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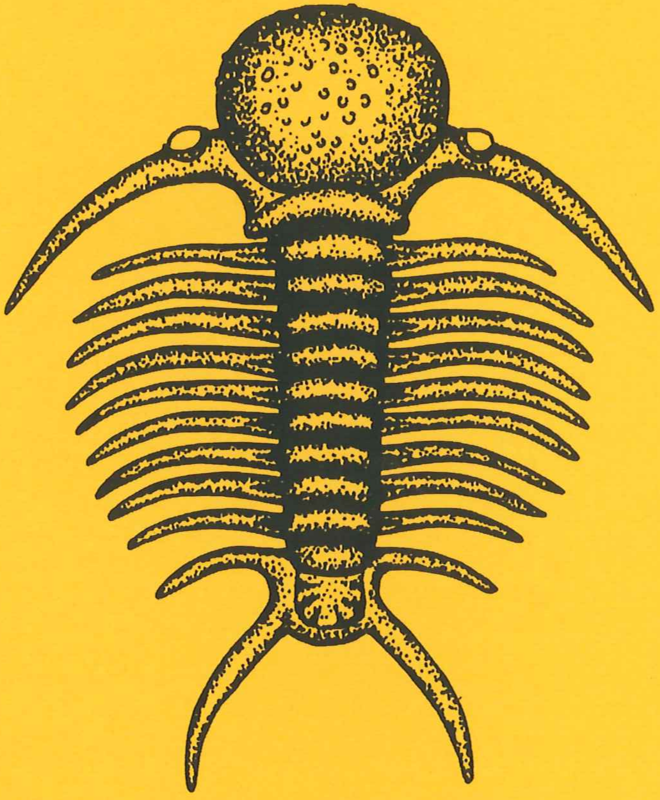

Uppermost Lower Cambrian - Middle Cambrian stratigraphy and sedimentary petrography of the Almbacken drill-core, Scania, southern Sweden.

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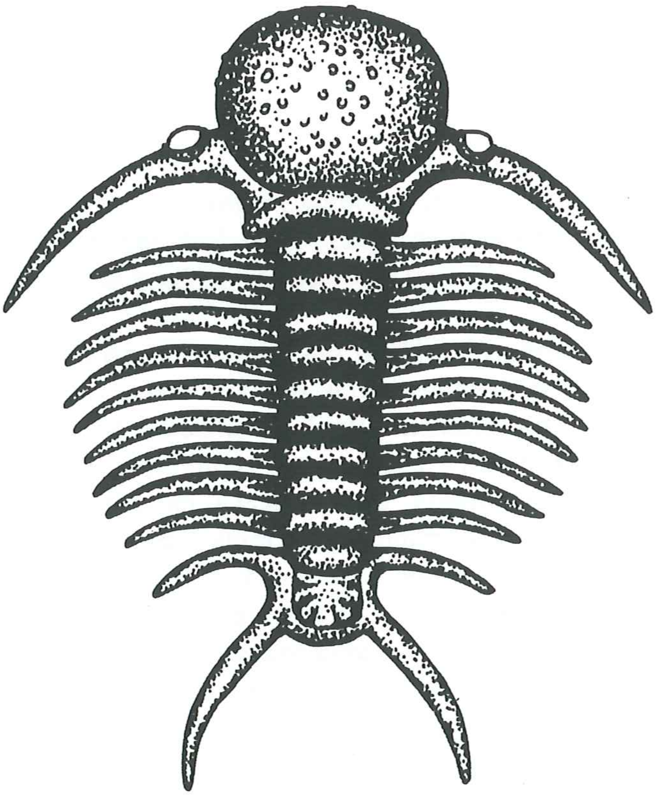

