

GRØNLANDS GEOLOGISKE UNDERSØGELSE

**G E U S**

Report file no.

22439

RAPPORT Nr. 102

*The Geological Survey of Greenland  
Report No. 102*

---

Thermal maturation of organic matter  
by a thick basaltic sill in Upper Cretaceous shales,  
Svartenhuk Halvø, central West Greenland

by

*E. J. Schiener and J. Perregaard*

---

KØBENHAVN 1981



# Grønlands Geologiske Undersøgelse

(The Geological Survey of Greenland)

Øster Voldgade 10, DK-1350 Copenhagen K

## Reports

- No. 77 West Greenland coal deposits, distribution and petrography. 1976 by E. J. Schiener. D.kr. 12.00
- No. 78 Late Precambrian acritarchs from the Eleonore Bay Group and Tillite Group in East Greenland. A preliminary report. 1976 by G. Vidal. D.kr. 10.00
- No. 79 Results of geological work in central West Greenland in 1973–1974. 1977. D.kr. 27.00
- No. 80 Report of activities, 1975. 1976. D.kr. 45.00
- No. 81 Volcanic geology of native iron bearing rocks from west Disko, central West Greenland. 1977. D.kr. 56.00
- No. 82 Cambrian-Silurian stratigraphy of Børglum Elv, Peary Land, eastern North Greenland. 1977 by R. L. Christie & J. S. Peel. D.kr. 24.00
- No. 83 Precambrian and Tertiary geology between Kangerdlugssuaq and Angmagssalik, East Greenland. A preliminary report. 1978 by D. Bridgewater *et al.* D.kr. 14.00
- No. 84 The migmatites, granites and metasediments of Danmark Ø and adjacent areas of Milne Land and Gáseland, East Greenland Caledonian fold belt. 1979 by K. Bucher-Nurminen. D.kr. 35.00
- No. 85 Report of activities, 1976. 1977. D.kr. 40.00
- No. 86 The Quaternary geology of the Narssaq area, South Greenland. 1979 by S. Funder. D.kr. 22.00
- No. 87 Project Westmar – A shallow marine geophysical survey on the West Greenland continental shelf. 1979 by C. P. Brett & E. F. K. Zarudzki. D.kr. 25.00
- No. 88 Report on the 1978 geological expedition to the Peary Land region, North Greenland. 1979. D.kr. 75.00
- No. 89 Nagssugtoqidian geology. 1979. D.kr. 95.00
- No. 90 Report of activities, 1977. 1978. D.kr. 70.00
- No. 91 Lower Palaeozoic stratigraphy and palaeontology: shorter contributions. 1979. D.kr. 95.00
- No. 92 Geology of the continental shelf off West Greenland between 61°15'N and 64°00'N: an interpretation of sparker seismic and echo sounder data. 1979 by M. M. Roksandić.
- No. 93 Structural and stratigraphic framework of the North Greenland fold belt in Johannes V. Jensen Land, Peary Land. 1979 by P. R. Dawes & N. J. Soper. D.kr. 36.00
- No. 94 Hydrological basins in West Greenland. 1980 by A. Weidick & O. B. Olesen. D.kr. 80.00
- No. 95 Report of activities, 1978. 1979. D.kr. 65.00
- No. 96 The status of the Neoglacial in western Greenland. 1980 by M. Kelly. D.kr. 25.00
- No. 97 The tholeiitic and komatiitic affinities of the Malene metavolcanic amphibolites from Ivisârtoq, southern West Greenland, 1980 by R. P. Hall. D.kr. 25.00
- No. 98 Regional modelling of ablation in West Greenland. 1980 by R. J. Braithwaite. D.kr. 22.00
- No. 99 Report on the 1979 geological expedition to the Peary Land region, North Greenland. 1980. D.kr. 90.00
- No. 100 Report of activities, 1979. 1980. D.kr. 65.00
- No. 101 Palaeontology and stratigraphy of Greenland: short contributions. 1980. D.kr. 65.00
- No. 102 Thermal maturation of organic matter by a thick basaltic sill in Upper Cretaceous shales, Svartenhuk Halvø, central West Greenland. 1981 by E. J. Schiener & J. Perregaard.
- No. 105 Report of activities, 1980. 1981.

GRØNLANDS GEOLOGISKE UNDERSØGELSE  
RAPPORT Nr. 102

Thermal maturation of organic matter  
by a thick basaltic sill in Upper Cretaceous shales,  
Svartenhuk Halvø, central West Greenland

*by*

*E. J. Schiener and J. Perregaard*

1981

## **Abstract**

Thermal effects of igneous intrusions on sedimentary organic matter indicate that organic compounds are more stable under geologically short but intense exposure to high temperature compared to those affected by slow burial.

In the immediate contact zone a drastic reduction occurs in kerogen content, accompanied by high reflectance values. The presence in this zone of *n*-alkanes in the C<sub>15</sub>–C<sub>20</sub> range suggests hydrogenation of kerogen. Heat effects are still recognisable at a distance of three times the thickness of the intrusive body.

## Contents

Introduction .....	5
Sample material .....	5
Experimental procedures .....	5
Organic geochemistry .....	5
Microscopy .....	6
Results .....	6
Organic carbon ( $C_{org}$ ) .....	6
Extractable organic matter (EOM) .....	8
Composition of hydrocarbons .....	8
Microscope investigations .....	11
Discussion .....	12
Conclusions .....	14
Acknowledgements .....	14
References .....	14

