Chapter 4

Palynological studies of the organic matter

H. Nøhr-Hansen

Palynological studies of the kerogen in potential source rocks and other sediments in petroliferous basins provide important data on quality, quantity and type of the organic matter. In addition the palynomorphs are useful for biostratigraphic correlation. The colour and preservation of palynomorphs and other kerogen particles are of value in thermal maturity evaluation (Staplin, 1969; Burgess, 1974; Dow, 1977). The kerogen composition, described as organic facies (Jones, 1987) or palynofacies (Combaz, 1964; Batten, 1981; Tyson, 1987), is yet another powerful tool in source rock characterization and evaluation.

Although palynological kerogen analysis is frequently used on Mesozoic and Cenozoic organic material and many of the resulting data are published, this is not the case in studies of Lower Palaeozoic sequences where palynomorphs are used mainly for biostratigraphic purposes and only rarely in organic facies and environmental studies (Aldridge *et al.*, 1979; Dorning, 1987) or in source rock studies (Legall *et al.*, 1981). The amorphous kerogen in Palaeozoic sediments has only been sporadically described from a palynological point of view (Venkatachala, 1981; Batten, 1984).

The present chapter concentrates on providing a systematic presentation of the results of palynological studies of the organic matter from selected intervals of the Lower Palaeozoic sequence in North Greenland. In addition to the organic-rich potential source rock units, most other lithological units from the Lower Palaeozoic sequence in North Greenland have been investigated.

The organic content of 455 samples was isolated by standard palynological preparation (Chapter 3). These samples had previously formed the basis for preliminary thermal maturity studies (Christiansen *et al.*, 1985, 1987), and were employed in a combined kerogen classification and thermal maturity study of the Silurian material (Christiansen & Nøhr-Hansen, 1989). The MGUH numbers used in the figure captions indicate that specimens are stored in the Geological Museum of the University of Copenhagen.

Classification of organic matter

The organic matter of the samples studied is dominated by amorphous kerogen without any structures reminiscent of its precursor. The very sparse information obtained from the amorphous kerogen, combined with a low palynomorph content and the absence of terrestrial material, makes it impossible to carry out a traditional kerogen facies analysis. Instead a tentative classification based on content and relative composition of the total kerogen was introduced (Christiansen & Nøhr-Hansen, 1989). Three types of kerogen are discerned: (1) large coherent particles of amorphous kerogen, (2) finely disseminated amorphous kerogen, and (3) palynomorphs. The total content of kerogen was evaluated, employing for each sample both the slide of unsieved organic material and the slide of sieved organic material (Chapter 3), and classified as poor, moderate or rich.

Samples dominated by finely disseminated amorphous kerogen are generally those poor in kerogen (Plate 1 A and B) and they display low TOC values ($<$ 1%). The kerogen from these samples often occurs in a silica gel in the unsieved organic material (Plate 1 A). Samples with a moderate kerogen content contain small to moderate amounts of large kerogen particles (Plate 1 C and D) and display TOC values in the range 1 to 3%. Samples rich in kerogen are generally dominated by large particles of amorphous kerogen (Plate 1 E and F) and display high TOC values ($>$ 3%).

Palynomorphs constitute only a minor amount of the total organic material from North Greenland (commonly 1–2% and never more than 20%). Chitinozoans, graptolite fragments, scolecodonts, acritarchs and spores were observed.

Solid bitumen is widespread in a number of samples. This may present some problems in the TAI (Thermal Alteration Index) evaluation since the migrated bitumen has often been through a different thermal history than the autochthonous kerogen. Another problem

Unit	Thickness	Lithology	n	Acritarchs	Chitinozoans	Scolecodonts	Trilete spores	Graptolite fragments	Kerogen
Ryder Gletscher Fm 3–6	< 650		7						P–M
Buen Fm & Polkorridoren Gp	250–500		3						P–M,B
Portfjeld Fm	150–300								
Pre–Portfjeld	< 30		3						P–M

Unit	Thickness	Lithology	n	Acritarchs	Chitinozoans	Scolecodonts	Trilete spores	Graptolite fragments	Kerogen
Tavsens Iskappe Gp	400–700		4			2			P B
Ekspedition Bræ Fm	30–80		3	(2)					P B
Sydpasset Fm	10–70		2	(1)					M
Henson Gletscher Fm	40–130		57						M–R,B
Aftenstjernesø Fm	50–70		5						P–M
Buen Fm & Polkorridoren Gp	250–500		1						P B
Portfjeld Fm	250–300								
Pre–Portfjeld	< 30		1						P

Fig. 13. Stratigraphic distribution based on 86 analysed Cambrian samples in the western (above) and eastern (below) part of North Greenland, thickness (m), lithology, number of analysed samples, number of samples with recorded palynomorphs (acritarchs, chitinozoans, scolecodonts, trilete spores, graptolite fragments), relative kerogen composition (finely disseminated amorphous kerogen: dotted, large amorphous particles of kerogen: black, palynomorphs: blank), relative kerogen content: empty (E), poor (P), moderate (M), and rich (R), and bitumen content (B).

with solid bitumen is the resemblance of palynomorph membranes to bitumen flakes which have been squeezed between minerals. Examples of bitumen in palynologically prepared samples are illustrated in Plate 10.

Cambrian shelf sequence

Organic matter from 86 Cambrian samples was analysed (fig. 13), the majority collected from the Henson Gletscher Formation (Ineson & Peel, in press; Christiansen *et al.*, 1987).

The organic matter from lime mudstones and interbedded shales is dominated by large particles of granular to spongy amorphous kerogen, whereas finely disseminated amorphous kerogen only occurs in moderate amounts. The relative kerogen content is moderate to high. Palynomorphs were not recorded from the Henson Gletscher Formation. Most of the other Cambrian units are dominated by finely disseminated amorphous kerogen and have a poor to moderate kerogen content.

Most of the Cambrian succession is barren of palynomorphs (fig. 13). It is remarkable that algae (Plate 2 A-F), which resemble the acritarch genus *Leiosphaeridia,* are only recorded from dolomite of the Sydpasset Formation and from lime mudstone of the Ekspedition

Unit	Thickness	Lithology	n	Acritarchs	Chitinozoans	Scolecodonts	Trilete spores	Graptolite fragments	Kerogen
Washington Land Gp	> 800		14		1	2			E–P,B
Aleqatsiaq Fjord Fm	250–340		28	17	13	14	(6)	3	P–M
Cape Calhoun Fm	30–60		4	3	3	3		3	P
Troedsson Cliff Mb	170–230		14	12	11	11	5	7	P
Gonioceras Bay Mb			10	7	5	9		2	P B
Cape Webster Fm	175–200		6						E–P,B
Stensby Gletscher Fm, Canyon Elv Fm, Nunatami Fm	90–125		15	4	1	4	(1)		E–P,B
Warming Land Fm	50–150		1						

Unit	Thickness	Lithology	n	Acritarchs	Chitinozoans	Scolecodonts	Trilete spores	Graptolite fragments	Kerogen
Børglum River Fm	430		4			4			P,B
Wandel Valley Fm	~ 360		3						P

Fig. 14. Stratigraphic distribution of 92 analysed Ordovician samples from the western (above) and eastern (below) part of the region, thickness (m), lithology, number of analysed samples, number of samples with recorded palynomorphs (acritarchs, chitinozoans, scolecodonts, trilete spores, graptolite fragments), relative kerogen composition (finely disseminated amorphous kerogen: dotted, large amorphous particles of kerogen: black, palynomorphs: blank), relative kerogen content: empty (E), poor (P), moderate (M), and rich (R), and bitumen content (B).

