Chapter 1

Background

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The present work is mainly based on the results of the 'Nordolie' project (1984–1987) that was undertaken to study the distribution and thermal maturity of potential hydrocarbon source rocks in central and western North Greenland (Christiansen & Rolle, 1985). The project was carried out concurrently with a geological mapping programme by the Geological Survey of Greenland (GGU) that also encompassed important petroleum-related disciplines such as stratigraphy, sedimentology and structural geology. This provided the first systematic survey of the possibilities of exploring hydrocarbons in the region.

Field work was carried out in 1984–1985 and a comprehensive report of the findings, which includes data published earlier, was prepared (Christiansen, 1988). The present publication is a condensed version of that report.

Physiography

The study area of more than 40 000 km^2 is situated between 80° and 83°N. It encompasses a number of major land areas (Washington Land, Hall Land, Nyeboe Land, Warming Land, Wulff Land, Nares Land and Freuchen Land), separated by permanently ice-covered fjords, glaciers and the Inland Ice (figs 2 and 3). A number of smaller islands and nunataks provide good exposures. Approximately half of the study area is ice-free land.

The physiography is quite variable and controlled to a large extent by bedrock lithology and structure with the geomorphic regions corresponding to the main stratigraphic–structural provinces (Davies, 1972; Dawes & Christie, in press). Hence the southern part of the region, characterized by flat-lying or gently northerly dipping carbonate strata, is dominated by plateaus with elevations up to about 1000 m. The plateaus are dissected by steep-sided, flat-floored valleys, lakes and glaciers into mesa-like blocks. The central and northern areas form lowland with an undulating surface dominated by gently dipping to slightly folded sandstones and shales. To the north, in the mainly clastic strata of the folded region along the northern coast, higher and rougher terrain with peaks over 1200 m is widespread.

Many of the north–south trending fjords and valleys provide well-exposed and often picturesque sections through the succession.

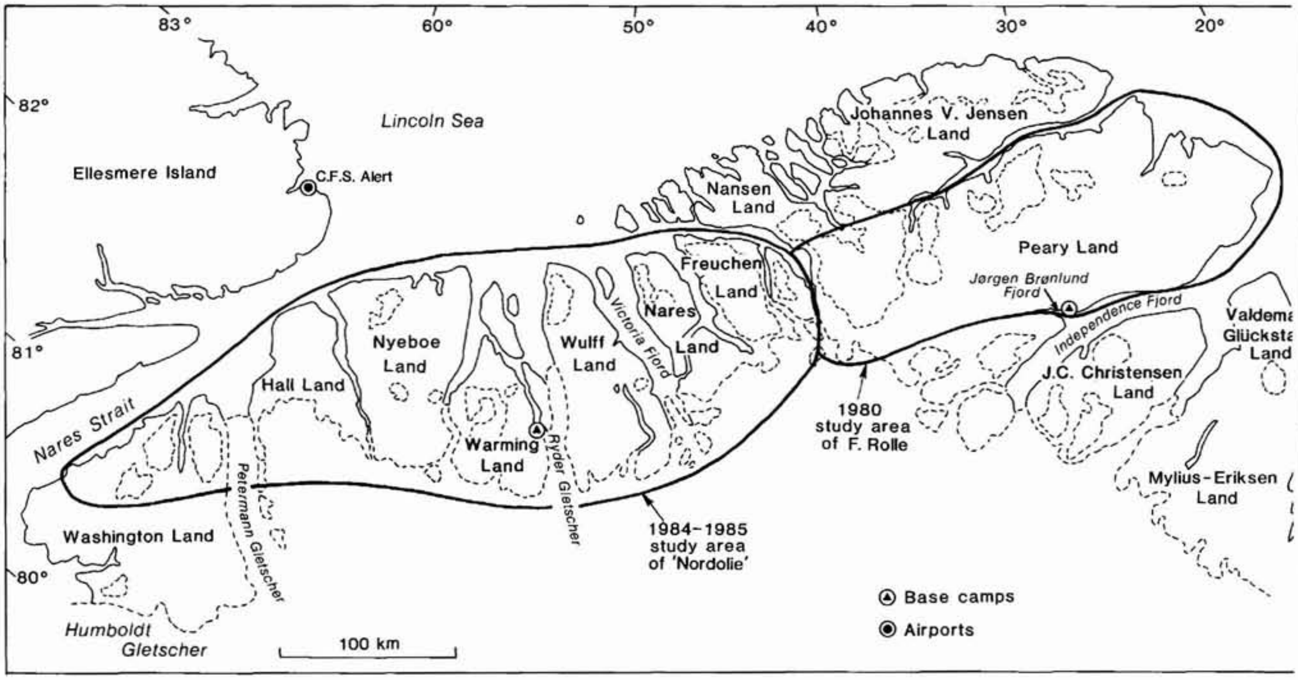
Preliminary studies of the physiographic and biological environment in relation to petroleum exploration were carried out in 1984–1985 by the Greenland Fisheries and Environmental Research Institute (GFM) and the Greenland Technical Organization (GTO). The biological part of the study (Grønlands Fiskeri- og Miljøundersøgelser, 1986) confirmed the barren nature of the region with few areas of continuous vegetation (*c.* 1%).

The coasts of the study area are ice-locked all year. GGU's field work was launched by C-130 Hercules aircraft operating through Thule Air Base (U.S. Air Force), the Canadian Forces Station at Alert, or Station Nord (Royal Danish Air Force) (fig. 2). Natural landing strips were established for local transport with Twin Otter. Most of the field work was supported by Bell 206 Jet Ranger helicopter.

North Greenland is characterized by a high-Arctic climate with long cold winters and short cool summers. Only June, July and August display average temperatures above freezing point. However, towards the Inland Ice the valleys have pleasant conditions for field work during the summer. During most of the winter period temperatures are from −25°C to −30°C. Precipitation is low (less than 200 mm per year), predominantly as snow. In the summer logistics in the coastal areas can be hampered for days by dense fog owing to local open water.

Early expeditions to North Greenland

The first geological knowledge of the region between Washington Land and Peary Land dates back to the end



of the last century – approximately to the beginning of the modern oil history. The first discovery of oil in a well by J. A. Drake, Titusville, Pennsylvania was in 1859, 12 years before Charles Francis Hall in the ship USS *Polaris* landed on the west coast of Hall Land. The main goals of Hall's North Polar Expedition, 1871–1873, and the following Royal Navy Arctic Expedition, 1875–1876 (under G. S. Nares), the U.S. Lady Franklin Bay Expedition, 1881–1884 (led by A. W. Greely), and the expeditions of R. E. Peary 1898–1902, 1905–1906, 1908–1909 were geographic exploration and 'flag waving'.

Scattered but important geological results were obtained. The most interesting details are summarized by Peter R. Dawes and co-workers (Dawes, 1971, 1976, 1984a; Dawes & Haller, 1979; Dawes & Christie, 1982).

The first systematic geological survey of North Greenland, including cartographic work of this 'terra incognita', was carried out by Lauge Koch on the 2nd Thule Expedition, 1916–1918 (led by Knud Rasmussen) and as leader of the Bicentenary Jubilee Expedition, 1920–1923. The results include important topographic and geological maps and stratigraphic–structural studies of the Lower Palaeozoic succession (e.g. Koch, 1925, 1929; Dawes & Haller, 1979). The regional geological elements of Koch's work, obtained under extremely severe conditions, remain essentially unaltered today.

The succeeding significant geological studies in northern Greenland were mainly made outside the present study area but were important in a regional assessment. J. C. Troelsen participated in the Danish Thule and Ellesmere Land Expedition 1939–1941 and revised Proterozoic and Lower Palaeozoic stratigraphy on both sides of Nares Strait (Troelsen, 1950). Additional stratigraphic and structural results were obtained during the Danish Northeast Greenland Expedition 1938–1939 and the Danish Peary Land Expedition 1947–1950 led by Eigil Knuth (e.g. Nielsen, 1941; Troelsen, 1949; Ellitsgaard-Rasmussen, 1955).

Modern expeditions

Aircraft have played an increasingly important role in the modern expeditions in North Greenland and geological knowledge has multiplied, especially in the last decade. Of importance to the present study are the results obtained during Operation Grant Land – a joint venture of the Geological Surveys of Canada and Greenland – in 1965–1966 (Allaart, 1965; Norford, 1972; Dawes, 1984a), the Peary Land Expeditions 1966–1970 (Jepsen, 1971), the Joint Services Expedition 1969 (Dawes & Soper, 1970, 1979), and GGU field work in southern Peary Land in 1974 (Christie & Peel, 1977) and Washington Land 1975–1977 (e.g. Henriksen & Peel, 1976; Hurst, 1980a,b).

More recently GGU has carried out systematic geological mapping and regional studies throughout North Greenland from Nares Strait to the Wandel Sea. These

Fig. 2. Map of northern Greenland showing the location of the 'Nordolie' study area, the previous study area in the east, and the geographic names used in the text.

expeditions, led by Niels Henriksen, worked in 1978–1980 in central and eastern North Greenland from a base camp in southern Peary Land, while in 1984–1985 the region to the west was studied from a base camp in southern Warming Land (fig. 2; Dawes, 1984b; Henriksen, 1985a,b, 1986, 1987). Many papers have appeared as a result of these five field seasons; details of structure and stratigraphy have been worked out and a flood of new stratigraphic names have appeared on maps and in new systematic descriptions.