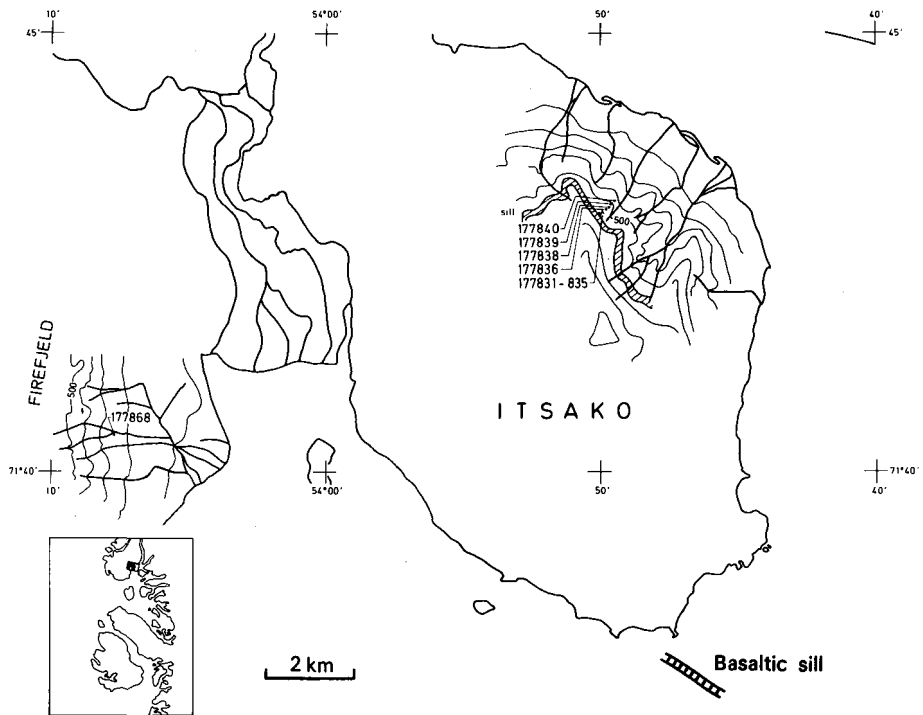


Fig. 1. Map of south-eastern Svartenhuk Halvø showing sampling positions at Itsako and Firefield.

## Introduction

Thermal maturation of organic matter in sediments is now generally recognised as the essential process in the formation of the main constituents of hydrocarbons. Investigation of potential source lithologies (dark shales) of the Nûgssuaq embayment has provided regional data on the content, composition and maturation of the sedimentary organic matter (Schiener & Leythaeuser, 1978; Perregaard, 1979). Basaltic sills & dykes of varying dimensions have locally intruded the organic rich shales and have provided an excellent opportunity for studying in detail the thermal effects on the organic matter. Similar investigations have been performed earlier (Bostick, 1974; Sauvan *et al.*, 1975; Simoneit *et al.*, 1978, Peters *et al.*, 1979), but were either restricted to a microscope approach, followed by pyrolysis experiments, or when applying organic geochemical methods produced slightly different results from the ones presented here.

The present study is a continuation of earlier work on West Greenland sediments, aiming at a comparison of the effects of geologically short lived maturation by igneous intrusions with diagenetically induced changes by subsurface burial over considerable geological periods. Both organic geochemical and microscopic methods were applied in order to achieve improved control between the various analytical parameters.

## Sample material

Samples were collected from outcrops in lithologically uniform carbonaceous silty shales below a 30 m thick basaltic sill on Itsako, Svartenhuk Halvø, West Greenland (fig. 1). Wherever possible samples were obtained from between 30 and 60 cm below the outcrop surface to avoid weathering effects (Clayton & Swetland, 1978). According to palynostratigraphic determinations (Croxtton, 1978) the sampled sequence is of Upper Cretaceous – Lower Tertiary age. Marine macrofossils of Turonian to Campanian age are reported from the Svartenhuk Halvø – Itsako region (Rosenkrantz, 1970) suggesting a possible contribution by marine organisms to the organic matter.

## Experimental procedures

### Organic geochemistry

Analytical arrangements follow largely the procedures described in Perregaard (1978). Samples are dried before grinding to particle size of  $<160 \mu$  for more than 90 percent of the particles. Before determination of the content of organic carbon (%  $C_{org}$ ) by combustion and

measurement of the quantity of liberated CO<sub>2</sub> by infrared absorption in a Leco IR 12 analyser, the carbonate carbon is removed by HCl treatment.

Soxhlett extraction, with dichloromethane (CH<sub>2</sub>Cl<sub>2</sub>) as solvent, is used for the quantitative determination of extractable organic matter (EOM). Extracts are subsequently separated by column chromatography (Al<sub>2</sub>O<sub>3</sub> + silicagel) into aliphatic hydrocarbons (eluted with *n*-hexane), aromatic hydrocarbons (eluted with dichloromethane), hetero components (eluted with methanol) and asphaltenes (retained on the column). The cut between different fractions is decided with UV and <sup>1</sup>H NMR analysis. All solvents are predestilled. Saturated hydrocarbons in the C<sub>15+</sub> boiling range are analysed by GLC separation on a Hewlett-Packard 5840A gas chromatograph equipped with an OV-1 (20 m) capillary column. Quantitative measurements were performed by integration of peak areas followed by an internal standard (using 1,2,3,4-tetrahydronaphthalene) calibration programme. A computer programme was used to provide plots of relative *n*-alkane distributions, tables of *n*-alkane concentrations in the analysed sediments and calculations of component ratios by treating selected analytical data from each sample.

<sup>1</sup>H NMR spectra were recorded at 60 MHz on a Varian T60 spectrometer using TMS as an internal reference standard.

### Microscopy

Crushed material (1 mm < diam. < 2 mm) was embedded in epoxy blocks as whole rock preparations in which the morphological characteristics and relationships between organic matter and mineral matrix remain preserved and thus aid correct identification. The blocks were subsequently polished to coal petrographic standards (Stach *et al.* 1975). A Zeiss Photomicroscope 03 equipped with photomultiplier and oil immersion objectives was used for measurement of vitrinite reflectance at 546 nm and for observation of the kerogen in both reflected white light and under UV-radiation at 365 nm.

Reflectance measurements were carried out in polarised light in order to record maximum reflectance ( $R_{\max}$ ) of the partly anisotropic vitrinite. Where possible between 40 and 60 vitrinite particles were measured per sample; readings were recorded digitally on punch tape and treated offline in a PDB 11 mini-computer to provide histogram plots and calculations of mean and standard deviation.