Bræ Formation; the latter also contains lumps of algae or spore-like palynomorphs (Plate 2 G-I). Both formations have a poor to moderate kerogen content. A few scolecodonts were recorded from the Tavsens Iskappe Group, which spans the Cambrian–Ordovician boundary.

Ordovician shelf and trough sequence

Organic matter from 92 samples of Ordovician shelf and trough deposits was analysed (fig. 14).

The organic-rich northern trough facies are postmature with regard to oil generation, whereas the shelf carbonates have a low organic content dominated by early mature finely disseminated amorphous kerogen.

Acritarchs (Plate 3 A and B) were recorded in 43 samples from the Ordovician succession and although the flora is of low diversity, the acritarchs seem to be biostratigraphically useful (K. J. Dorning, personal communication, 1986). Chitinozoans occur in 34 samples with a generally low diversity, but a number of biostratigraphically significant species have been recorded (Grahn & Nøhr-Hansen, 1989). Graptolite fragments (Plate 3 C) occur in 15 samples, and scolecodonts (Plate 3 D) occur in 47 samples.

The Troedsson Cliff Member and Aleqatsiaq Fjord Formation yielded the largest numbers of palynomorphs. The Troedsson Cliff Member is particularly interesting due to its content of presumed trilete spores (Plate 3 G-L) described in detail by Nøhr-Hansen & Koppelhus (1988). Two samples from the Aleqatsiaq Fjord Formation contain algal structures (Plate 3 E and F).

Silurian outer shelf and trough sequence

The organic matter of 277 Silurian samples from outcrops and shallow cores was systematically analysed (fig. 15; Christiansen & Nøhr-Hansen, 1989). The majority of the samples (259) are black shales from the Thors Fjord Member (lower part of the Wulff Land Formation), the Wulff Land Formation and the age-equivalent Lafayette Bugt Formation. Locally these shales reach more than 400 m in thickness.

The Thors Fjord Member is dominated by large amorphous kerogen particles and is tentatively characterized as rich in kerogen. The Lafayette Bugt Formation has a moderate kerogen content with a weak dominance of large amorphous kerogen particles. In contrast, the upper part of the Wulff Land Formation is dominated by finely disseminated amorphous kerogen and has a relatively poor kerogen content.

The Silurian shales in general have a low content of palynomorphs compared to the Ordovician carbonates. Chitinozoans (Plate 4 A and B) and graptolite fragments (Plate 4 C and D) are common. Scolecodonts are less abundant and trilete spores occur in only a few samples. Acritarchs have only been reported from one Upper Silurian sample in western Hall Land (Armstrong & Dorning, 1984). Chitinozoans were recorded in 120 samples. The diversity is low, but the species are stratigraphically distinct (Grahn & Nøhr-Hansen, 1989). A chitinozoan biostratigraphy combined with biostratigraphic schemes on graptolites (Bjerreskov, 1986) and conodonts (Armstrong & Aldridge, 1982) are useful for correlation of the source rock intervals.

The graptolite fragments recorded have no biostra-

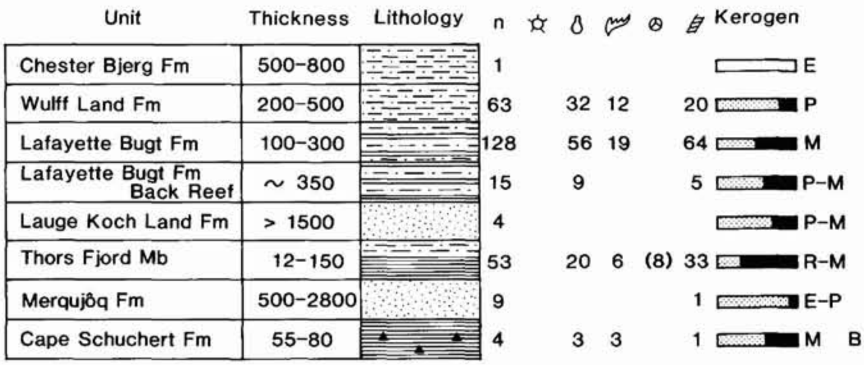

Fig. 15. Stratigraphic distribution of 277 analysed Silurian samples, thickness (m), lithology, number of analysed samples, number of samples with recorded palynomorphs (acritarchs, chitinozoans, scolecodonts, trilete spores, graptolite fragments), relative kerogen composition (finely disseminated amorphous kerogen: dotted, large amorphous particles of kerogen: black, palynomorphs: blank), relative kerogen content: empty (E), poor (P), moderate (M), and rich (R), and bitumen content (B).

tigraphic value, but measurements of graptolite reflectance contribute to the evaluation of the thermal maturity (Stouge *et al.*, 1988; Chapter 6).

The scolecodonts, which were observed in 40 samples, have so far not proved useful in either biostratigraphic or maturity studies.

Degraded and disintegrated palynomorphs, probably trilete spores having the appearance of degraded bitumen, were recorded from a few samples from the Lafayette Bugt, Wulff Land and Nyeboe Land Formations (Plate 4 E-H). The Lafayette Bugt Formation also contains spherical folded bodies (Plate 4 I) resembling the acritarch-like algae from the Cambrian Ekspedition Bræ Formation and rounded to drop-shaped palynomorphs (Plate 4 L).

Plant megafossils were reported from the Nyeboe Land Formation of Ludlow age (Larsen *et al.*, 1987). The same samples contain, in addition to the above mentioned degraded spore-like bodies (Plate 4 G and H), tubular structures (Plate 4 J and K) comparable to the material illustrated from Ordovician (Vavrdová, 1984), Llandovery (Duffield, 1985) and Wenlock (Strother & Traverse, 1979) successions elsewhere.

Amorphous kerogen

The state of preservation of the kerogen and the dominance of large amorphous kerogen particles indicate that the shale-dominated units with a moderate to rich kerogen content (figs 13 and 15) were deposited in oxygen-poor environments. In contrast, the carbonate-dominated units with a relatively poor to moderate kerogen content (fig. 14) represent more oxygenated depositional environments.

The differentiation, classification, and origin of amorphous kerogen are poorly known. Since most hydrocarbon targets are within Mesozoic deposits, very few palynological publications present descriptions of Lower Palaeozoic amorphous kerogen. Among the few Lower Palaeozoic examples are Venkatachala's (1981) illustrations of Precambrian to Ordovician filamentous algae. Venkatachala interpreted these algae as remains of blue-green algae (or cyanobacteria) which formed algal mats. Biodegradation of these filamentous algae leads to the formation of flaky or granular organic matter (Venkatachala, 1981, p. 184).

Batten (1984) illustrated Lower Palaeozoic lumps of amorphous kerogen with shapes interpreted as inherited from faecal pellets. He also mentioned that apparently amorphous masses occasionally prove to be composed largely of acritarchs.

Remains of blue-green algae were rarely identified in the palynological slides although commonly observed in thin-sections (Larsen, 1989). However, probably filamentous algae very similar to those reported by Venkatachala (1981) were recorded from a single Upper Ordovician – Lower Silurian sample (Plate 3 F).

Neither faecal pellets nor amorphous masses composed of acritarchs were recorded in the present organic material. Biodegradation and thermal alteration have destroyed any direct sign of the precursors of the amorphous kerogen from North Greenland.