Commercial activities

Commercial petroleum activities have only taken place in North Greenland in a single period from 1968 to 1973 by a group of companies under Greenarctic Consortium. The consortium was founded in February 1969, with the aim of exploring minerals and hydrocarbons in northern Greenland. Ponderay Exploration Company, an Edmonton-based independent oil company, headed the consortium which included a number of Canadian shareholders as well as two small Danish companies, Internationalt Mineselskab A/S and Nordkalotten Mineselskab A/S. The Danish subsidiary company Ponderay Polar A/S (wholly owned by Greenarctic Consortium) held a non-exclusive five-year concession to explore for minerals and oil north of latitude 74° 30′.

Field work was carried out in the summers of 1969, 1971 and 1972 by geologists mainly from J. C. Sproule and Associates Ltd., a consulting company well known for pioneering work on the economic potential of the Arctic. Also in 1971 an aeromagnetic study was flown by Grumman Ecosystem Corporation, a subsidiary of Grumman Aircraft with major interests in Greenarctic Consortium. Results from this commercial activity were not published, apart from an abstract (Stuart-Smith, 1970) and a short paper on Silurian reefs in Peary Land (Mayr, 1976). However, permission was granted for GGU to include data in review papers on North Greenland (e.g. Dawes, 1976), and on petroleum geology of Greenland (Henderson, 1976). Other information is contained in a review of hydrocarbons in the Canadian Arctic (Stuart-Smith & Wennekers, 1977). A number of confidential reports prepared for Greenarctic Consortium consider hydrocarbon prospects in both the Lower Palaeozoic strata and the Wandel Sea Basin. Upper Ordovician and Silurian reefs or basal Cambrian sandstones were proposed as the main targets for future exploration. Neither oil seepage nor bitumen impregnation were reported, but carbonates with a petroliferous odour were noted in the Cambrian Brønlund Fjord Formation and the Ordovician Wandel Valley Formation. The lack of interest in and knowledge of source rocks, which is typical for all hydrocarbon exploration prior to the seventies, is also apparent in the Greenarctic study: "The Paleozoic section within this area is comprised almost entirely of carbonates and shales of marine origin, and can therefore be considered as potential source rocks".

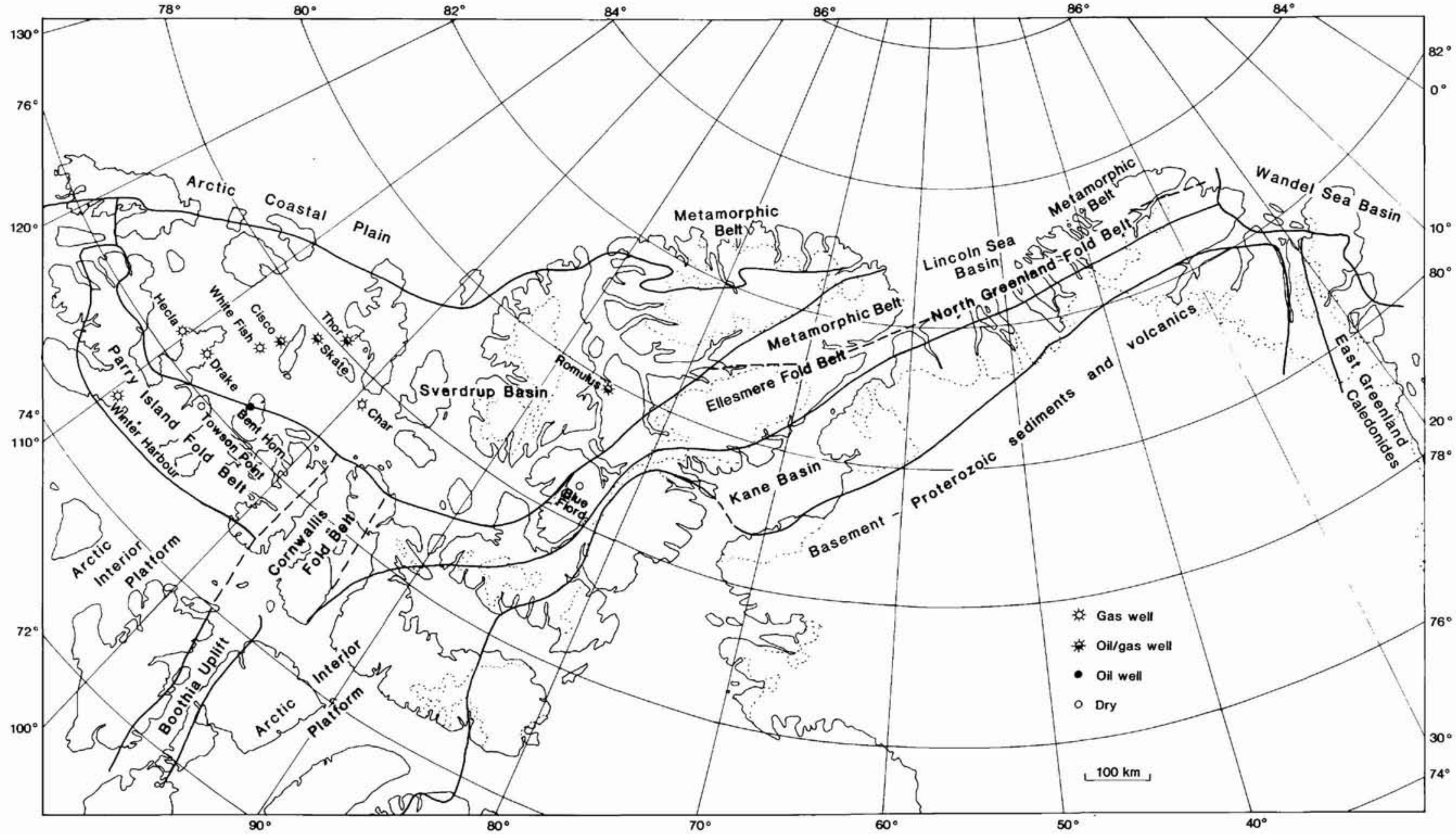


Fig. 3. Geological provinces in Arctic Canada and northern Greenland. Compiled after numerous sources. The locations of some of the mentioned wells in the Sverdrup and Franklinian basins are indicated.

Influence from Canadian activities

The obvious geological connection and the similarity of climatic conditions between North Greenland and the Canadian Arctic Islands makes a comparison of the hydrocarbon activities, and the implications of the results obtained so far very relevant.

Compared to North Greenland, activities in Canada started much earlier and have now reached an early-mature stage with more than 180 completed wells (see reviews by Stuart-Smith & Wennekers (1977), Rayer (1981), Nassichuk (1983), and Embry *et al.* (in press)). The highlights of the exploration history in the Canadian Arctic Islands include (see localities in fig. 3):

1960: first exploration permits.
1962: first well completed (Winter Harbour, some gas in Devonian sandstone).
1967: Panarctic Oils Ltd formed.
1969: first major gas discovery (Drake Point, 5.3 TCF in Jurassic sandstone).
1972: first oil discoveries (Thor, Triassic sandstone; Romelus, Triassic sandstone).
1974: first off-shore well (Hecla N-52, ice-strengthened platform, 128 m water depth).
1974: oil discovery at Bent Horn, Cameron Island (in Devonian carbonates).
1980: discovery of major gas fields through thick layer of ice (White Fish, Cretaceous sandstone; Char, Jurassic sandstone).
1981: first major Mesozoic oil discoveries (Skate, Jurassic sandstone; Cisco, Jurassic sandstone).
1985: first production (Bent Horn A-02 drilled in 1976, Middle Devonian Blue Fiord reefal limestone; 100 000 barrels of crude shipped to refinery in Montreal).

The drilling activities culminated in the early seventies (23 wells completed within 1973). In the eighties, a constant level of 4 to 5 wells per year has been maintained, by far the most active operator being Panarctic Oils Ltd. Exploration since the mid-seventies has concentrated in the Mesozoic succession in the Sverdrup Basin where a number of major gas fields have been discovered; less effort was devoted to the Lower Palaeozoic Franklinian Basin (neither the folded deep-water siliciclastics of the 'Franklinian Geosyncline' nor the stable shallow-water carbonates of the 'Arctic Interior Platform'; fig. 3).

Nassichuk (1983) estimated the mean oil and gas potential as follows (discovered and undiscovered recoverable resources):

Arctic Interior Platform: 1.1×10^9 barrels of oil, 8.5 TCF gas (no discoveries as yet).

Franklinian Geosyncline: 0.5×10^9 barrels of oil, 7.8 TCF gas (only minor discoveries).

Sverdrup Basin: 2.9×10^9 barrels of oil, 69.9 TCF gas (minor oil discoveries, more than 15 gas discoveries with recoverable reserves of approximately 15 TCF). Estimates by Procter *et al.* (1984) show almost the same range of values.

The major discoveries of gas have been made in clastic reservoirs of Triassic and Jurassic age in the Sverdrup Basin and are of particular relevance to future studies in the Wandel Sea Basin in eastern North Greenland.