## Results

Organic geochemical parameters reflecting the thermally induced changes in content and composition of both extractable and non-extractable organic matter (bitumen and kerogen) of the samples are reported in Table 1. Vitrinite reflectance values are presented as reference data to indicate the extent of thermal alteration.

### Organic carbon (C<sub>org</sub>)

The high organic carbon content in the range of 3–4% C<sub>org</sub> characteristic of the Upper Cretaceous and Paleocene of Svartenhuk Halvø (Perregaard, 1979), is found in the unafected samples investigated. A marked decrease in the content of C<sub>org</sub> is found close to the



Table 1. Geochemical data and vitrinite reflectance values on organic matter in Cretaceous shales matured by thermal alteration

GGU No.	Dist. from basaltic sill margin (m)	C <sub>org</sub> w/wt%	Vitrinite reflectance R <sub>max</sub> (R <sub>m</sub> )*	Extractability mg EOM/g C <sub>org</sub>	Hydrocarbons (% of EOM)	Sat. hydrocarbons (% of EOM)	CPI (24-32)	Pristane/n-C <sub>17</sub>	Ratio <sup>†</sup> aliph. to aromat. hydrogen
177835	contact	0.11	6.00	-	-	-	-	-	-
177831	1.5	0.29	5.80	-	-	-	-	-	-
177832	2.0	0.63	4.60	-	-	-	-	-	-
177833	2.5	1.49	2.61	2.5	-	-	-	-	-
177834	3.0	2.29	3.37	1.9	86.4	65.9	-	-	-
177836	40.0	3.42	1.00	17.3	70.8	46.6	1.16	0.3	1.71
177838	55.0	3.27	0.72	17.7	65.6	34.7	1.34	0.6	2.50
177839	65.0	3.66	0.65*	16.7	58.8	23.0	1.46	0.9	2.81
177840	85.0	3.00	0.68*	12.6	55.2	17.5	1.48	3.5	2.92
177868	reference sample	4.00	0.45*	8.7	37.4	6.3	1.47	4.1	-

\* Average reflectance values

† <sup>1</sup>H NMR analyses of aromatic fractions

Aliphatic hydrogen: integrated area in the range 40-200 Hz

Aromatic hydrogen: integrated area in the range 400-550 Hz

igneous body (Table 1). In the immediate contact zone only 0.11% C<sub>org</sub> is preserved. This decrease is equally well observed under the microscope where high reflecting organic matter (R<sub>max</sub> > 5%) is condensed to wispy stringers parallel to the bedding and to irregular microveins at roughly right angles to the bedding (pyrobitumen?) (fig. 2c).

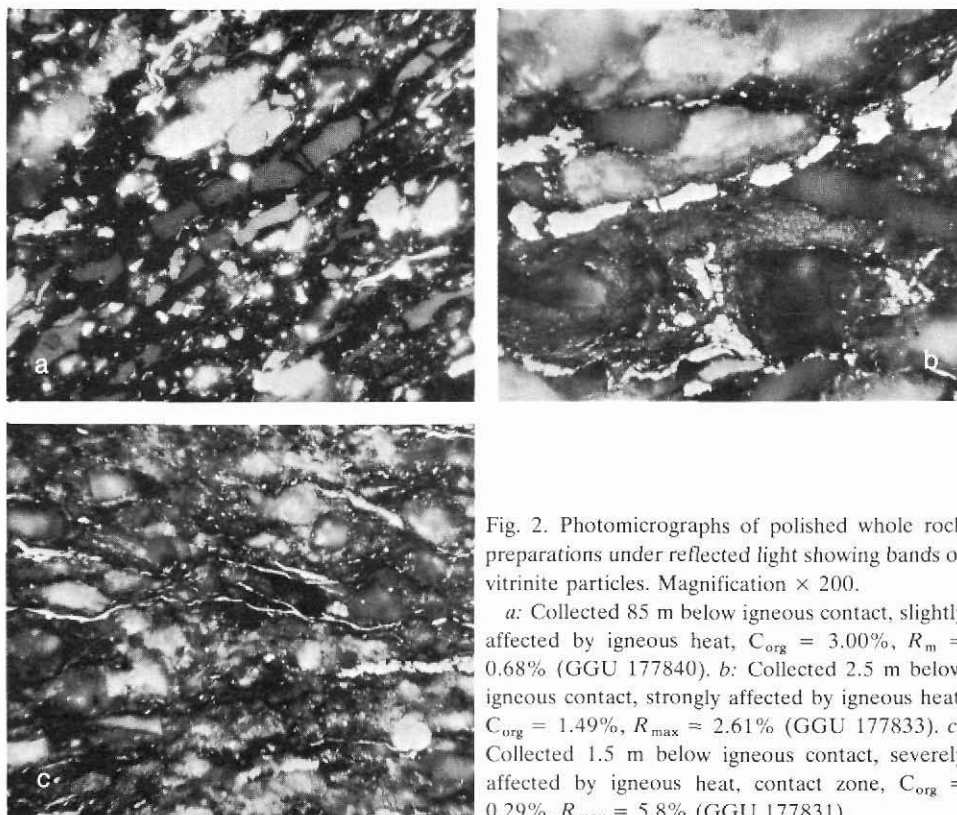


Fig. 2. Photomicrographs of polished whole rock preparations under reflected light showing bands of vitrinite particles. Magnification  $\times 200$ .

a: Collected 85 m below igneous contact, slightly affected by igneous heat, C<sub>org</sub> = 3.00%, R<sub>m</sub> = 0.68% (GGU 177840). b: Collected 2.5 m below igneous contact, strongly affected by igneous heat, C<sub>org</sub> = 1.49%, R<sub>max</sub> = 2.61% (GGU 177833). c: Collected 1.5 m below igneous contact, severely affected by igneous heat, contact zone, C<sub>org</sub> = 0.29%, R<sub>max</sub> = 5.8% (GGU 177831).