Palynomorph distribution – depositional or preservational control

Palynomorphs were recorded in 76% of the analysed samples of Ordovician limestone, all of which were deposited in relatively shallow water, and in 67% of the Silurian shales which represent deeper water deposition. Thus the Ordovician versus Silurian palynomorph distribution illustrates a shallow to deep-water trend which, despite the age difference, clearly indicates the preferred habitat of the organisms.

Acritarchs, chitinozoans and scolecodonts were recorded from 38 to 54% of the analysed Ordovician samples, whereas graptolite fragments occur in only 17% of the samples (Table 1).

Table 1. The distribution of palynomorphs in the Ordovician limestone samples

	Number of analysed samples	Ac	Ch	Sc	Gr	Number of barren samples
Washington Land Gp	14	0	1	2	0	12
Aleqatsiaq Fjord Fm	28	17	13	14	3	3
Cape Calhoun Fm	4	3	3	3	3	0
Troedsson Cliff Mb	14	12	11	11	7	1
Gonioceras Bay Mb	10	7	5	9	2	0
Børglum River Fm	4	0	0	4	0	0
Steensby Glet. Fm	15	4	1	5	0	5
	89	43	34	48	15	21
% of analysed samples	100	48	38	54	17	24

Chitinozoans and graptolite fragments are represented in 43% and 44% of the Silurian samples, respectively. Scolecodonts occur in only 14%, and acritarch-like palynomorphs in less than 1% of the Silurian samples (Table 2).

The presumed benthic scolecodonts seem to prefer a shallow-water and/or limestone environment in contrast to the planktonic graptolites. The frequency of scoleco-

Table 2. The distribution of palynomorphs in the Silurian shale samples

	Number of analysed samples	Ac	Ch	Sc	Gr	Number of barren samples
Chester Bjerg Fm	1	0	0	0	0	1
Wulff Land Fm	63	0	32	12	20	26
Lafayette Bugt Fm	128	0	56	19	64	37
Lafayette Bugt Fm back reef	15	0	9	0	5	3
Thors Fjord Mb	53	0	20	6	33	11
Cape Schuchert Fm	4	0	3	3	1	1
Amundsen Land Gp	13	0	0	0	0	13
	277	0	120	40	123	92
% of analysed samples	100	0	43	14	44	33

dont and graptolite fragments in the Silurian deep-water deposited shales is the opposite of that in the shallow-water facies. The distribution of the supposedly planktonic chitinozoans indicates that this group tolerated shallow as well as deep-water conditions.

It is remarkable that acritarchs were not recorded from the Silurian shales in North Greenland, since acritarchs have been reported in moderate to large numbers in all marine lithologies except reef limestone, sandstone and conglomerate, in the Silurian of Britain and Ireland (Aldridge *et al.*, 1979). In North Greenland acritarchs are common in the Ordovician limestones, whereas only one Silurian sample, also a limestone, has revealed acritarchs (Armstrong & Dorning, 1984). Likewise, the very few Cambrian acritarch-like palynomorphs recorded from North Greenland were recovered from carbonates. The present distribution pattern is in accordance with the observations of both Aldridge *et al.* (1979) and Dorning (1987) who suggest that microfossils are more diverse, abundant and well-preserved in Palaeozoic platform carbonates than in graptolitic shale and sandstone turbidite sequences.

The analyses of the Ordovician and Silurian samples revealed 24 and 33% of the samples, respectively, to be barren of palynomorphs. The deviation is small and probably not significant. The Ordovician organic matter is generally less mature than the Silurian.

Although the data have not been strictly treated statistically, the palynomorph distribution clearly illustrates environmentally controlled trends.

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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