In Canada, Early Palaeozoic basin development simulates that of North Greenland. To the south there is a stable platform dominated by shallow-water carbonates; to the north deep-water siliciclastics occur with a complex border zone of carbonate reefs and debris which roughly corresponds to the southern limit of Ellesmerian (Late Palaeozoic) folding.

A detailed source rock study comprising material from 21 wells penetrating the Lower Palaeozoic succession suggested several potential source rock units in the deep-water sequence (Powell, 1978). Intervals in the Upper Ordovician to Silurian Cape Phillips Formation (comparable to the Silurian shales in North Greenland) and in the Devonian Bathurst Island, Eids, Weatherall and Bird Fiord Formations contain rich oil-prone organic matter. The main problem with the source rocks in the Lower Palaeozoic in Canada seems to be the high thermal maturity. Many of the intervals penetrated by drilling are thermally postmature and the generation probably took place already in Middle to Late Devonian time (Powell, 1978).

Hydrocarbon staining and bitumen occurrences at the surface have been reported from many locations, especially in Ordovician to Devonian carbonates (e.g. Sproule, 1966; Rayer, 1981, figs 12, 13, 43). Oil shows in wells are restricted to three structures: Blue Fiord, Towson Point, Bent Horn. In the latter case several wells have been tested with a production of up to 5000 barrels/day from Middle Devonian carbonates (Rayer, 1981). In September 1985 crude from this field was shipped to Montreal and this continued in the summers of 1986, 1987 and 1988.

The main oil prospects in Canada include only one type that is relevant to North Greenland, namely reservoirs in Ordovician to Devonian reefs along the shelf margin or in isolated reefs encased in shale. Other play types are related to folding and diapirism of Ordovician evaporites (not recognized in North Greenland) and to Upper Devonian sandstones (not present in North Greenland due to deep erosional level or non-deposition).

The accumulative knowledge from the Canadian Arctic has had important geological implications for North Greenland. It is notable that the Greenarctic operations overlapped with one of the most active and optimistic periods in the Canadian Arctic Islands. The withdrawal roughly took place at a time when activities were redirected and concentrated on Mesozoic prospects in the Sverdrup Basin. The low activities in the Franklinian basin at present must be taken as evidence of very little interest in Palaeozoic prospects in this setting and in this part of the world.

Initiation of 'Nordolie'

The Greenarctic enterprise in northern Greenland was influenced by commercial activities in the Canadian Arctic and was also inspired by findings, especially of reef complexes, in Greenland during Operation Grant Land in 1965 and 1966. Kerr (1967) used Greenland data in his regional appraisal and showed that the Silurian reef complex of the Arctic Islands continues into the Hall Land – Washington Land area, while Dawes (1971) indicated its regional extent across North Greenland. Subsequent to Greenarctic's withdrawal, development of ideas of the petroleum geology, both in form of analytical work, reports and papers, was sporadic in North Greenland due to concentration of resources in the major exploration programme off-shore West Greenland in the mid-seventies.

Norford (1972) mentioned residual bitumen at Kap Tyson in western Hall Land and provided a few TOC analyses of nearby shales. Henderson (1976) quoted several unpublished OLEXCON reports with analytical data of organic-rich shales in Washington Land, Hall Land and Nyeboe Land. Perregaard (1979) reported promising analytical results of two organic-rich lime mudstones (and one organic-lean limestone) of Silurian age from Washington Land. Possible source rocks for petroleum in the Brønlund Fjord Group and potential traps associated with the unconformity at the base of the Wandel Valley Formation and east–west trending faults in Peary Land were mentioned for the first time by Peel (1979). Many of the geologists participating in GGU's Peary Land activities in 1978 and 1979 collected random samples of dark, often stinking, limestone, dolomite and shale. Subsequent analytical work on 64 samples (later included in Rolle & Wrang, 1981) gave promising results.

Consequently, hydrocarbon studies were included in GGU's Peary Land programme in 1980 (Rolle, 1981). This work aimed at systematic source rock sampling with preliminary examination of most of the Lower Palaeozoic succession and more detailed investigations of the Brønlund Fjord Group. Analytical work of the sampled material suggested the presence of potential source rocks in Peary Land (Rolle & Wrang, 1981), and hence formed the background for new and more detailed studies. These, carried out in 1984 and 1985, aimed at a combined geological–geochemical study of potential source and reservoir rocks, and a source rock programme was integrated in GGU's regional studies of central and western North Greenland.

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Plate 1. Kerogen

A. Sample with a relatively low (0.21% TOC) kerogen content and a dominance of finely disseminated amorphous kerogen in a silica gel, Lafayette Bugt Formation, Nyeboe Land, GGU 316490–1, unsieved organic material.
B. As A., Lafayette Bugt Formation, Nyeboe Land, GGU 316490–2, sieved organic material (on 10 μm nylon mesh).
C. Sample with a relatively moderate (1.15% TOC) kerogen content and small to moderate amounts of large amorphous kerogen particles, Thors Fjord Member, Nares Land, GGU 318007–18–1 unsieved organic material.
D. As C., Thors Fjord Member, Nares Land, GGU 318007–18–2, sieved organic material (on 10 μm nylon mesh).
E. Sample with a relatively large (5.09% TOC) kerogen content and a dominance of large amorphous kerogen particles, Thors Fjord Member, Nares Land, GGU 318007–32–1, unsieved organic material.
F. As E., Thors Fjord Member, Nares Land, GGU 318007–32–2, sieved organic material (on 10 μm nylon mesh).

Scale bar: 20 μm.

Plate 2. Cambrian palynomorphs

A. Acritarch-like folded alga. Middle Cambrian Sydpasset Formation, Freuchen Land, MGUH 19334 from GGU 315873–2; 139.5–13.9.
B. Acritarch-like folded alga. Middle Cambrian Sydpasset Formation, Freuchen Land, MGUH 19335 from GGU 315873–2; 150.6–7.0.
C. Two acritarch-like folded algae. Middle Cambrian Sydpasset Formation, Freuchen Land, MGUH 19336 (large light body), MGUH 19337 (dark small body), both from GGU 315873–2; 122.0–15.3.
D. Acritarch-like folded alga. Middle Cambrian, Ekspedition Bræ Formation, Freuchen Land, MGUH 19338 from GGU 324217–2; 139.2–14.9.
E. Acritarch-like folded alga. Middle Cambrian, Ekspedition Bræ Formation, Freuchen Land, MGUH 19339 from GGU 324300–2; 131.2–13.4.
F. Acritarch-like folded alga. Middle Cambrian, Ekspedition Bræ Formation, Freuchen Land, MGUH 19340 from GGU 324217–2; 141.9–11.4.
G. Lump of algal or spore-like elements. Middle Cambrian, Ekspedition Bræ Formation, Freuchen Land, MGUH 19341 from GGU 324300–2; 127.8–14.4.
H. Diad-like lump of algal or spore-like elements. Middle Cambrian, Ekspedition Bræ Formation, Freuchen Land, MGUH 19342 from GGU 314300–2; 138.5–17.8.
I. Lump of alga or spore-like elements. Middle Cambrian, Ekspedition Bræ Formation, Freuchen Land, MGUH 19343 from GGU 324300–2; 157.7–14.7.

Scale bar: 20 μm.

Plate 3. Ordovician palynomorphs

A. Acritarch. Upper Ordovician Troedsson Cliff Member, Washington Land, MGUH 19344 from GGU 316968–2; 145.3–17.8.
B. Acritarch. Upper Ordovician – Lower Silurian Aleqatsiaq Fjord Formation, Washington Land, MGUH 19345 from GGU 316085–4; 124.1–21.3.
C. Graptolite fragment, Upper Ordovician Troedsson Cliff Member, Washington Land, MGUH 19346 from GGU 316968–2; 128.1–2.9.
D. Scolecodont, Upper Ordovician, Troedsson Cliff Member, Washington Land, MGUH 19347 from GGU 316968–2; 148.8–15.1.
E. Alga. Upper Ordovician – Lower Silurian Aleqatsiaq Formation, Nyeboe Land, MGUH 19348 from GGU 316103–2; 135.0–15.0.
F. Filamentous alga. Upper Ordovician – Lower Silurian Aleqatsiaq Formation, Washington Land, MGUH 19349 from GGU 316058–2; 135.1–4.2.
G.-L. Spores with trilete rays. Upper Ordovician, Troedsson Cliff Member, Washington Land (Nøhr-Hansen & Koppelhus, 1988).
G.-I. *Besselia nunaatica*, MGUH 17539 from GGU 316968–2; 125.5–8.3.
G. Distal view illustrating the minute ornamentation.
H. Equatorial view.
I. Internal proximal view.
J. *Besselia nunaatica,* two connected spores, internal proximal view, MGUH 17541 from GGU 316968–2; 155.1–11.9.
K.-L. *Besselia nunaatica*. MGUH 17542 from GGU 316968–2; 123.8–15.9.
K. Distal view illustrating the ornamentation.
L. Internal proximal view.

Scale bar: 20 μm.