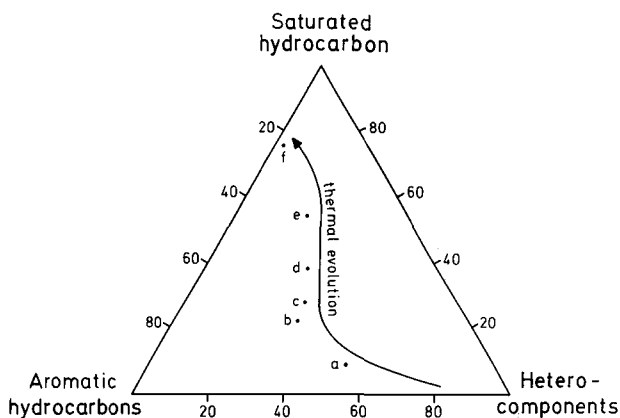
### Extractable organic matter (EOM)

From the immature sample to the mature samples (GGU 177868 ( $R_m = 0.45\%$ ) → GGU 177836 and GGU 177838 ( $R_{max} > 0.7\%$ )) extract yields are seen to double, followed by a sharp drop in the metamorphosed zone (Table 1).

From liquid chromatography of the extractable organic matter it was found that both absolute concentration (mg HC/g  $C_{org}$ ) and the relative proportion of hydrocarbons of EOM reach a maximum at a maturation level of between 0.7 and 1.0%  $R_{oil}$ .

This agrees with earlier observations that progressive thermal alteration of sedimentary organic matter during the burial process results in increased production of hydrocarbons (Albrecht *et al.*, 1976). In particular the proportion of saturated hydrocarbons in EOM increases with corresponding decrease of the thermally unstable NSO (nitrogen-sulphur-oxygen) compounds (fig. 3). Only a moderate increase in the absolute concentration (mg/g  $C_{org}$ ) of aromatics has been observed.

Fig. 3. Relative distribution of saturated hydrocarbons, aromatic hydrocarbons and hetero components in extracts. Asphaltenes and evaporative losses during preparation are excluded. Increasing thermal alteration is indicated on the diagram. a: 177868, b: 177840, c: 177839, d: 177838, e: 177836, f: 177834.



### Composition of hydrocarbons

The changes in distribution of *n*-alkanes (fig. 4) confirm the progressive thermal alteration of the organic matter as the sill is approached. Compared to the thermally unaffected sample GGU 177868 sample GGU 177840 shows only slight effects of thermal influence (Table 1) indicated by the dominant pristane peak and the predominance of higher boiling *n*-alkanes (heavy end) with odd numbers of carbon atoms. The carbon preference index (CPI)\* is the numerical expression of this odd/even dominance (Table 1). The range of *n*-alkanes for the CPI calculations was chosen to include as many of the heavy end *n*-alkanes as possible within a reasonable performance range of the gas chromatographic system. Above  $n\text{-C}_{31}$  integration of peak areas becomes uncertain and values below  $n\text{-C}_{25}$  are generally insignificant.

\* Carbon preference index (CPI) used in this report is expressed by

$$\frac{1}{2} \cdot \left( \frac{C_{25} + C_{27} + C_{29} + C_{31}}{C_{24} + C_{26} + C_{28} + C_{30}} \right) + \left( \frac{C_{25} + C_{27} + C_{29} + C_{31}}{C_{26} + C_{28} + C_{30} + C_{32}} \right)$$