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Abstract: The uppermost Lower Cambrian and Middle Cambrian of the Almbacken drill-core, drilled 1949 in Södra Sandby, are described and correlated with other sections in Scania (the Gislövshammar-2 core and the Forsemölla, Gislövshammar and Brantevik sections). The core consists of Middle Cambrian bituminous alum shales with stinkstone lenses and three beds of fossiliferous limestone, the Andrarum, *Exsulans,* and "Fragment" limestones. The lower part of the core, containing the Middle-Lower Cambrian boundary, consists of calcareous and siliciclastic shallow marine deposits. The alum shale has a fairly high calcium carbonate content ($CaCO_3$) and a low total organic content (TOC) compared to the alum shales in other areas in Scandinavia. The low TOC in the alum shales of the Almbacken core is due to a high content of terrigenous material and heating through Permo-Carboniferous igneous activity (resulting in migration of lighter hydrocarbons) in the Södra Sandby area. The thickness of the Middle Cambrian in Södra Sandby is c. 34.6 m, which is the maximum thickness recorded in Scania. The Middle Cambrian is thinning out towards the southeast and on Bornholm it measures only c. 3 m. The higher content of terrigenous material reported in the "Fragment" and *Exsulans* limestones in localities located southeast of Södra Sandby, compared to Almbacken, may indicate deposition in shallower water during the Middle Cambrian.

Keywords: Middle Cambrian, Lower Cambrian, alum shale, limestones, stratigraphy, Almbacken, Forsemölla, Gislövshammar, Brantevik, Scania, Sweden.

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In Scania, southern Sweden, Cambrian deposits occur mainly in the southeast and central parts of the province (Fig. 1). The Lower Cambrian consists of sandstones and limestones (divided into the Hardeberga Sandstone, the Norretorp Formation, the Rispebjerg Sandstone and the Gislöv Formation). The succession continues with the bituminous Middle and Upper Cambrian alum shales with lenses of stinkstone and minor beds of limestone, referred to as the Alum shale Formation (Bergström & Ahlberg 1981; Ahlberg 1984). The Middle Cambrian limestone beds are referred to as the Andrarum, *Exsulans* and ”Fragment limestones (Hadding 1958). The uppermost Lower Cambrian succession in Scania is a shallow marine deposit (de Marino 1980). The uniform phosphoritic quartz arenite containing lime mud at the top of the Rispebjerg Sandstone occurs in several localities in Scania (see Bergström & Ahlberg 1981). The strata of the superimposed Gislöv Formation were deposited under more unstable conditions, and the interval shows local differences in Scania according to their sedimentary petrography. The Lower to Middle Cambrian beds are separated by a hiatus, which seem to be correlative with the Hawke Bay regression of North America (Bergström & Ahlberg 1981). This regression may have been eustatic and no sediments of this event are so far recognized in Scandinavia (Bergström & Gee 1985).