Plate 4. Silurian palynomorphs

A. Chitinozoan, *Angochitina* cf. *A. elongata*. Upper Silurian Wulff Land Formation, Wulff Land, MGUH 19350 from GGU 315950–3; 136.9–17.2.
B. Chitinozoans, *Linochitina erratica*. Upper Silurian Wulff Land Formation, Wulff Land, MGUH 19351 from GGU 315950–2; 154.3–9.6.
C. *Retiolites*, graptolite fragment. Upper Silurian, Wulff Land Formation, Wulff Land, MGUH 19352 from GGU 315950–3; 155.1–11.1.
D. Graptolite fragment, Upper Silurian, Wulff Land Formation, Wulff Land, MGUH 19353 from GGU 315950–2; 127.3–5.7.
E.-H. Trilete spore-like bodies, figs E and F with a degraded bitumen-like appearance.
E. Lower Silurian Lafayette Bugt Formation, Washington Land, MGUH 19354 from GGU 211760–2; 143.3–17.2.
F. Upper Silurian Wulff Land Formation, Wulff Land, MGUH 19355 from GGU 315950–3; 15950–3; 155.5–8.2.
G. Upper Silurian Nyeboe Land Formation, Nyeboe Land, MGUH 19356 from GGU 319234–2; 119.3–11.0.
H. Upper Silurian Nyeboe Land Formation, Wulff Land, MGUH 19357 from GGU 319210–3; 130.6–21.4.
I. Spherical folded algae, acritarchs? Lower Silurian Lafayette Bugt Formation, Hall Land, MGUH 19358 from GGU 324157–2; 144.2–8.5.
J. Tubular structure. Upper Silurian Nyeboe Land Formation, Wulff Land, MGUH 19359 from GGU 319210–3; 146.6–16.5.
K. Tubular structure. Upper Silurian Nyeboe Land Formation, Nyeboe Land, MGUH 19360 from GGU 319234–2; 138.8–8.0.
L. Rounded drop-shaped palynomorphs. Lower Silurian Lafayette Bugt Formation, Washington Land, MGUH 19361 from GGU 316061–2; 137.1–14.8.

Scale bar: 20 μm.