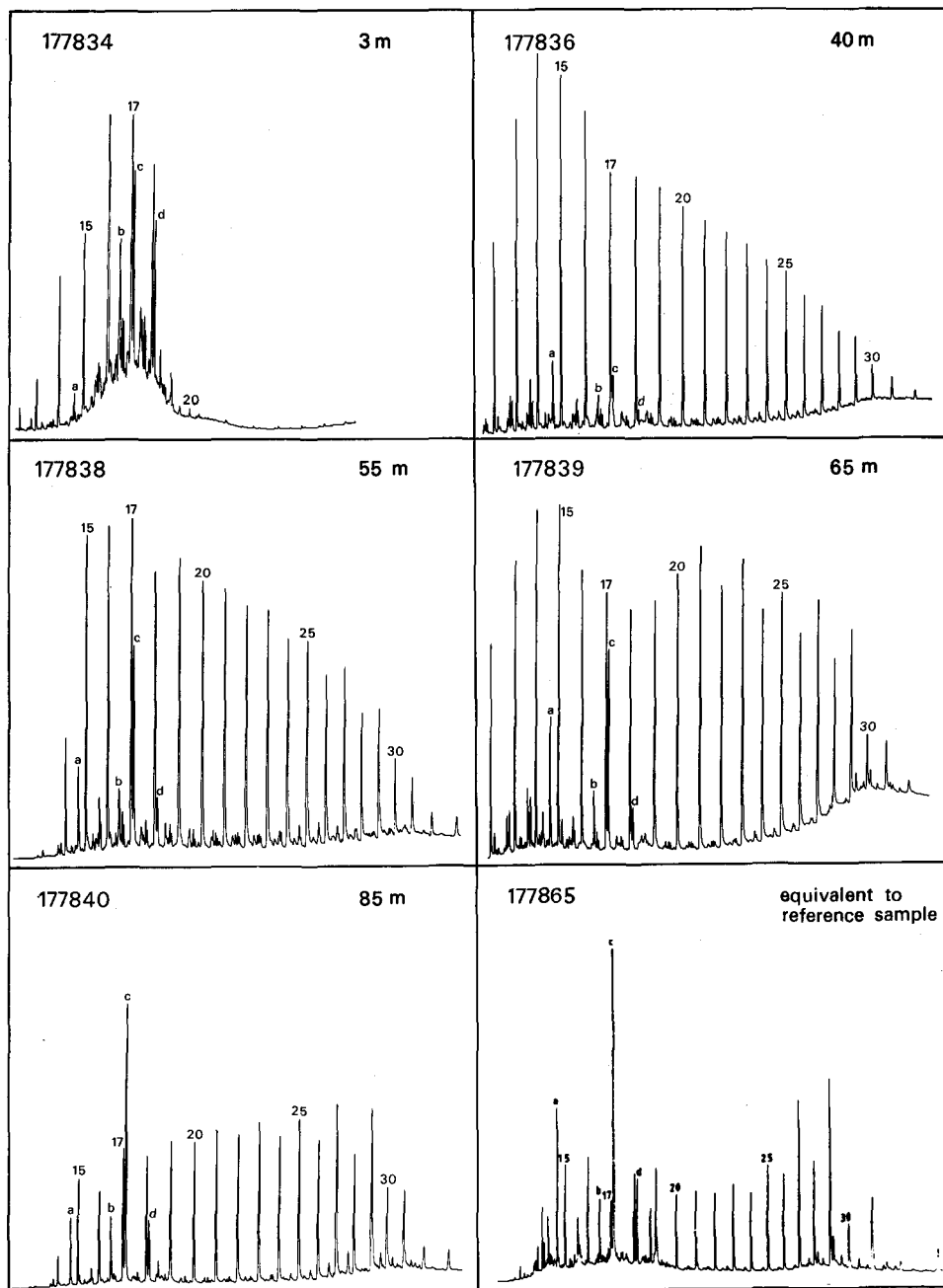


Fig. 4. GLC chromatograms of saturated hydrocarbon fractions. Distances given are in metres from the heat source. Sample 177865 is equivalent to the reference sample 177868 on Firefield. Figures indicate chain lengths of *n*-alkanes. a: C<sub>16</sub>-isoprenoid, b: nor-pristane, c: pristane, d: phytane.

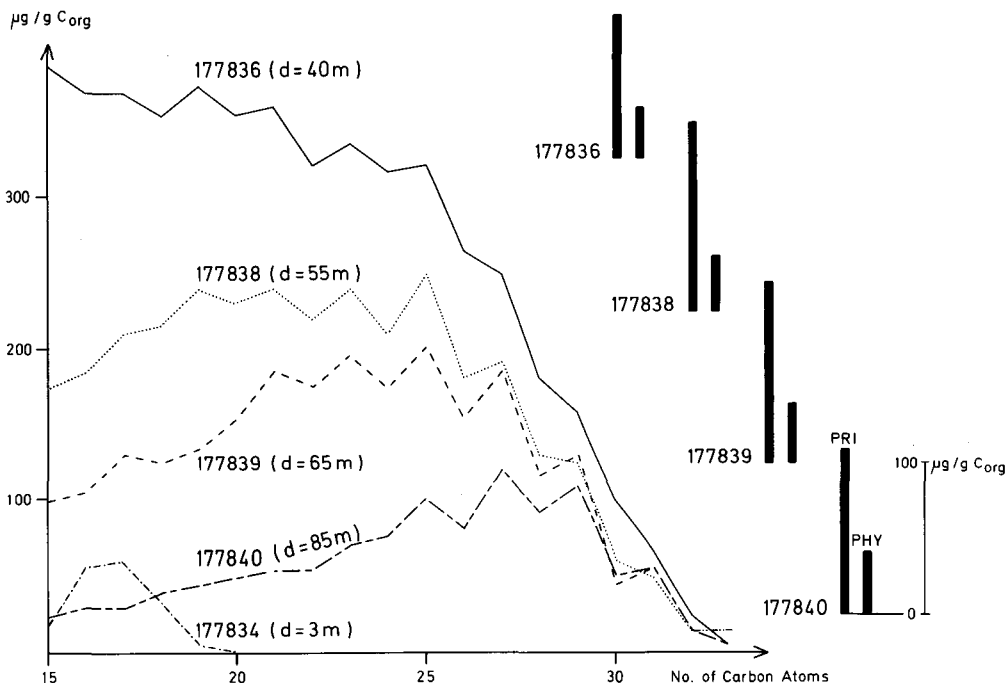


Fig. 5. Concentrations of *n*-alkanes pristane and phytane as function of distance from intrusion.

Similar distributions are found in recent immature sediments and biological systems where humic kerogen contributes to the organic matter (Tissot *et al.*, 1977).

The unaffected reference sample (GGU 177868) contains saturated hydrocarbons with an analogous distribution. Nearer the igneous intrusive the predominant contribution of heavy *n*-alkanes is replaced by a light end predominance and the CPI values approach unity. Crude oils are usually characterised by CPI values close to 1.

By quantitative GLC analysis it is found that *n*-alkanes increase in yield while the concentration of the isoprenoids pristane and phytane remain almost constant throughout the oil generating zone ( $0.5 < R_m < 1.35$ , Dow, 1977) (fig. 5). These features appear in Table 1 as declining pristane/*n*-C<sub>17</sub> ratios concurrent with increasing maturation. Only lower boiling alkanes below C<sub>20</sub> are found in the severely heated sample GGU 177834 (figs 4 & 5).

Compositional changes among the aromatic hydrocarbons were also observed by GLC analyses. With increasing maturation lower boiling aromatic compounds are generated. Heating results in dealkylation of aliphatic side chains and aromatisation of partly saturated rings.

These changes are reflected in <sup>1</sup>H NMR analyses. Hydrogen atoms bound to aromatic rings resonate in the range 400–550 Hz, while hydrogen bound to aliphatic parts of the hydrocarbon molecule resonates in the range 40–200 Hz (fig. 6). With increasing thermal influence the ratio of aliphatic hydrogens to aromatic hydrogens decreases (Table 1).