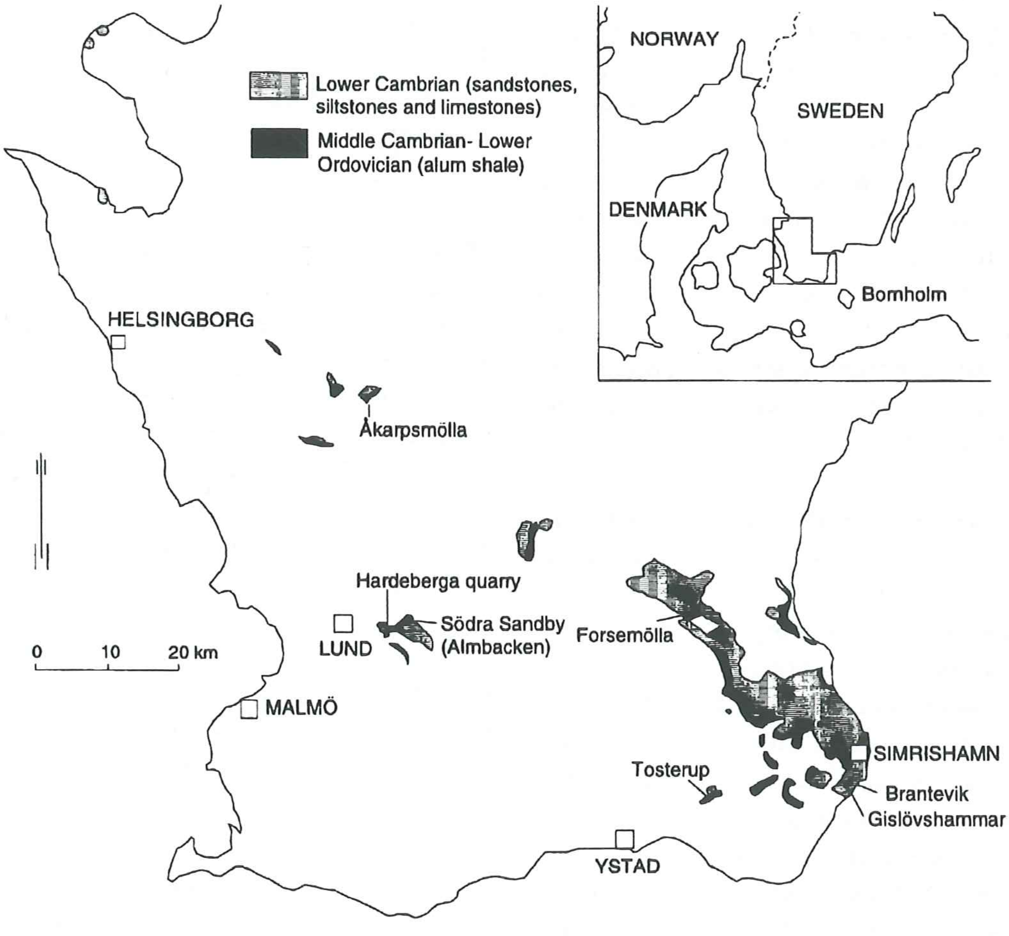


Fig. 1. Map of Scania showing the extent of Lower Cambrian-Tremadocian outcrops. Modified after Bergström & Ahlberg (1981) and Andersson et al. (1985).

The Middle Cambrian to Tremadocian alum shale has a broad distribution in Scandinavia, the beds in Scania are thicker and the zonal succession is more complete than elsewhere in southern and central Sweden (Andersson et al. 1985). The alum shale was deposited under anoxic conditions and the sedimentation rate was very slow (Andersson et al. 1985; Thickpenny 1984). The change from the shallow marine to the deeper anoxic to dysoxic alum shale deposition has generally been interpreted as reflecting small changes in the evolution of the passive margin of Western Baltica (Gee 1987). Another explanation to the Middle Cambrian transgression is that the early Caledonian subduction started along the outer margin of Baltica in (Gee 1987). From the beginning of the Middle Cambrian the sedimentation became more uniform. In Scandinavia the Gislöv Formation is only known from Scania and the Mjösa district in Norway while the alum shale, the *Exsulans* limestone, and the Andrarum limestone and corresponding beds represent a broad distribution of shallow marine areas in Scandinavia (cf. Hadding 1958; Martinsson 1974; Bergström & Gee 1985). The late Middle Cambrian seashore was probably oriented in a north-south direction across Sweden with deposition of carbonates and shelf clastics from the peneplaned Precambrian basement to the east, and anoxic to dysoxic mud forming alum shale to the west (Thickpenny 1987).

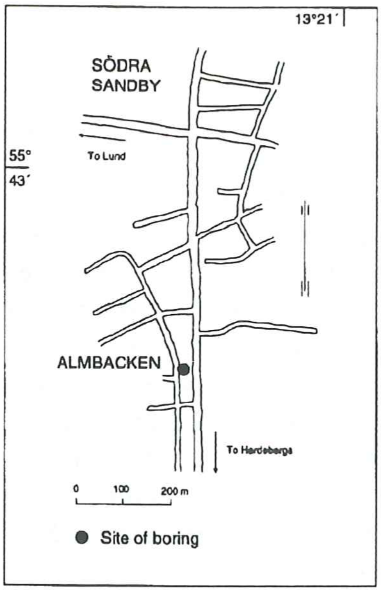


Fig. 2. Location of the well-site.