Plate 1. Kerogen

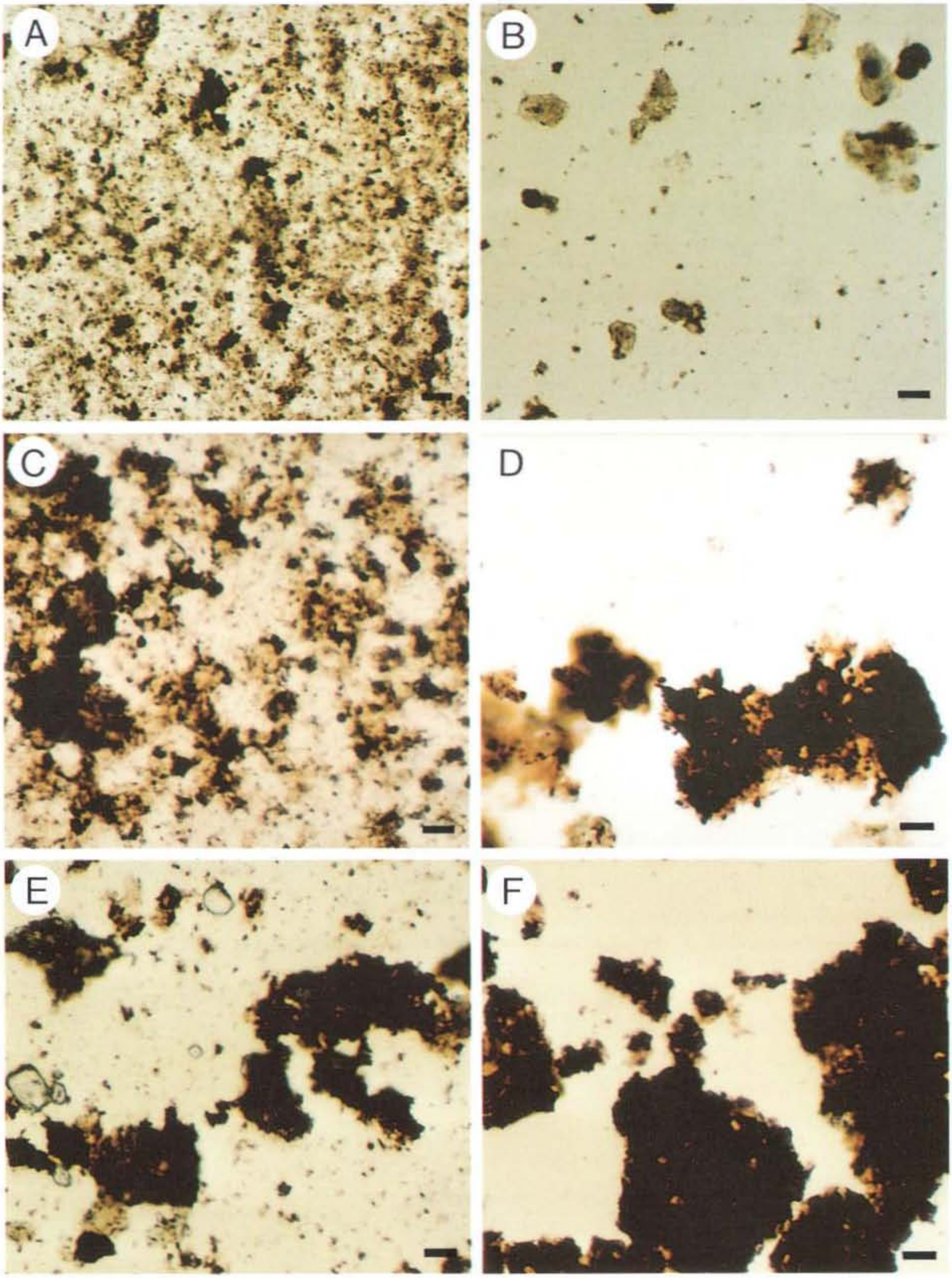

Plate 2. Cambrian palynomorphs

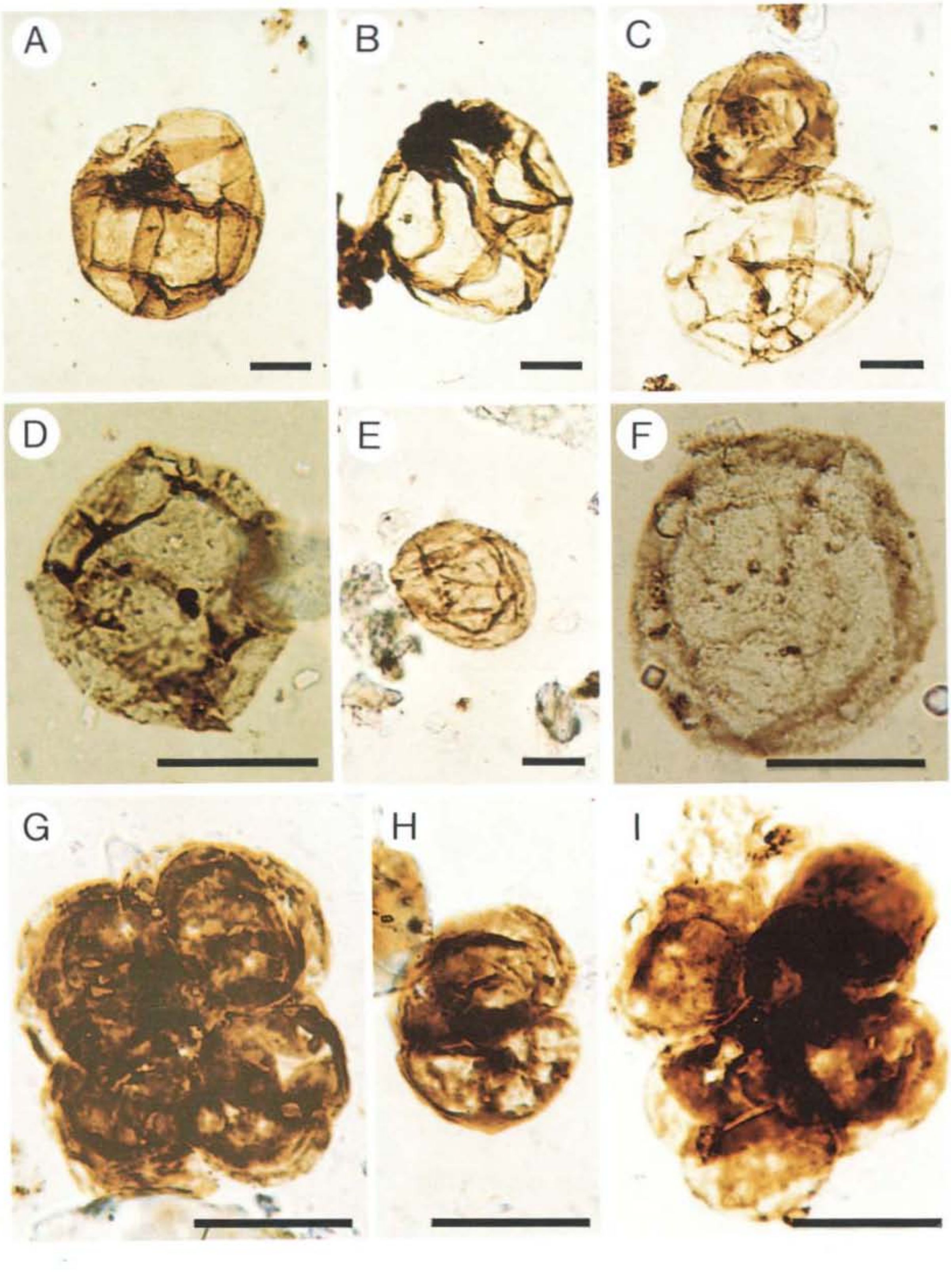

Plate 3. Ordovician palynomorphs

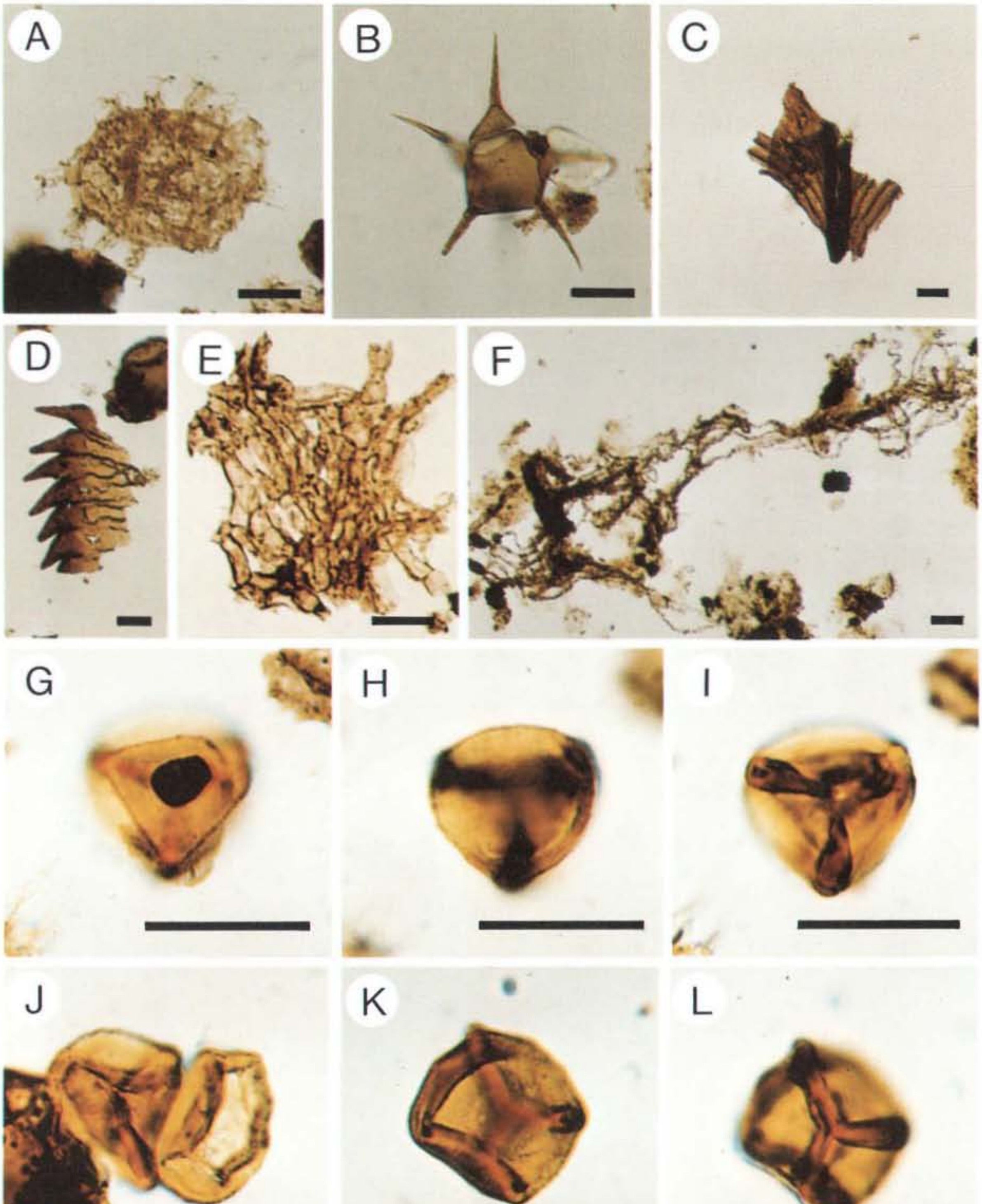

Plate 4. Silurian palynomorphs

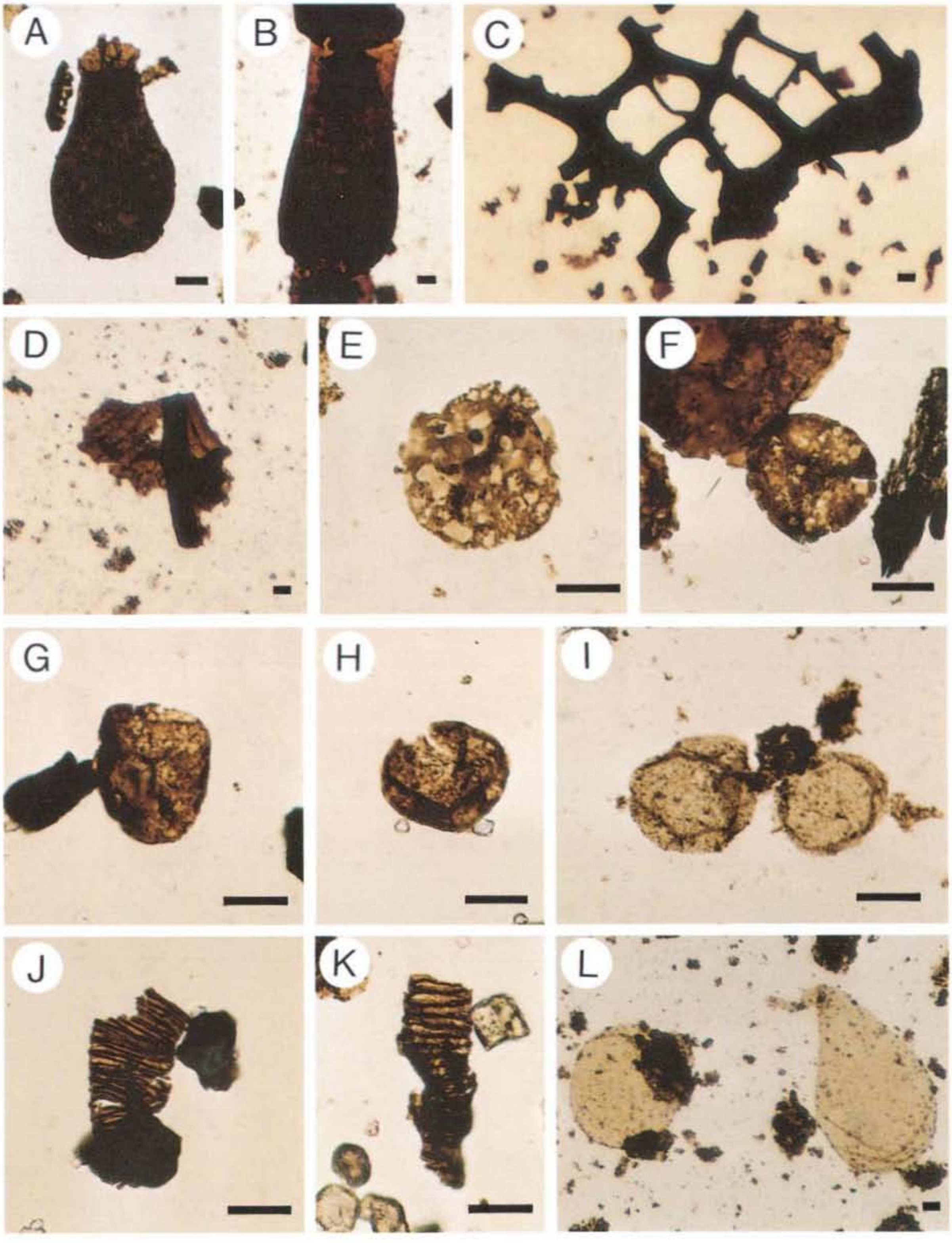

Plate 5. Progressive coloration of amorphous kerogen with increasing thermal alteration