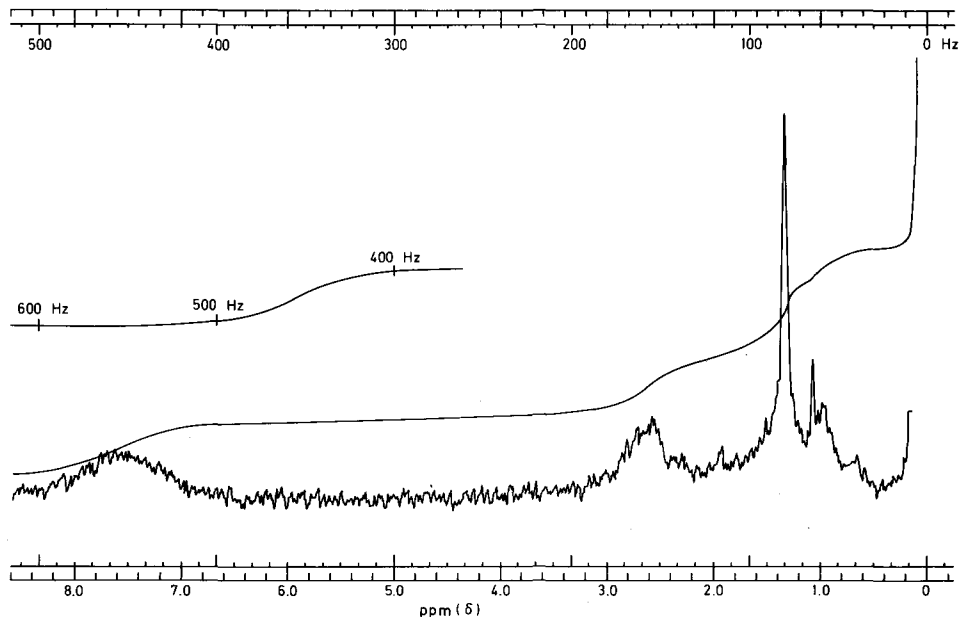


Fig. 6.  $^1\text{H}$  NMR spectrum of total aromatic hydrocarbon fraction from sample GGU 177839.

## Microscope investigations

In the samples where vitrinite reflectance ranges from 0.45% to 1.00% the organic matter is characterised by a predominance of humic constituents (vitrinite + fusinitic inertinite 95–98%). Two types of vitrinites may be distinguished by their morphology. The equigranular, particulate vitrinites show signs of strong oxidation (higher reflecting rims of fissures and grain margins). In vitrinite seamlets and wisps parallel to the bedding the degree of oxidation is less well developed.

The sample suite from Itsako (fig. 1) is characterised by a predominance of particulate organic matter of uniformly small grain size (10–20  $\mu\text{m}$ ).

Low reflecting material occurring as fillings of irregular microfissures, frequently orientated oblique to the bedding, is interpreted as non-fluorescing asphaltic bitumen (? pyrobitumen) (fig. 2a).

The reference sample from Firefjeld (GGU 177868) differs in the humic components only in considerably larger grain size (50–100  $\mu\text{m}$ ) of the particulate vitrinites and more continuous and thicker vitrinite bands.

Only a few microspores are found in the figured exinitic constituents, but in sample GGU 177868 some yellow fluorescing amorphous material occurs which might represent microbial degradation products of exinitic components. In the same sample faintly yellow fluorescing interstices between calcite crystals are indicative of generated bitumen (bituminite: Teichmüller, 1974).

## Discussion

Thermal maturation of sedimentary organic matter is now generally recognised as the essential process in the formation of hydrocarbons found in petroleum. Depending upon geothermal conditions and on the effective time of exposure to elevated temperatures of the sediments, burial to adequate depths results in the formation of hydrocarbons from kerogen (Philippi, 1965; Tissot *et al.*, 1971). The main generation phase is taken to lie in the temperature range of 60–150°C. Laboratory pyrolysis of sediments and kerogens has shown that hydrocarbons are released in the temperature range 300–500°C, depending on experimental conditions and on the maturity and type of the organic matter used in the experiments (Douglas *et al.*, 1975; Espitalié *et al.*, 1977).

The drastic drop in organic carbon content close to igneous intrusions where the sedimentary organic matter suffered exposure to the most intense heating is now well established from detailed studies in the Nûgssuaq Embayment, West Greenland (Perregaard, 1979) and from the study of a series of Jurassic outcrops in Milne Land, East Greenland (Perregaard & Schiener, 1979). Similar findings are reported by other authors (Degens, 1968; Sauvan *et al.*, 1975; Akiyama *et al.*, 1979; Peters *et al.*, 1979). Oxidation and gasification of the organic carbon to CO<sub>2</sub> or CO through reduction with pore or absorbed water of the mineral matrix is thought to be responsible for the reduction in kerogen content (Sauvan *et al.*, 1975; Perregaard & Schiener, 1979). Laboratory pyrolysis of sediments containing immature kerogen at 500–700°C in an inert atmosphere in glass ampoules corroborate these findings (Perregaard, unpublished results). According to Bostick (1974) vitrinite reflectance values of  $R_{\max} > 4.0\%$  correspond to pyrolysis temperatures in excess of 600°C for shales containing humic organic matter.

The quantity of extractable hydrocarbons (EHC) (3.3 mg EHC/g C<sub>org</sub>) found in the immature reference sample (GGU 177868) is in accordance with concentrations of C<sub>15+</sub> hydrocarbons reported by Philippi (1968) for recent shallow marine sediments (4.3 mg EHC/g C<sub>org</sub>) and recent sediments from deep marine basins (3.7 mg EHC/g C<sub>org</sub>). Also in the matured Itsako samples the hydrocarbon concentrations are comparatively low, evidently owing to the unfavourable humic origin of the organic matter. Weathering effects may be responsible for some additional reduction in hydrocarbon content (Clayton & Swetland, 1978). Good petroleum source rocks are reported to contain 30–150 mg EHC/g C<sub>org</sub> (Philippi, 1968). In the Itsako samples the highest concentration of hydrocarbons was found in sample GGU 177836 (12.2 mg EHC/g C<sub>org</sub>) which, according to the reflectance value of  $R_{\max} = 1.0\%$ , falls well within the zone of peak hydrocarbon generation for the humic type kerogen. The abundant contribution of *n*-alkanes to the saturated hydrocarbon fractions similarly is an expression of the higher land plant origin of the organic matter (Brooks, 1973; Lijmbach, 1975).