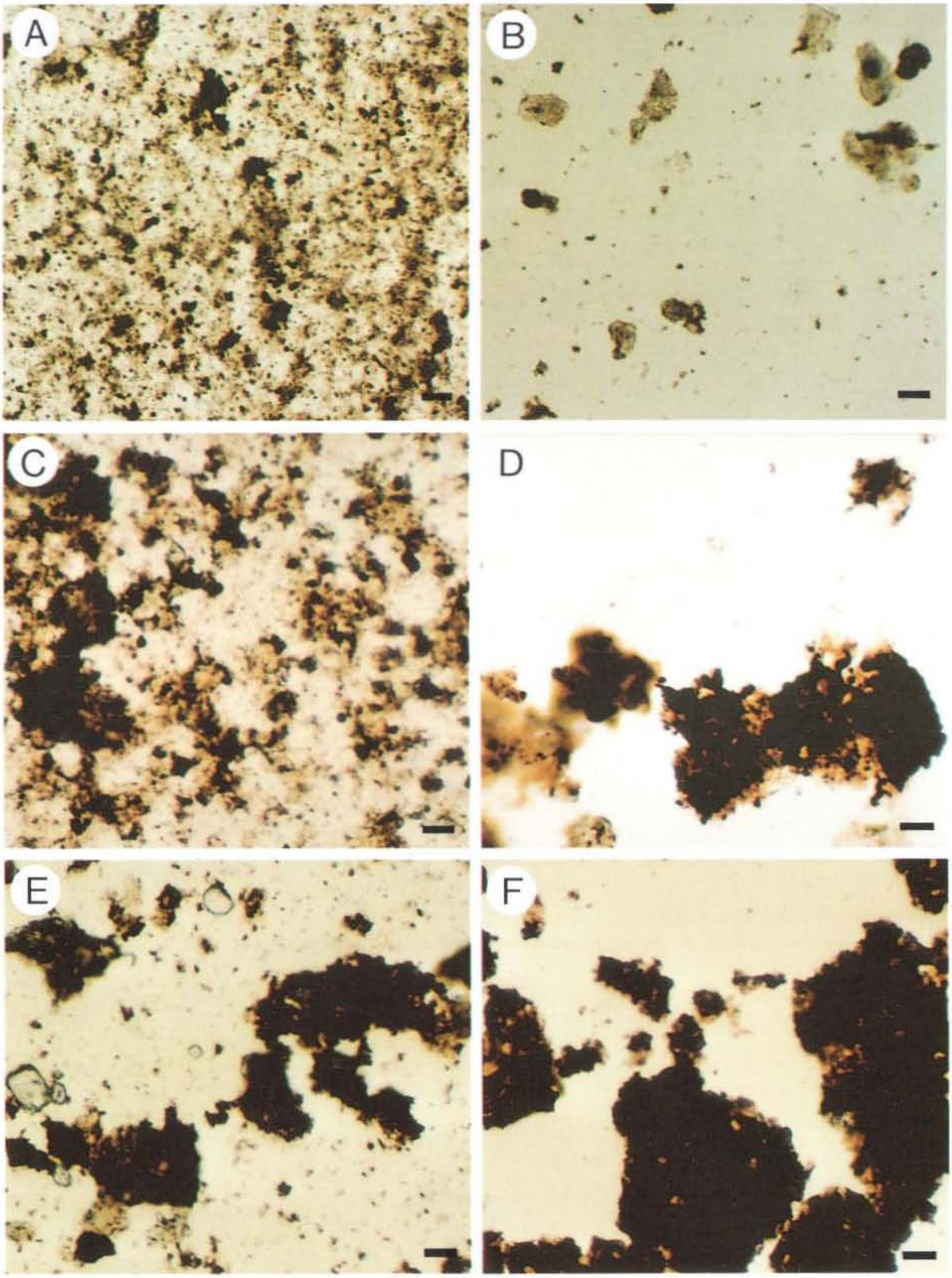

Plate 2. Cambrian palynomorphs

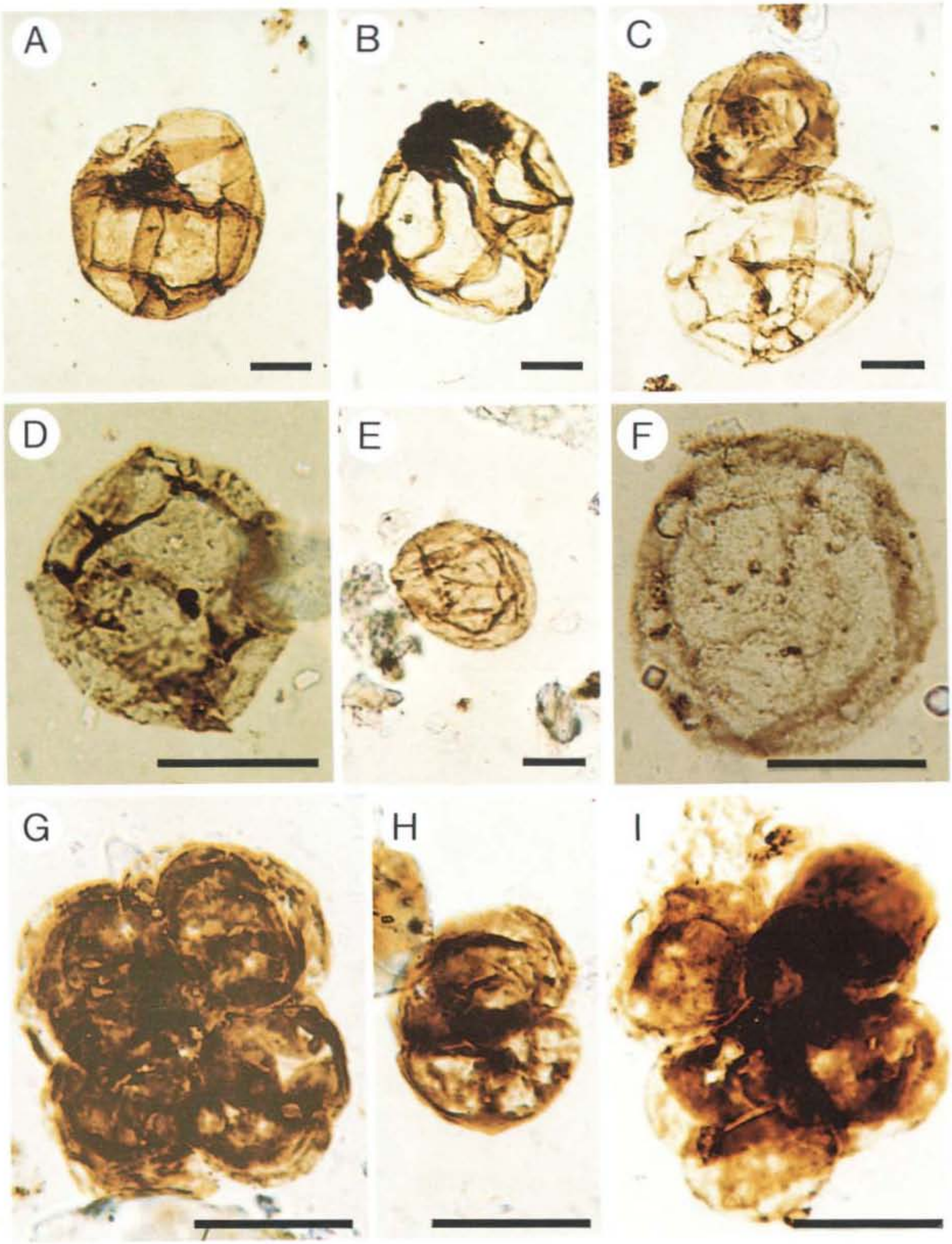

Plate 3. Ordovician palynomorphs

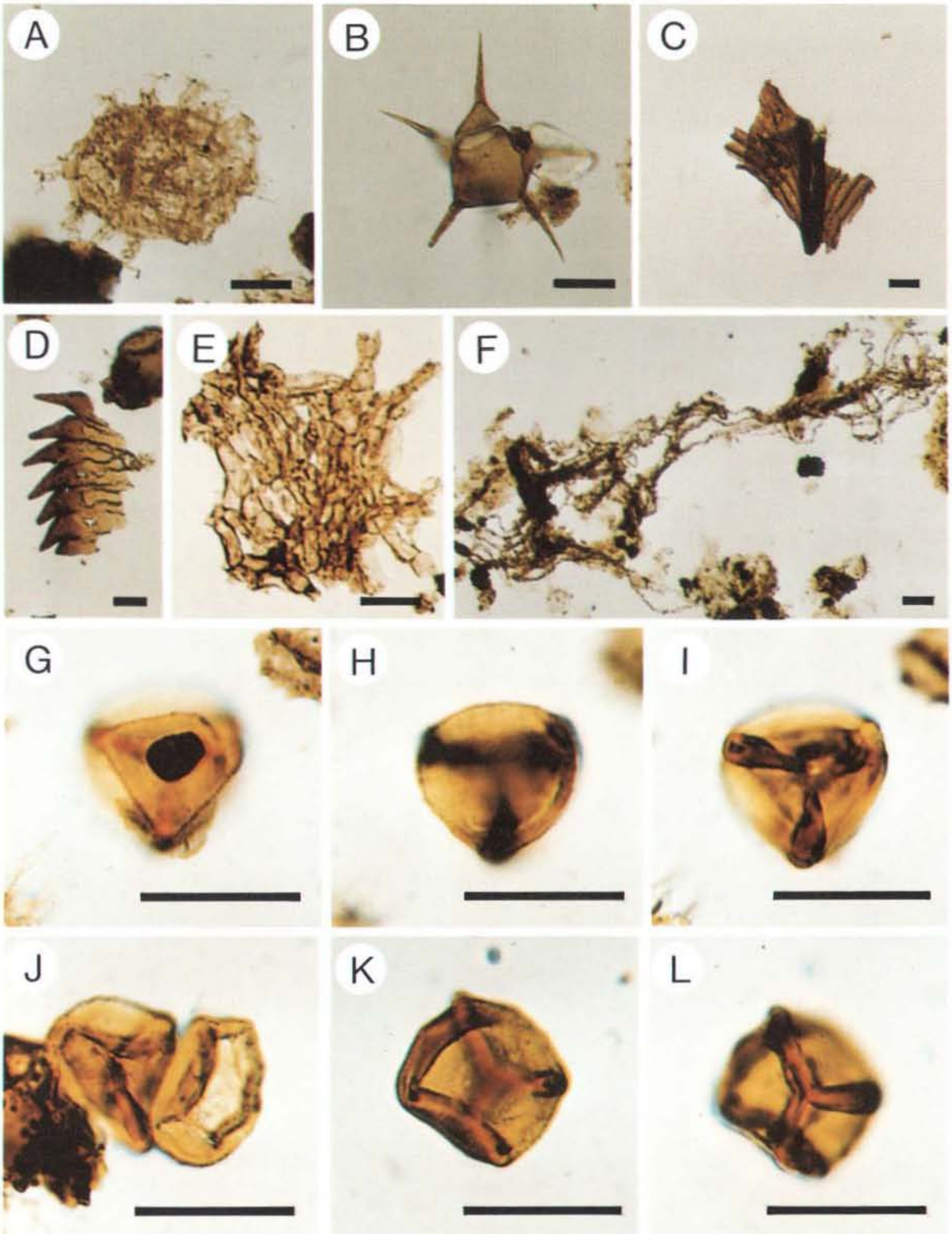

Plate 4. Silurian palynomorphs