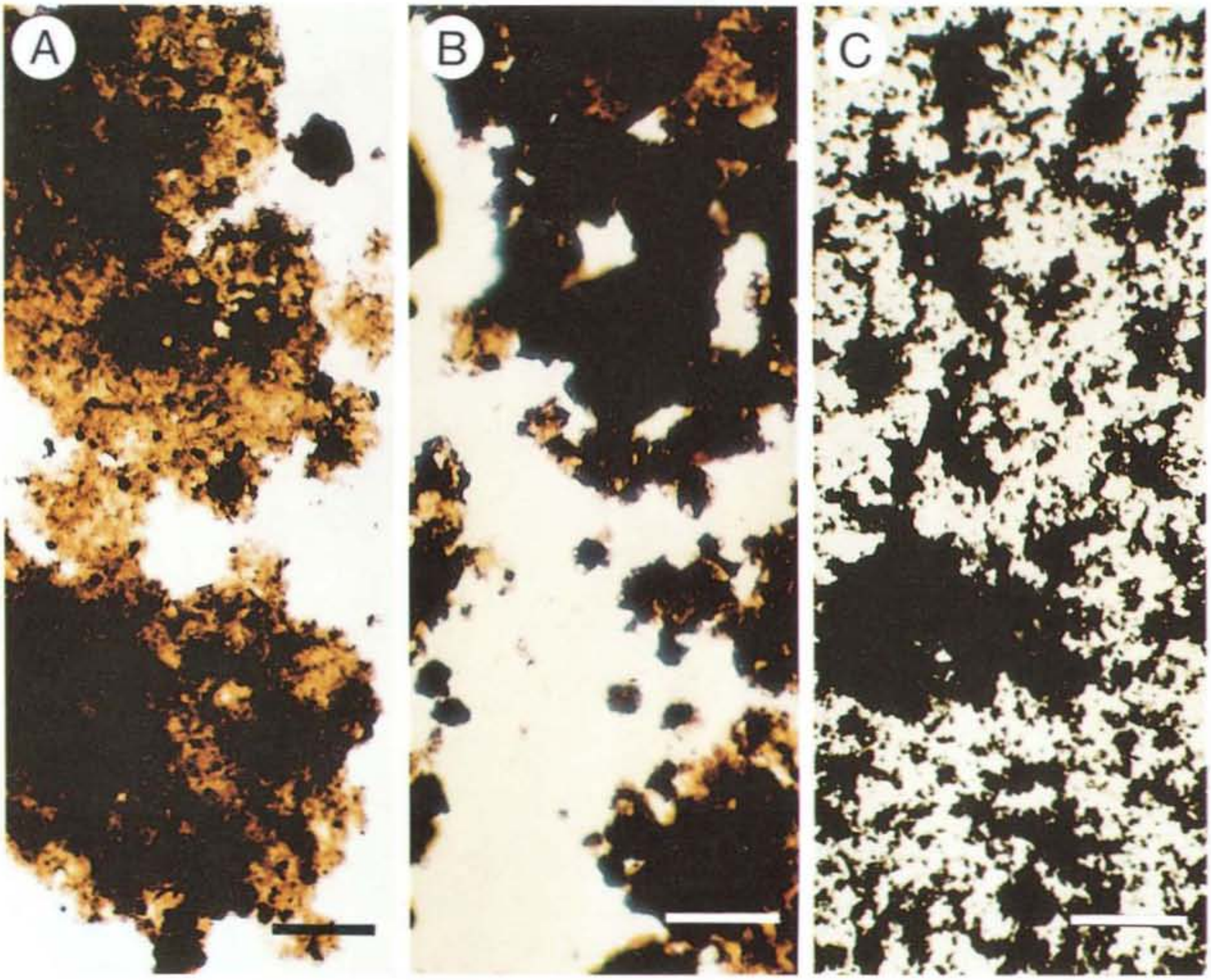

Plate 5. Progressive coloration of amorphous kerogen with increasing thermal alteration

Scale bar: 50 μm

A. TAI: (2)–2^+, GGU 211759–2. B. TAI: 2^+–(3^-), GGU 324405–2. C. TAI: 4^+, GGU 316475–1.

Plate 6. Change in structure of amorphous kerogen with increasing thermal alteration as observed in the scanning electron microscope

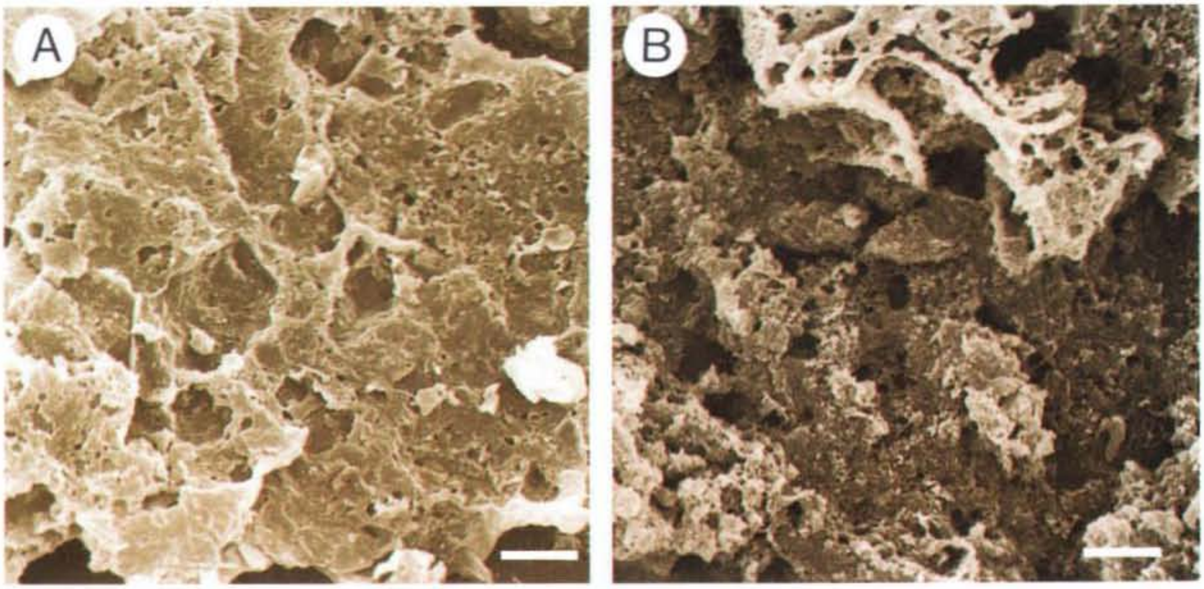

Plate 6. Change in structure of amorphous kerogen with increasing thermal alteration as observed in the scanning electron microscope

A. TAI: 2^+–(3^-), T_{max}: 446, GGU 324405–2, scale bar: 10 μm.

B. TAI: 4^+, T_{max}: n.d., GGU 316475–2, scale bar: 10 μm.

Plate 7. Field appearance of bitumen

A. Seeping asphalt from southern Wulff Land (equivalent to GGU 324200).

B. Hard solid bitumen in dolomite vug in the Sydpasset Formation (equivalent to GGU 324287–324299, core GGU 318003).

Plate 8. Macroscopic bitumen in slabs

A. Asphalt from seep in dolomite breccia. GGU 324200A.

B. Like A. Stained. D0, D1, D2, C1, C2 correspond to generations of dolomite and calcite.

C. Asphalt from seep in dolomite breccia. Stained. Same generations of carbonates as A and B. GGU 324200E.

D. Hard solid bitumen in vugs and veins in dolomite grainstone. DO: dolomite grainstone, D1: saddle dolomite. Core GGU 318003.

Plate 9. Bitumen in thin section

A. Bitumen in coral. GGU 324130B, Lafayette Bugt Formation, Nyeboe Land. Plane light, stained, C: calcite, Fe-C: Fe-rich calcite, B: bitumen, scale bar: 1 mm.

B. Bitumen in coral. GGU 316067, Lafayette Bugt Formation, Washington Land. Crossed nicols + gypsum plate. Q: quartz, C: calcite, B: bitumen, scale bar: 1 mm.

C. Bitumen-filled fracture in calcarenite. GGU 318013–09, Lafayette Bugt Formation, Nyeboe Land. Plane light, scale bar: 2 mm.

D. Two-phased bitumen (black and yellow) (B1, B2) in saddle dolomite veins (D1) cross-cutting dolomite grainstone (D0). See close-up (arrow) in Plate 11. GGU 318003–53, Henson Gletscher Formation, Freuchen Land. Plane light, scale bar: 2 mm.

E.-F. Saddle dolomite vein (D1) in dolomite grainstone (D0). Bitumen occurs as impregnation in DO (B1), as residual matter in the contact between D0 and D1 (B2, R_o: 0.92%) and in the centre of the vein (B3, R_o: 1.21%). GGU 318003–21, Sydpasset Formation, Freuchen Land. Plane light, scale bars: 1 mm.

Plate 10. Bitumen in palynologically prepared samples observed in microscope or in SEM

A. Bitumen with flaky appearance (note crystal impressions). GGU 315172–1. Ryder Gletscher Group Fm 6, Wulff Land. Scale bar: 25 μm.

B. Globular bitumen. GGU 315865–2, Aftenstjernesø Formation, Nares Land, scale bar: 50 μm.

C. Globular bitumen which has been extruded during and after sample preparation by the xylene-containing mounting medium. GGU 315199, Ryder Gletscher Group Fm 6, Warming Land. Scale bar: 12.5 μm.

D. Bitumen with flaky appearance (note crystal impressions). GGU 315172–1, Ryder Gletscher Group Fm 6, Wulff Land. Scale bar: 10 μm.

E. Bitumen mirroring imprints of crystals from coral space. GGU 316067–2, Lafayette Bugt Formation, Washington Land. Scale bar: 10 μm.