Generation of hydrocarbons by exposure to increasing subsurface temperatures creates a relative increase in *n*-alkanes compared to cyclic and branched alkanes with increasing maturation (Tissot, *et al.*, 1971; Milner *et al.*, 1977). A similar temperature related evolution emerges for the Itsako samples. From the slightly matured sample GGU 177840 where *n*-alkanes constitute approximately 40%, the *n*-alkane contribution in the well matured sample GGU 177836 increases to approximately 70% of the total saturated hydrocarbon fraction.

The relatively high proportion of isoprenoid alkanes (figs 4 & 5) is thought to indicate



high photosynthetic activity prior to deposition. The chlorophyll molecule includes a phytol side chain which may be hydrolysed during early diagenesis to the acyclic diterpenoid phytol. In an oxygen deficient environment phytol may then be directly reduced to phytane whereas under oxidising conditions it may become oxidised and subsequently decarboxylated to pristane. The ratios of pristane/phytane may thus be used as indicators for the depositional environment (Powell & McKirdy, 1973). In the analysed samples concentrations and ratios of pristane to phytane remain constant throughout the temperature regime of the oil generating zone (samples GGU 177836 to 177840, fig. 5) and would thus seem to indicate a low temperature, diagenetic origin of these isoprenoids. Laboratory pyrolysis of mature sediments and kerogens has shown that only insignificant amounts of these compounds are formed by thermal cracking of mature kerogens (Perregaard, 1979, and unpublished results). Only low energy oxidation and reduction processes seem to control the formation of these isoprenoids.

Deeply buried sediments (well into the metamorphic dry gas zone) generally do not contain liquid hydrocarbons in the  $C_{15+}$  range (Hunt, 1977). Nevertheless, even in the severely metamorphosed samples GGU 177834 and 177833 appreciable quantities (1.5–2.0 mg EHC/g  $C_{org}$ ) of low molecular weight hydrocarbons, particularly saturated hydrocarbons in the  $C_{15+}$  range, were present. Migration cannot be ruled out to explain the presence of these hydrocarbons. It should be remembered that the chemical conditions for the cracking process that generates hydrocarbons under relatively high temperature conditions differ from those that exist during the geological burial situation. In the case of geologically short but intense heating by igneous intrusions, the extractable hydrocarbons of low molecular weight in the range  $C_{15}$  to  $C_{20}$  can also be considered as having formed *in situ* by hydrogenation of kerogen (Akiyama *et al.*, 1979). Their preservation in the high temperature environment is tentatively related to particular kinetic conditions where the carbon-carbon bonds of free hydrocarbons show greater stability than the bonds of aliphatic structures containing heteroatoms. These considerations are just an exemplification of the behaviour of chemical structures in relation to the different activation energies established for the thermal cracking processes of the three different types of kerogens as outlined in Tissot & Welte (1978).

In the literature it is claimed that heat effects of igneous intrusions on sedimentary organic matter are limited to a distance of approximately 100% of the thickness of the intrusion (Degens, 1968; Bostick, 1974; Sauvan *et al.*, 1975; Perregaard & Schiener, 1979). In the references cited, the thickness of the intrusive bodies did not exceed about five metres. In the present study maturation parameters like vitrinite reflectance, extractability and hydrocarbon distribution indicate that the thermal effects may reach up to 300% of the thickness. This is attributed to the considerably greater thickness of the intrusive body, with accordingly greater capacity for heat flow (Jaeger, 1959). During burial to comparable maturation levels the organic matter is exposed to considerably lower temperatures, but over much longer periods of time.

The microscopically observable organic matter is predominantly of humic origin, which commonly is not rated as a source for significant amounts of saturated hydrocarbons in the  $C_{15+}$  range. Thermal maturation of humic substances yields proportionally greater quantities of aromatic and asphaltic compounds. The asphalt observed in fissures in the matured samples is thus probably derived from the vitrinitic components. But the relatively high proportion of paraffinic hydrocarbons in the extracts (Table 1) can partly be attributed to thermally effected reduction of polar lipid components and partly to a derivation from a

minor part of the kerogen (derived from exinitic organic matter – leaf cuticles, spores and pollen) by thermal cracking (Brooks, 1973). Figured exinites constitute less than 5% of the organic matter (microspores and cuticular fragments). The weak fluorescence of the matrix, as well as of intergranular spaces, suggests the presence of additional microscopically irresolvable exinitic material which may have originated from microbial degradation of figured organic matter (Lijmbach, 1975).

## Conclusions

The following conclusions can be drawn from the study of the Upper Cretaceous–Tertiary samples from Svartenhuk Halvø.

1. The content of organic matter of samples with no or only moderate exposure to heat from the igneous intrusive is above average compared to oil source rocks.
2. A drastic reduction in organic carbon content is observed in the zone of extreme heating and is tentatively related to oxidation processes leading to the formation of CO or CO<sub>2</sub>.
3. The extracts and hydrocarbon fractions undergo progressive changes dependent on the distance from the intrusion, which are correlatable to temperature zones observed in deep bore holes.
4. The concentration per unit of C<sub>org</sub> of the isoprenoid alkanes pristane and phytane are practically unaffected by increasing temperatures within the oil generating zone suggesting thermal stability.
5. Results of similar investigations of organic rich sediments intruded by igneous rocks can be used in the evaluation of their hydrocarbon source potential.

## Acknowledgements

Financial support for the organic geochemical studies from the Danish Natural Science Research Council is gratefully acknowledged. <sup>1</sup>H NMR analyses were kindly performed in the Department of General and Organic Chemistry, H. C. Ørsted Institute, University of Copenhagen.

GGU technicians J. Abécassis and J. Boserup ably assisted with the experimental work.