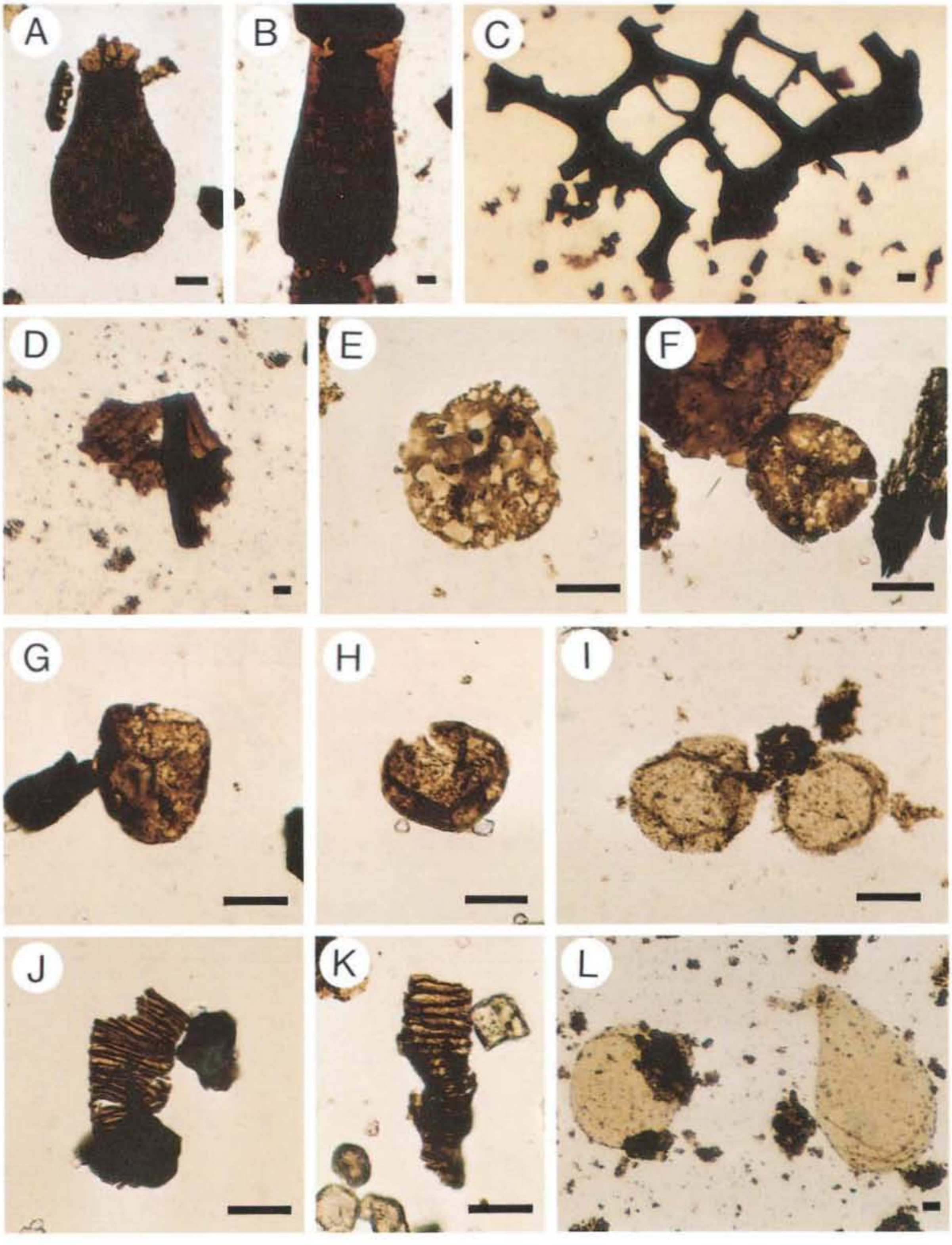

Plate 5. Progressive coloration of amorphous kerogen with increasing thermal alteration

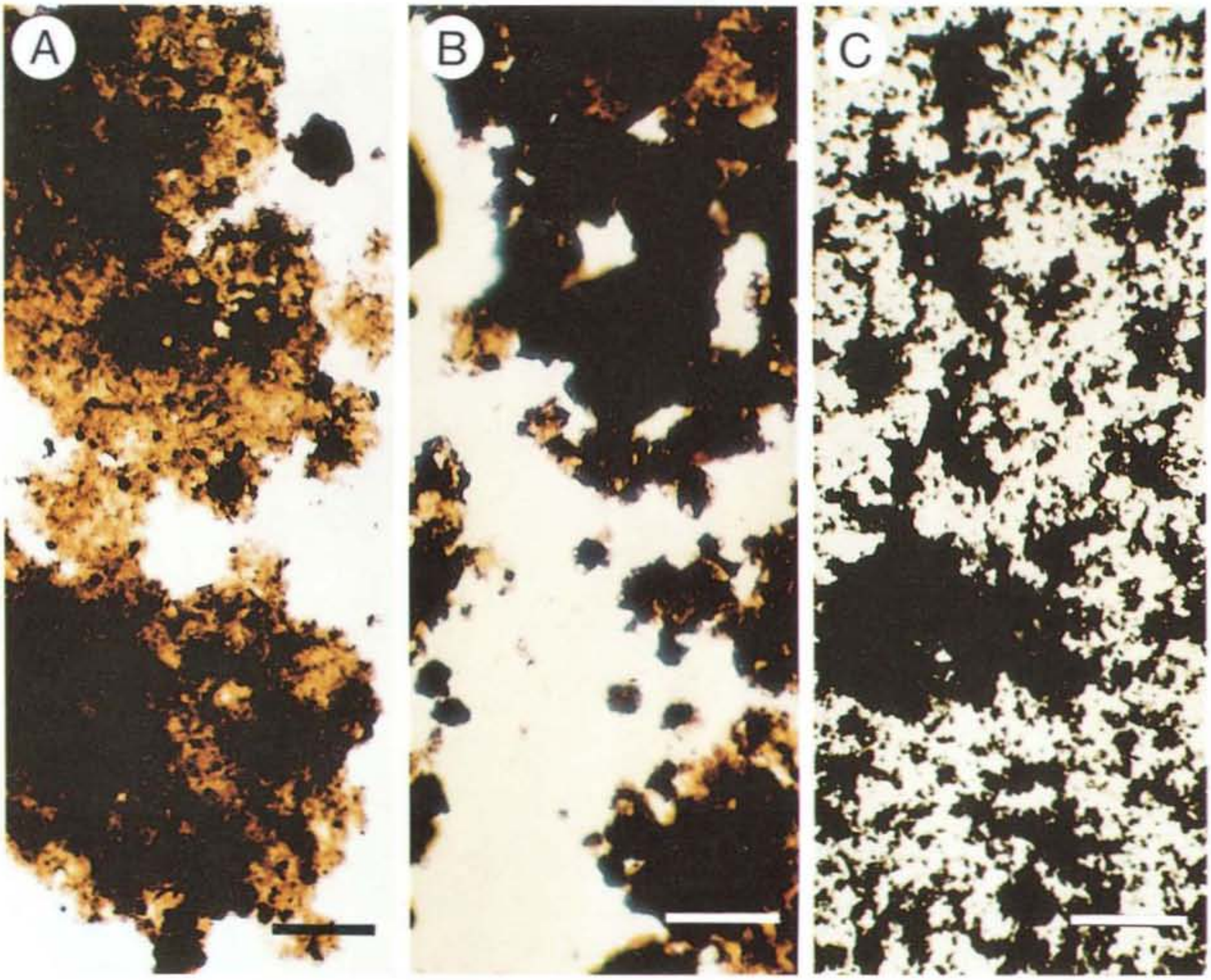

Plate 5. Progressive coloration of amorphous kerogen with increasing thermal alteration