F. Thread-like bitumen. GGU 324453, Buen Formation, Wulff Land. Scale bar: 25 μm.

Plate 7. Field appearance of bitumen

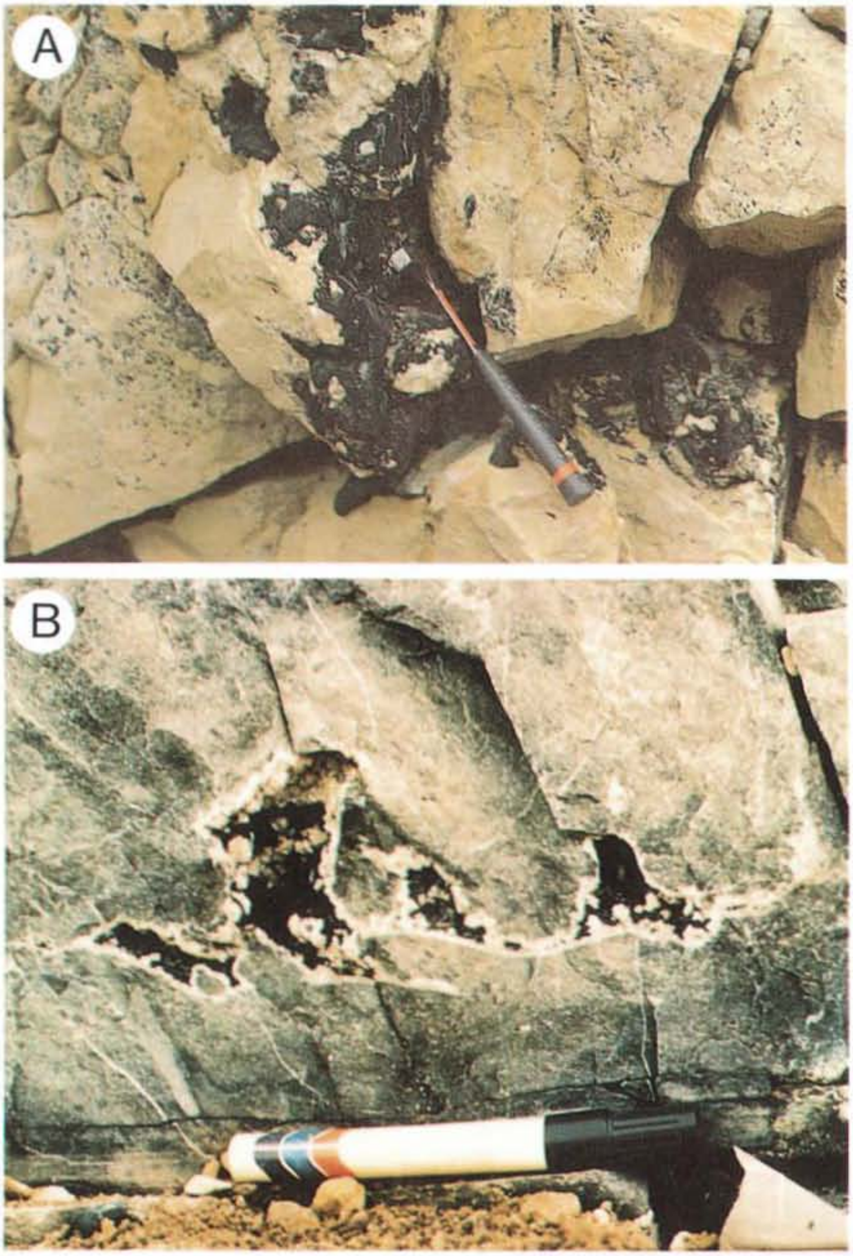

Plate 8. Macroscopic bitumen in slabs

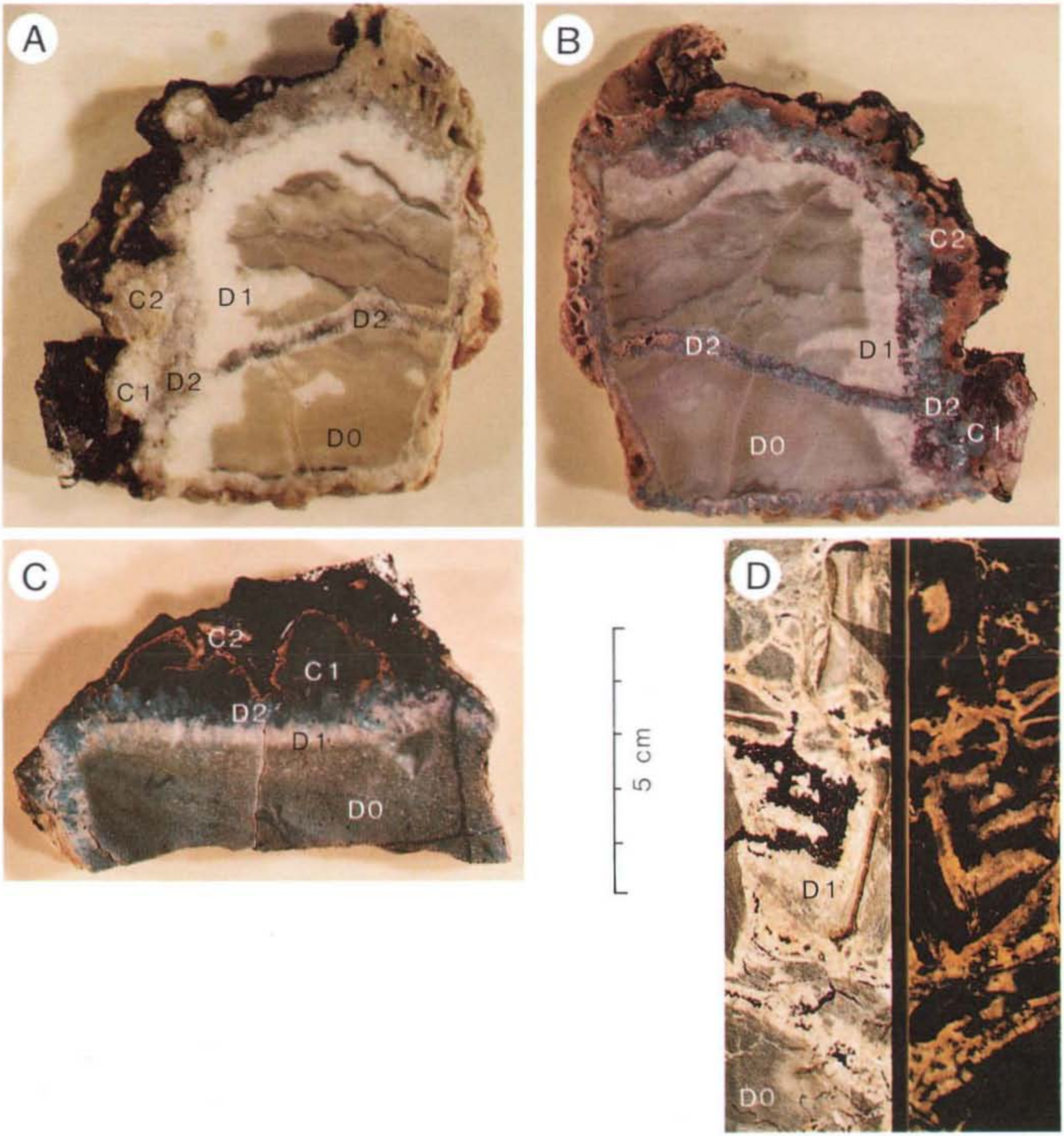

Plate 9. Bitumen in thin section

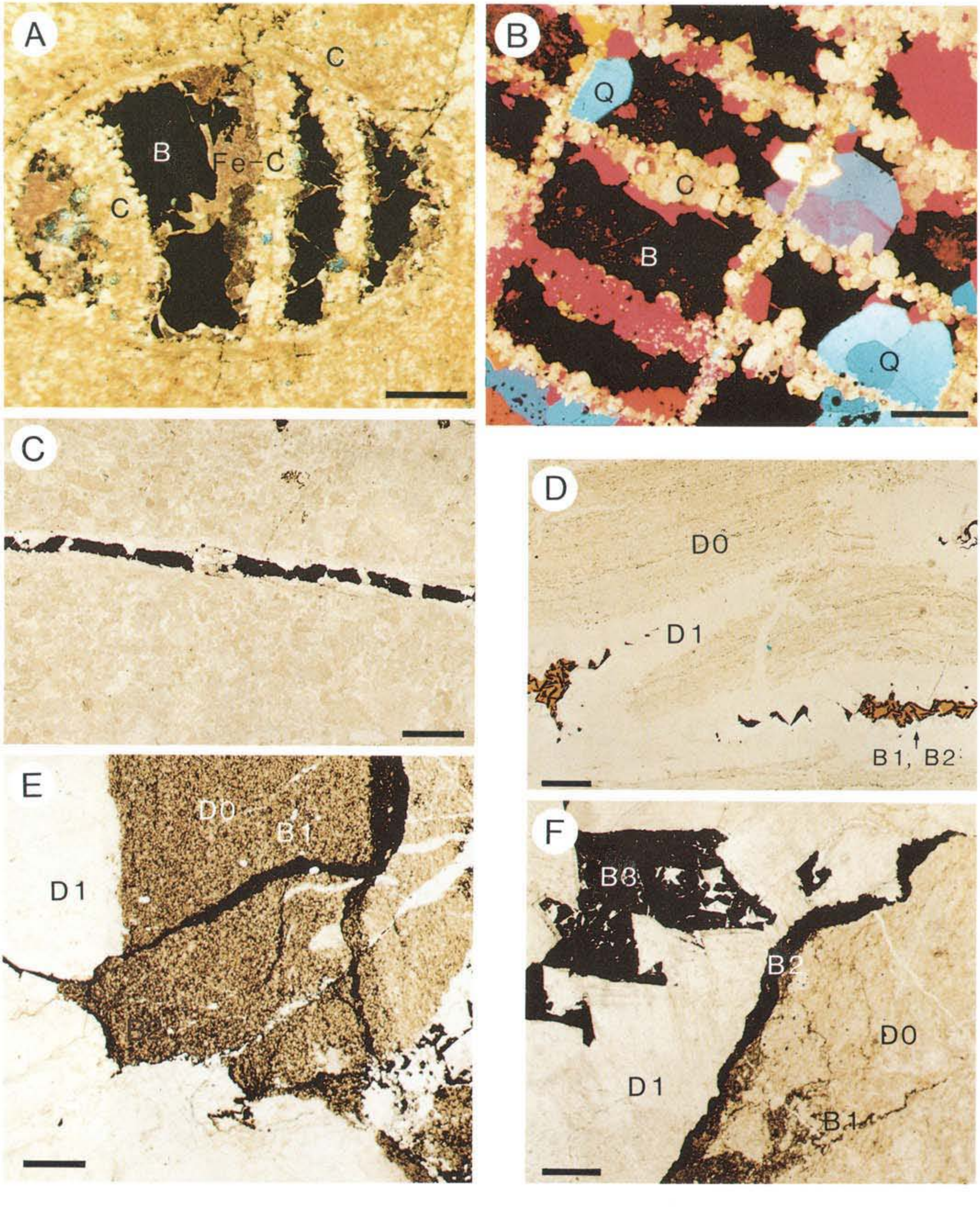

Plate 10. Bitumen in palynologically prepared samples observed in microscope or in SEM

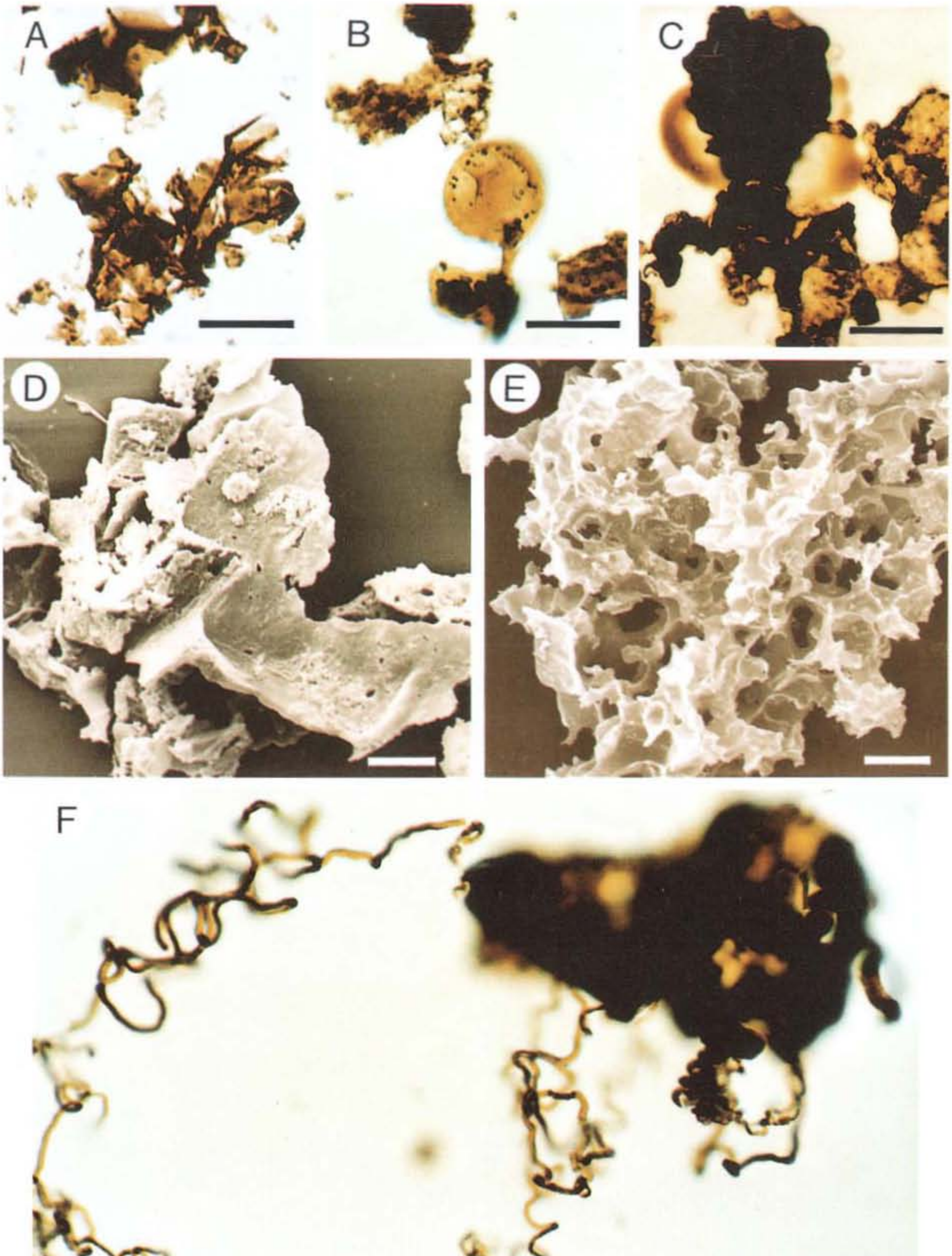

Plate 11. Bitumen in polished section