## References

- Akiyama, M., Hirata, S. & Ujiie, Y. 1979: Thermal alteration of kerogen by basalt dykes intruded in the Oligocene Porouai Formation, Hokkaido, Japan. *J. Fac. Sci. Hokkaido Univ. (IV)* **19**, 149–156.
- Albrecht, P., Vandenbroucke, M. & Mandengué, M. 1976: Geochemical studies on the organic matter from the Douala Basin (Cameroon). I. Evolution of the extractable organic matter and the formation of petroleum. *Geochim. cosmochim. Acta* **40**, 791–799.
- Bostick, N. H. 1974: Phytoclasts as indicators of thermal metamorphism, Franciscan Assemblage and Great Valley Sequence (Upper Mesozoic), California. *Geol. Soc. Amer. Spec. Pap.* **153**, 17 pp.
- Brooks, J. D. 1973: The generation of oil and gas in some Australian sedimentary basins. *Biogeochemistry* **2**, 222–237.

- Clayton J. L. & Swetland, P. J. 1978: Subaerial weathering of sedimentary organic matter. *Geochim. cosmochim. Acta* **42**, 305–312.
- Croxton, C. A. 1978: Report of field work undertaken between 69°N and 72°N, central West Greenland in 1975 with preliminary palynological results. Unpubl. int. GGU report, 99 pp.
- Degens, E. T. 1968: *Geochemie der Sedimente*. Stuttgart: Ferdinand Enke Verlag.
- Douglas, A. G., Coates, R. C., Bowler, B. F. J. & Hall, K. 1975: Alkanes from the pyrolysis of recent sediments. In R. Campos & J. Goni (edit.) *Advances in Organic Geochemistry*, 357–374. Madrid: Enadimsa.
- Dow, W. G. 1977: Kerogen studies and geological interpretations. *J. geochem. Explor.* **7**, 79–99.
- Espitalié, J., Laporte, J. L., Madec, M., Marquis, F., Leplat, P., Paulet, J. & Boutefeu, A. 1977: Méthode rapide de caractérisation des roches meres de leur potentiel pétrolier et de leur degré d'évolution. *Rev. Inst. franç. Petrole* **32**, 23–42.
- Hunt, J. M. 1977: Distribution of carbon as hydrocarbons and asphaltic compounds in sedimentary rocks. *Bull. Amer. Ass. Petrol. Geol.* **61**, 100–104.
- Jaeger, J. C. 1959: Temperatures outside a cooling intrusive sheet. *Am. J. Sci.* **257**, 44–54.
- Lijmbach, G. W. M. 1975: On the origin of petroleum. *Ninth World Petrol. Cong. Tokyo. Spec. Pap.* **1**, 13 pp.
- Milner, C. W. D., Rogers, M. A. & Evans, C. R. 1977: Petroleum transformations in reservoirs. *J. geochem. Explor.* **7**, 101–153.
- Perregaard, J. 1978: Establishment of an organic geochemical laboratory in GGU. *Rapp. Grønlands geol. Unders.* **90**, 150–154.
- Perregaard, J. 1979: Organic geochemistry of sedimentary organic matter from Greenland. A petroleum source rock evaluation. Unpubl. int. GGU report, 113 pp.
- Perregaard, J. & Schiener, E. J. 1979: Thermal alteration of sedimentary organic matter by a basalt intrusive (Kimmeridgian shales, Milne Land, East Greenland). *Chem. Geol.* **26**, 331–343.
- Peters, K. E., Simoneit, B. R. T., Brenner, S. & Kaplan, I. R. 1979: Vitrinite reflectance-temperature determinations for intruded Cretaceous black shale in the Eastern Atlantic. In Oltz, O. F. (edit.) *A symposium in Geochemistry: Low temperature metamorphism of kerogen and clay minerals*. SEPM, Pacific Section, 53–58.
- Philippi, G. T. 1965: On the depth, time and mechanism of petroleum generation. *Geochim. cosmochim. Acta* **29**, 1021–1049.
- Philippi, G. T. 1968: Essentials of the petroleum formation process are organic source material and a subsurface temperature controlled chemical reaction mechanism. In Schenck, P. A. & Havenaar, I. (edit.) *Advances in Organic Geochemistry*, 25–46. Oxford: Pergamon Press.
- Powell, T. G. & McKirdy, D. M. 1973: Relationship between ratio of pristane to phytane, crude oil composition and geological environment in Australia. *Nature, Lond.* **243**, 37–39.
- Rosenkrantz, A. 1970: Marine Upper Cretaceous and lowermost Tertiary deposits in West Greenland. *Bull. geol. Soc. Denmark*, **19**, 406–453.
- Sauvan, P., Esquevin, J. & Chennaux, G. 1975: Transformations induites par des intrusions doléritiques dans une série argileuse: L'Écca de Bergville (Afrique du Sud). *Bull. Centre Rech. Pau-SNPA*, **9**, 261–351.
- Schiener, E. J. & Leythaeuser, D. 1978: Petroleum potential off W. Greenland. *Oil Gas J.* **76** (40), 223–234.
- Simoneit, B. R. T., Brenner, S., Peters, K. E. & Kaplan, I. R. 1978: Thermal alteration of Cretaceous black shale by basaltic intrusions in the Eastern Atlantic. *Nature, Lond.* **273**, 501–504.
- Stach, E., Mackowsky, M.-Th., Teichmüller, M., Taylor, G., Chandra, D., Teichmüller, R. 1975: *Stach's textbook of Coal Petrology*, 2nd ed. Berlin-Stuttgart: Gebrüder Borntraeger.
- Teichmüller, M. 1974: Über neue Macerale der Liptinit-Gruppe und die Entstehung von Micrinit. *Fortschr. Geol. Rheinld Westf.* **24**, 37–64.

- Tissot, B., Califet-Debyser, Y., Deroo, G. & Oudin, J. L. 1971: Origin and evolution of hydrocarbons in early Toarcian shales, Paris Basin, France. *Bull. Amer. Ass. Petrol. Geol.* **55**, 2177–2193.
- Tissot, B., Pelet, R., Roucache, J. & Combaz, A. 1977: Utilisation des alcanes comme fossiles géochimiques indicateurs des environnements géologiques. In Campos, R. & Goni, J. (édit.) *Advances in Organic Geochemistry 1975*, 117–154. Madrid.
- Tissot, B. P., & Welte, D. H. 1978: *Petroleum formation and occurrence. A new approach to oil and gas exploration*. Springer-Verlag.