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

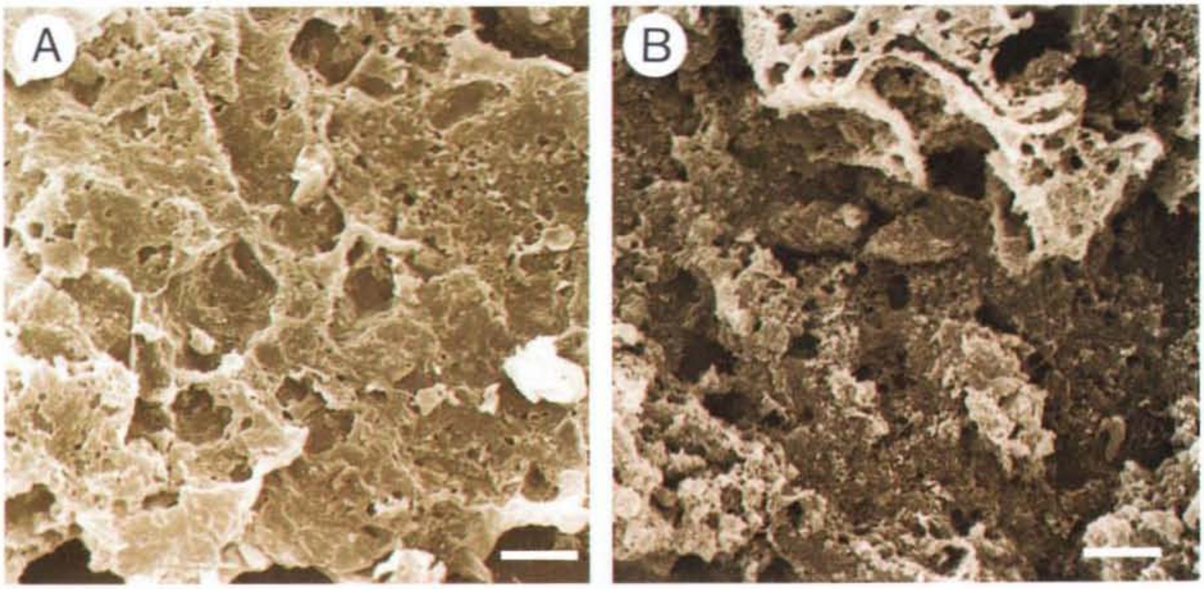

Plate 6. Change in structure of amorphous kerogen with increasing thermal alteration as observed in the scanning electron microscope

