to increased maturity in particular, but also to a certain degree caused by migration and weathering processes.

Source characteristic parameters

In the m/z 191 mass chromatograms which represent the terpanes, the hopanes and moretanes are the major components in most extracts and oils. Of the hopanes the C_{27} and C_{29}-C_{35} homologs are ubiquitous, while the C_{28} bisnorhopane is believed to be typical of certain types of source rocks. This is also the case for the component, probably gammacerane, sometimes seen to coelute with the 22S isomer of the C_{31} 17α(H)-hopanes (H). In the sterane mass chromatograms, m/z 217 and m/z 218, the molecular weight distribution of the C_{27}-C_{29} regular steranes is believed to be representative of the original input of organic matter. The highest molecular weight compounds, the C_{29} steranes, represent organic matter of terrestrial origin, while the lower molecular weight analogs originate from more marine type environments.

Maturity dependent parameters

The biological isomers of the hopanes, the 17β(H),21β(H)-hopanes, undergo structural changes during the maturation process. The isomerisation reactions are thought to be produced via the 17β(H),21α(H)-hopanes (moretanes) to the most stable 17α(H),21β(H)-hopanes. At equilibrium 100% of the 17α(H)-hopanes are seen. The ratio αβ/αβ+βα is used to describe this reaction. In the extended hopanes (>C_{31}), the thermally stable S configurations at C-22 become increasingly more abundant as compared to the biologically preferred R configurations at increased maturity level. The equilibrium ratio is approximately 60% of the 22S configuration. Another ratio that is known to change with maturity is the Tm/Ts (Seifert et al., 1978) of the C_{27} hopanes. The maturable 18α(H)-trisnorneohopane (Tm) is reduced in intensity relative to the more stable 17α(H)-trisnorneohopane (Ts), causing the Tm/Ts to decrease at increased maturity. This ratio is also believed to be source dependant, and this should be born in mind when applying the ratio for maturity comparison. The amount of tricyclic terpanes is also to

a certain extent seen to be maturity dependant.

Two isomerisation reactions taking place in the steranes are most commonly applied for maturity assignments from the m/z 217 mass chromatograms. The biologically preferred 14α(H),17α(H)-isomers of the regular steranes is transformed to the thermally stable 14β(H),17β(H)-steranes, the %ββ approaching 75% at equilibrium. An equilibrium concentration of 50% is seen of the stable S configuration at C-20 as opposed to the 100% of the biological 20R epimer (Mackenzie et al., 1980). The abundance of rearranged steranes increased with increasing maturity.

One of the reactions taking place at an early stage of diagenesis is the aromatisation of steranes, leading to the formation of mono- and triaromatic analogs. This process is measured as the abundance of triaromatic relative to mono-aromatic compounds (% tri/tri + mono) in the m/z 231 and 253 mass chromatograms, respectively. In addition the degree of side chain cracking, as $\%C_{20}/C_{26,27}$ and $\%C_{21}/C_{28,29}$ respectively, is applied. These cracking processes are also taking place during early diagenesis, and are used for maturity assignment together with the previously mentioned ratios.

Migration and weathering

The effect on the geochemical fossils of migration and weathering, is less apparent than the maturity induced changes. Migration is believed to cause an increase in the relative amounts of rearranged and 14β(H),17β(H) regular steranes (Seifert and Moldowan, 1978, 1981). Severe biological alteration leads to the formation of desmethyl-hopanes (Seifert and Moldowan, 1979).