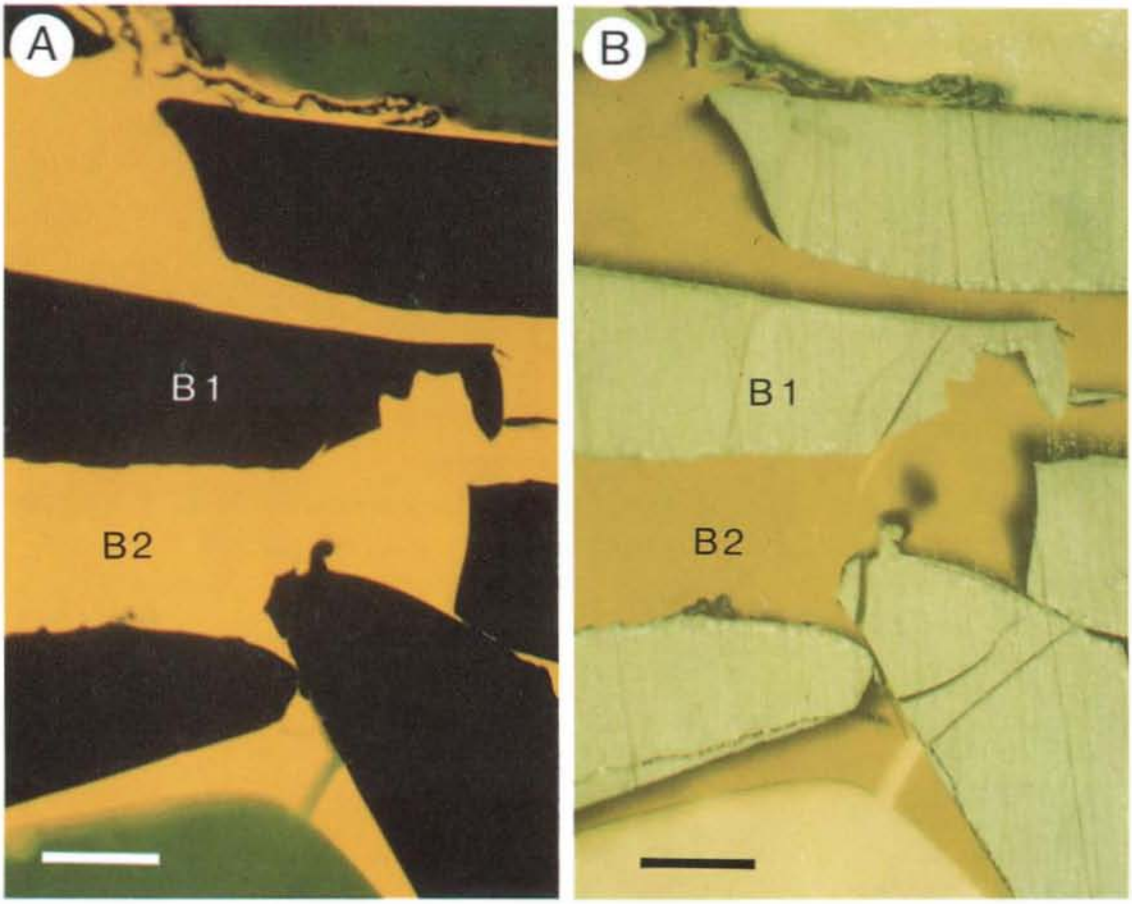

Plate 11. Bitumen in polished section

GGU 318003–53, Henson Gletscher Formation, Freuchen Land.
Scale bar: 50 μm

A. Fluorescent light photograph of two-phase bitumen.

B. Normal reflected light photograph of same field. The yellow-fluorescent low-reflecting bitumen (B2) has a R_o of 0.08% and the dark non-fluorescent high-reflecting bitumen (B1) a R_o of 1.17%.

Cover picture
Cambrian and Ordovician strata at Blue Cliffs, Wulff Land, North Greenland. Photo: J. Lautrup, GGU.