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

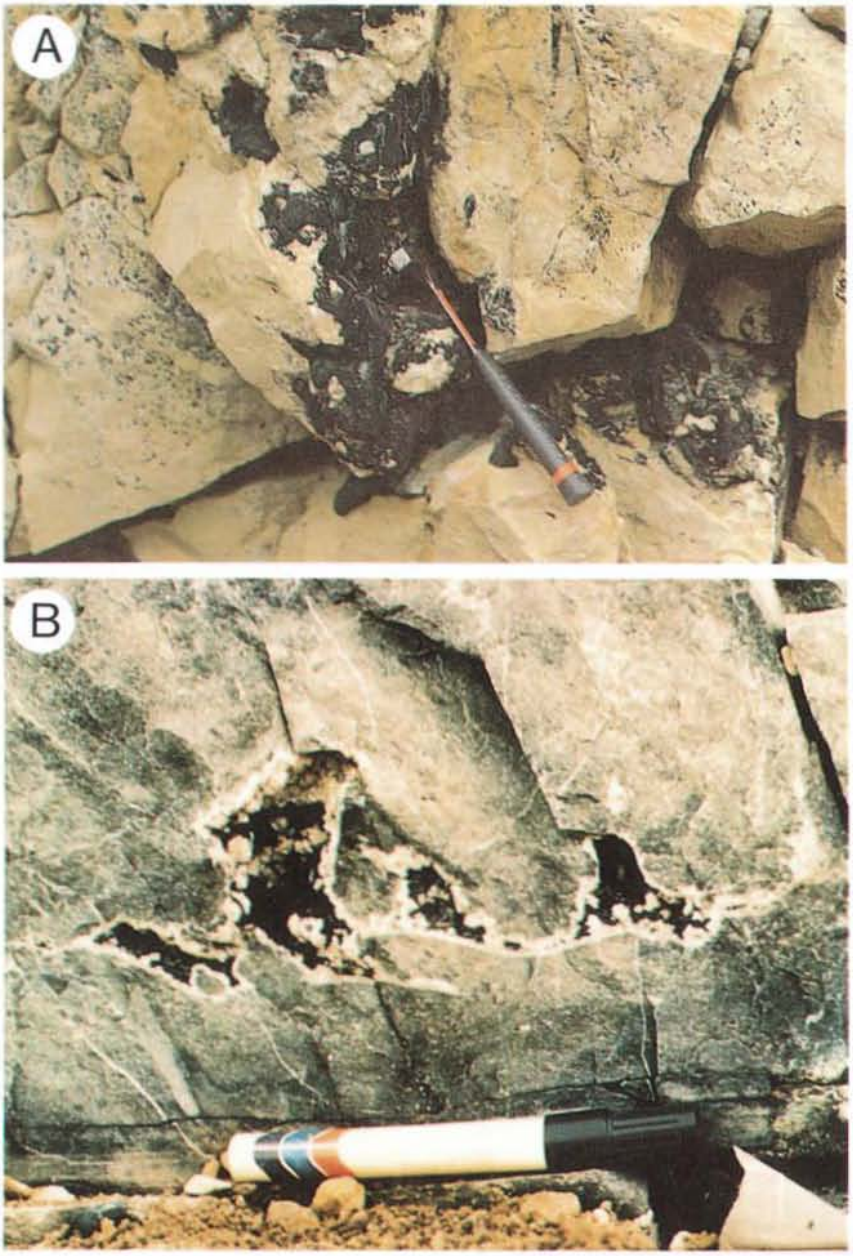

Plate 8. Macroscopic bitumen in slabs

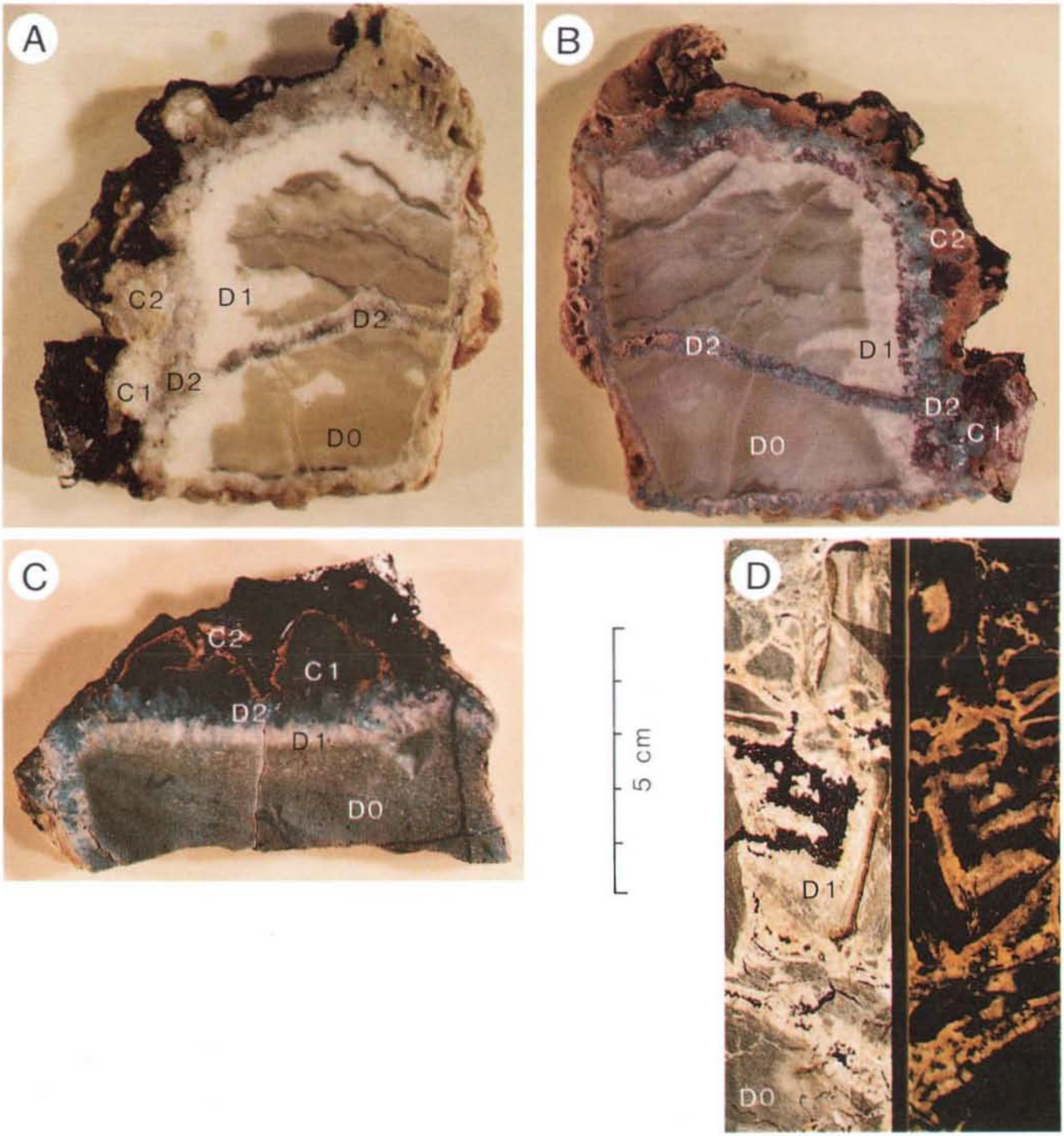

Plate 9. Bitumen in thin section

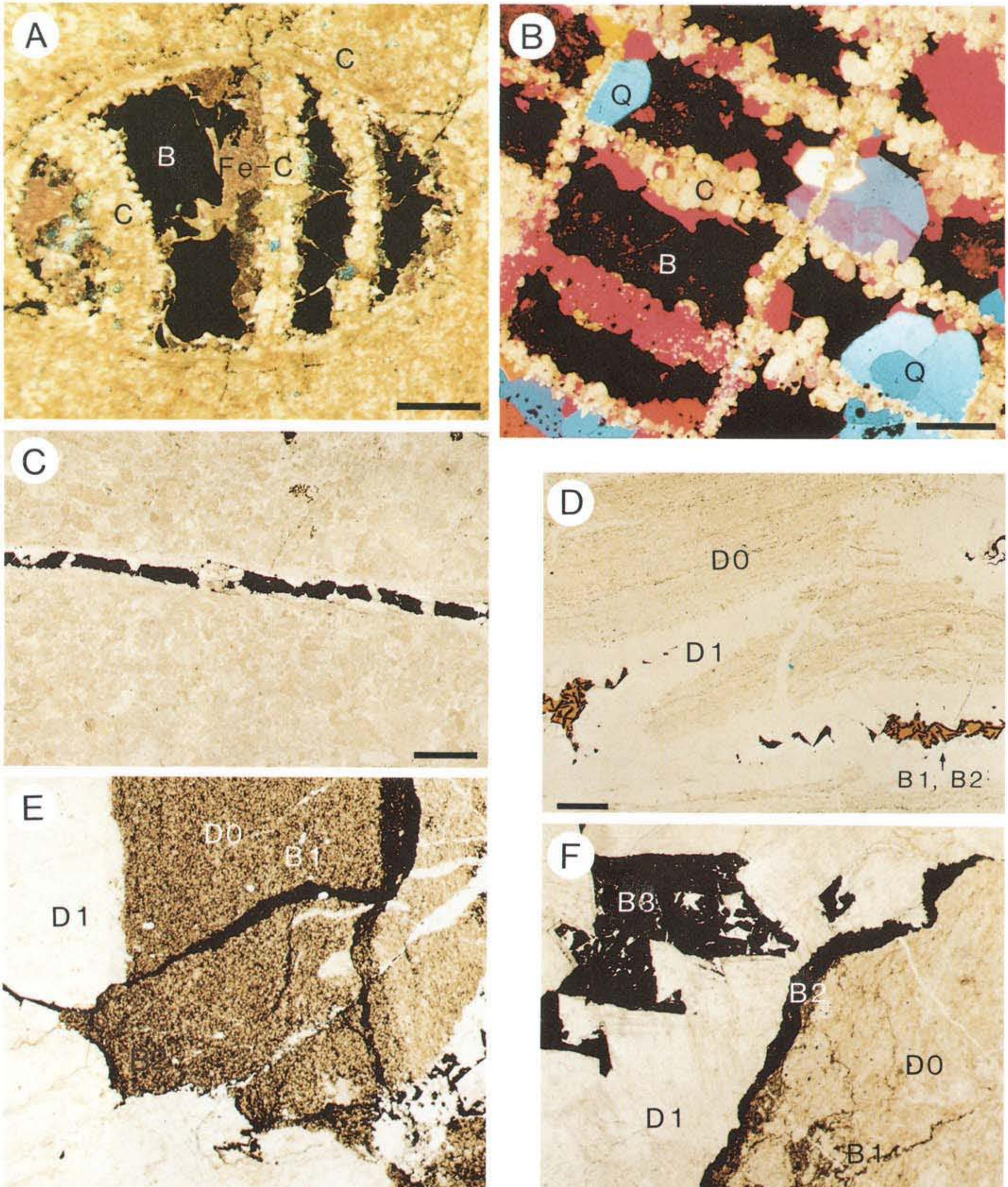

Plate 10. Bitumen in palynologically prepared samples observed in microscope or in SEM