In 1941-1942, a series of drill cores were made to log the thickness of the alum shales in Scania. The cores were taken up at Åkarpsmölla, Södra Sandby, Andrarum and Gislövshammar (Westergård 1944). The boring in Södra Sandby struck a dolerite dyke and it was not possible to drill through the entire Middle Cambrian strata (Westergård 1944). On commission of the University of Lund, a supplementary borehole was carried out in 1949 at Almbacken. The Palaeozoic beds of the Södra Sandby-Fågelsång area, east of Lund, are dislocated by numerous NW-SE trending faults and penetrated by Permo-Carboniferous dolerite dikes. Beneath the beds, the Proterozoic basement of the Romeleåsen Horst dips towards the north-west (Bergström 1982). The area has been intensively examined since the middle of the 19th century (see Ahlberg 1992 and references therein). In 1936 a temporary section at the Almbacken farm was examined by Stenström (1940). On the basis of the results from the examination of the section, supplementary diggings made in the immediate surrounding area and geophysical data, a borehole was made 100 m north of the farm (Fig. 2). The boring was carried out by Svenska Diamantbergborrnings Aktiebolaget and preliminary logged by Seth Stenström (1949, unpublished data).

The intention of this paper is to present the petrography and stratigraphy of the core and to compare the detrital petrology with contemporaneous sections in Scania. Diagenetic structures and features, which are common in the lower Palaeozoic strata, are treatened briefly (mainly the diagenetic evolution of organic matter in the alum shales in the Almbacken core).

Material and methods

The core, 31.08 m long and with a diameter of 7 cm, was logged. Thirteen thin sections were made for petrographical studies. When possible, a pointcount (300 points) for a classification of lithology was made. The siliciclastic sediments were classified according to Folk (1974) and Pettijohn et al. (1987), and limestones were classified according to Dunham (1962). Measurements of calcium carbonate content ($CaCO_3$, eighteen samples) in all lithologies and TOC (total organic content, ten samples) in the alum shale, for comparasion with other sections, were carried out with standard methods (cf. Fairchild et al. 1988). Five samples from the shales were used for XRD analysis (cf. Hardy & Tucker 1988) to identify the clay mineralogy. They were analysed untreated and pre-treated with heating to 550°C and ethylene glycol, respectively, in order to discriminate smectite, kaolinite and chlorite. One of the thin sections (JM 160) was used for scanning electron microscope (SEM) analysis in order to identify the matrix. Two pieces of rocks were cut, polished and photographed. The biozonation and naming of lithologies is according to Seth Steneström (unpublished data 1949) and Per Ahlberg (personal information).

Description of the succession

The core recovery is nearly total, except for losses of about 50% in the interval 2.87-3.24 m. The bedding is horizontal with the exception for a slight dip above and below stinkstone lenses. The entire core (all lithologies) is penetrated by narrow fissures, in most cases filled with calcite, less often with calcite and pyrite. A few slickenside surfaces occur. The lithologic succession is shown in Fig. 3. Pointcount data is shown in Table A1.

Surface (0) = 37 m (approx.) above sea level.

0-2.87 m: Pipe drive. Quaternary deposits, till (consisting mainly of alum shale fragments) and crushed alum shale.

2.87-4.56 m: Alum shale (black, bituminous, laminated and fissile claystone), consisting of alternating lighter and darker layers (0.2-0.4 mm thick) due to shiftly organic contents. Elliptic, horizontally orientated calcite (sparite) nodules ranging from 0.1 to 1.4 mm in length occur scattered. The shale has thin intercalating laminae of pyrite and calcite, and narrow fissures partly filled with calcite.

4.56-5.71 m: "Andrarum" Limestone (classified as mudstone *sensu* Dunham 1962). Consists of lithologies, a dark grey to black one and a light grey one. The latter occur as nodules, bands or irregulary portions in the dark one. At 5.60 m (in the dark lithology) plume-shaped burrow marks occur, 2 mm across and orientated in all directions. The fossil content in the lime mud consists mainly of trilobite fragments (Plate 1a). Crystals of pyrite and fissure fillings of crystalline calcite occur.

5.71-11.80 m: Alum shale (black, bituminous, laminated and fissile claystone), in some parts with a low organic content (showing a dull streak when scratched). Concretions and thin laminae of pyrite and narrow fissures (0.5-1.0 m), partly filled with calcite, occur.