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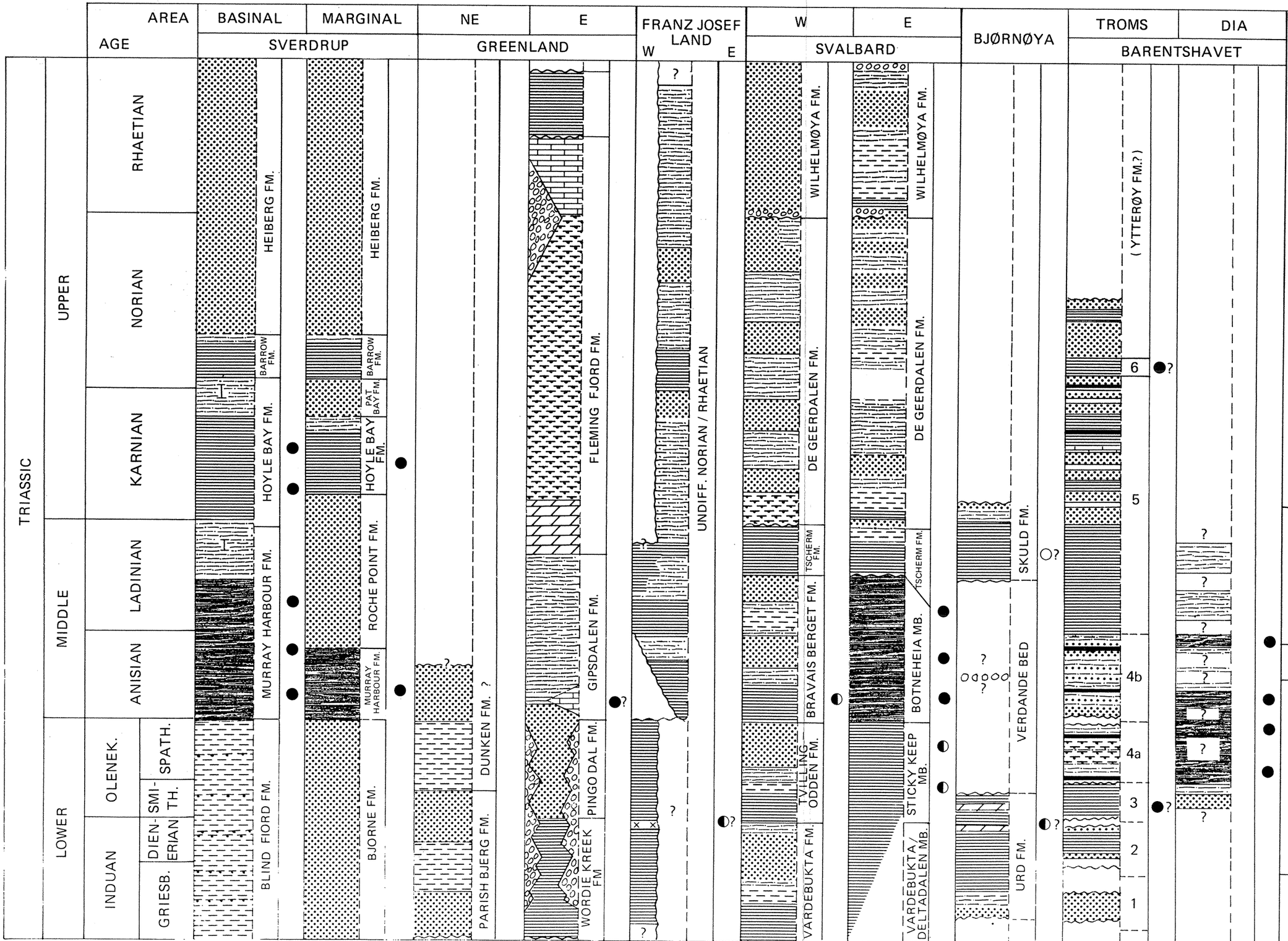


ENCLOSURE E.1

KEY

- DARK , ORG-RICH SHALE
- SHALE
- SILTY SHALE/CLAYSTONE
- SILTSTONE
- MIXED CLASTICS
- SANDSTONE
- CONGLOMERATE
- LIMESTONE
- DOLOMITE
- IGNEOUS ROCK
- EVAPORITE
- CO_3^{2-} INTERBEDS
- COAL
- OIL – PRONE
- GAS – PRONE
- OIL / GAS – PRONE

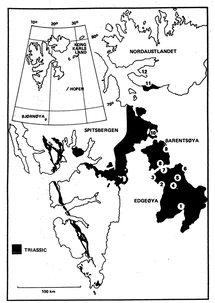
SEDIMENTATION IN THE BARENTS SHELF AND SURROUNDING AREAS DURING THE TRIASSIC

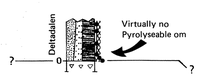
COMPILED BY: L. LEITH

REFERENCES :

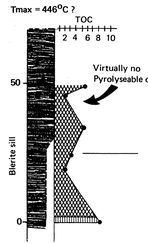
CLEMMENSEN (1980),
EMBRY (1984), HÅKANSSON AND STEMMERIK (1984), IKU (1986),
JACOBSEN AND VAN VEEN (1984),
MØRK ET AL. (1982),
PERCH–NIELSEN ET AL. (1974),
ULMISHEK (1982),
VGCECHOVSKAJA (1985).

IKU
SINTEF-GRUPPEN





ZEIPELFJELLET
(12)



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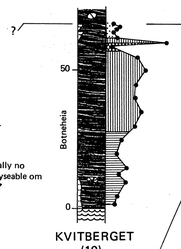

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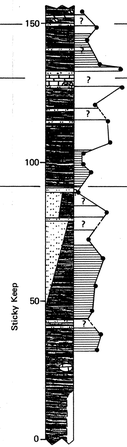
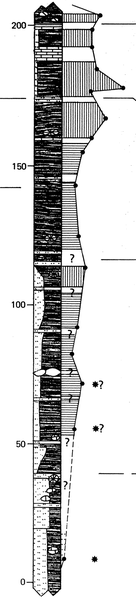


LOMBERGET
(9)



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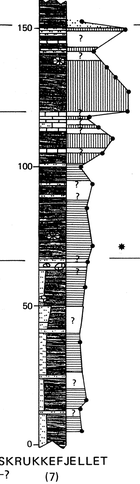