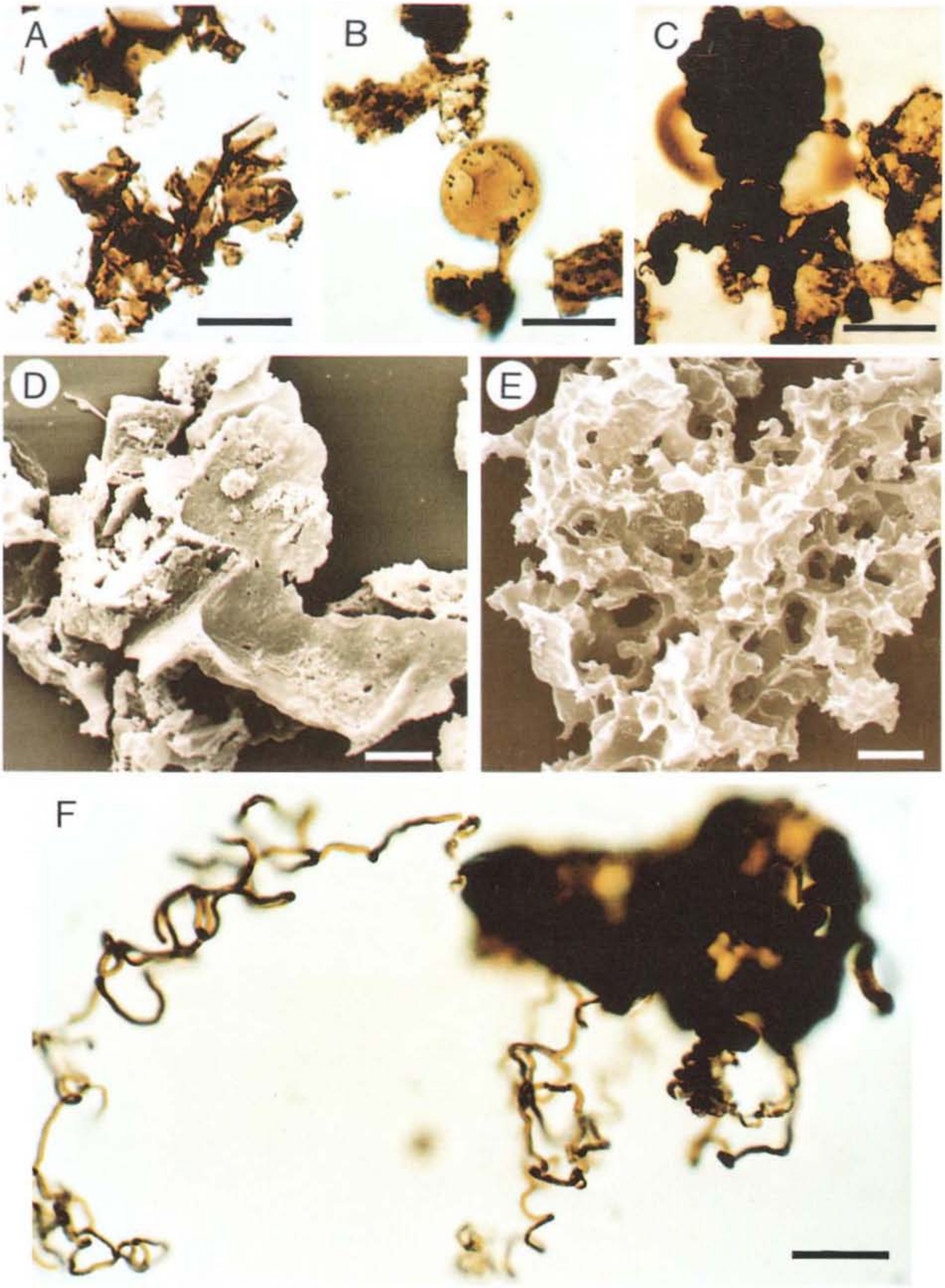

Plate 11. Bitumen in polished section

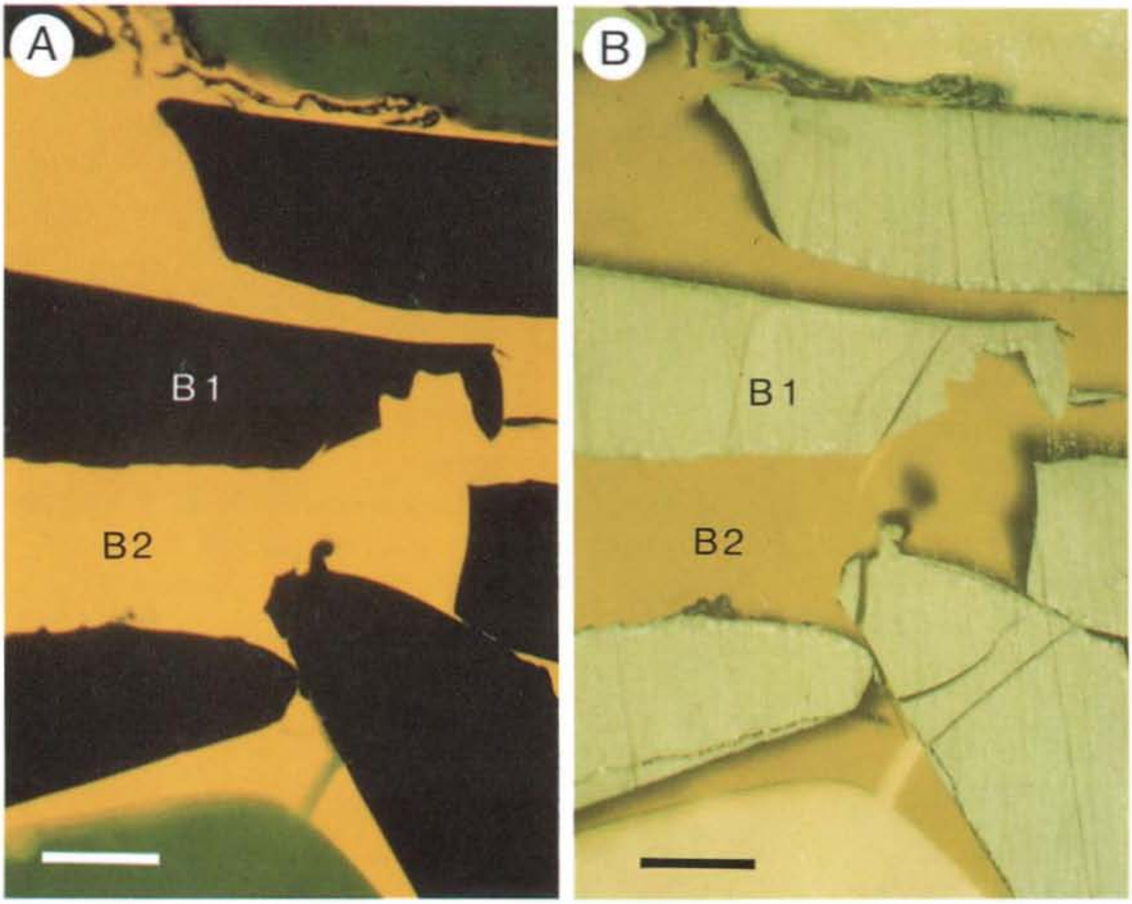

Plate 11. Bitumen in polished section

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.