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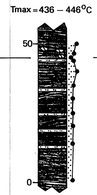

KAPP PEUCHEL LÖSCHE
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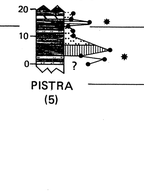

PISTRA
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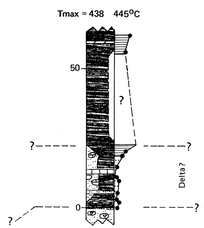

KROKÁ
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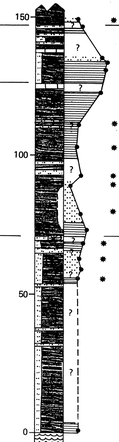

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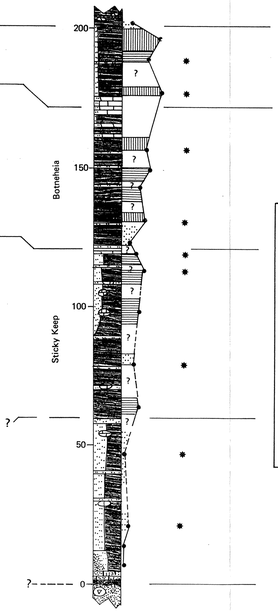


VEIDEMANNEN /
VEIDEBREEN
(1)

ENCLOSURE E.2

IKU SINTEF GROUP

ORGANIC RICHNESS / ROCK – EVAL KEROGEN TYPE
OF THE BARENTSØYA FORMATION ON EDGEØYA ,
BARENTSØYA AND NORDAUSTLANDET

Compileed by L. Leith
(After AA. Mørk 1986)

- Possible bitumen staining
- Shale
- Siltstone
- Sandstone
- Carbonate

KEY TO KEROGEN TYPE

- Type I (HI>600 mg/g TOC)
- Type II (HI = 400 – 600 mg/g TOC)
- Type II/III (HI = 200 – 400mg/g TOC)
- Type III (HI = 50 – 200mg/g TOC)
- Type IV (HI<50 mg/g TOC)

Tmax = 435 – 445°C
TOC
2 4 6 8 10

BERTILRYGGEN
(24)

Tmax = 435 – 445°C
AvVR = 0,52%

BOTNEHEIA Mb.
STICKY KEEP Mb.
DELTADALEN Mb.
Base Anisian

TSCHERMAKFJELLET
(23)

Tmax = 439 – 447°C
AvVR = 0,57%

?Sill

BOTNEHEIA
(22)

Tmax = 435 – 443°C

Tmax = 438 – 443°C

VIKINGHØGDA /
DELTADALEN
(21)

STICKY KEEP
(20)

Tmax = 439 – 445°C
AvVR = 0,60%

VENDOMDALEN
(18)

Tmax = 442 – 452°C
AvVR = 0,57%

JINBREEN
(17)

Tmax = 437 – 443°C
AvVR = 0,49%

STENSIÖFJELLET
(16)

Tmax = 444 – 454°C
AvVR = 0,72%

KRAPOTKINFJELLET
(15)

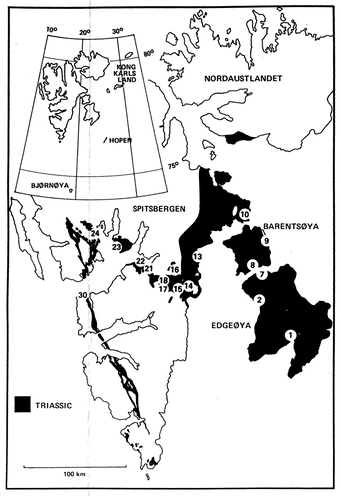
No org. Geochem. data!!
(See boreholes)

Tmax = 438 – 450°C
AvVR = 0,53%

ROSLAGENFJELLET
(14)

Tmax = 429 – 442°C
AvVR = 0,45%

TEISTBERGET
(13)



ENCLOSURE E.3

IKU SINTEF GROUP

ORGANIC RICHNESS / ROCK – EVAL KEROGEN TYPE
OF THE BARENTSØYA FORMATION ON EASTERN
AND CENTRAL SPITSBERGEN

Compiled by L. Leith
(After A. Mørk 1986)

- Possible bitumen staining
- Shale
- Siltstone
- Sandstone
- Carbonate

KEY TO KEROGEN TYPE

- Type I (HI>600 mg/g TOC)
- Type II (HI = 400 – 600 mg/g TOC)
- Type II/III (HI = 200 – 400mg/g TOC)
- Type III (HI = 50 – 200mg/g TOC)
- Type IV (HI<50 mg/g TOC)

Comparative Organic Geochemisstry of Triassic Rocks from the Dia - Structure, Svalbard and surrounding areas.

1988
by
L. Leith

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