11.80-12.00 m: Stinkstone (black, crystalline and bituminous limestone, anthraconite). No depositional texture is visible, except a pyritic laminae, 4-5 mm, at 11.92 m. The limestone consists of recrystallized calcite grains in a great variety in size (from 10 µm), separated by thin bitumen coatings. Dark microcrystalline and bituminous calcite grains are surrounded by radial calcite crystals. Fossil cavities have a secondary filling of crystalline calcite. Pyrite

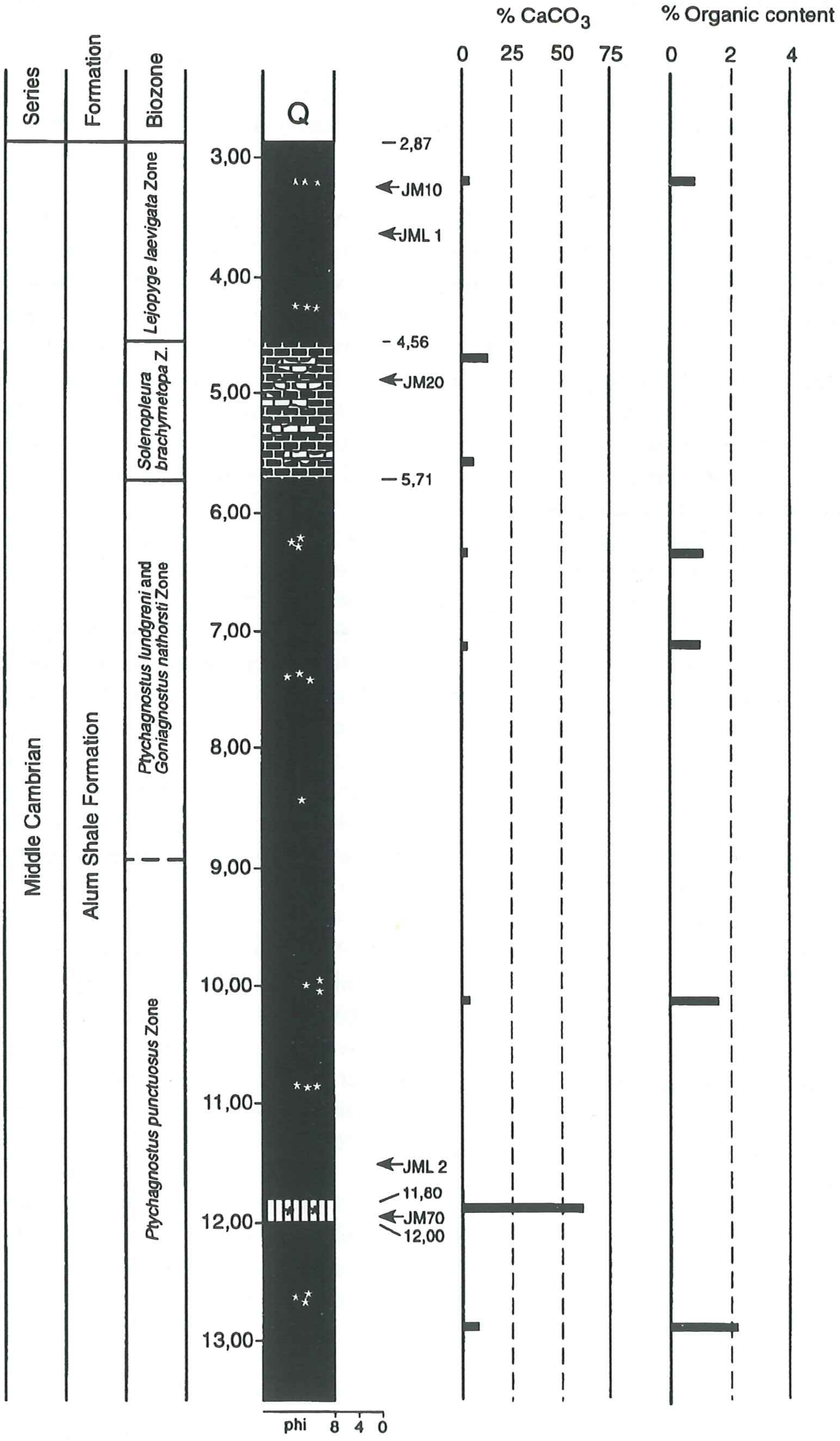
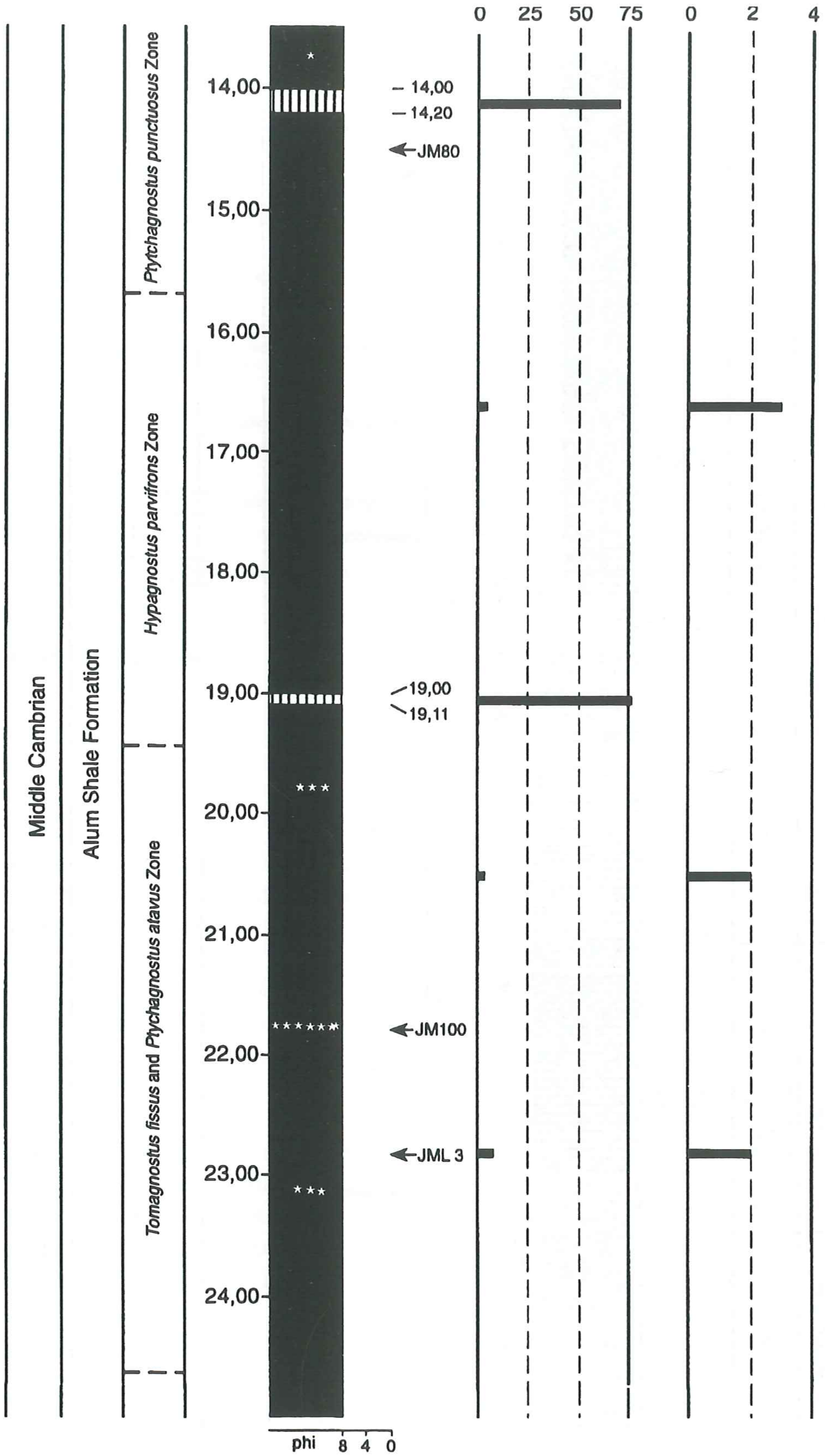
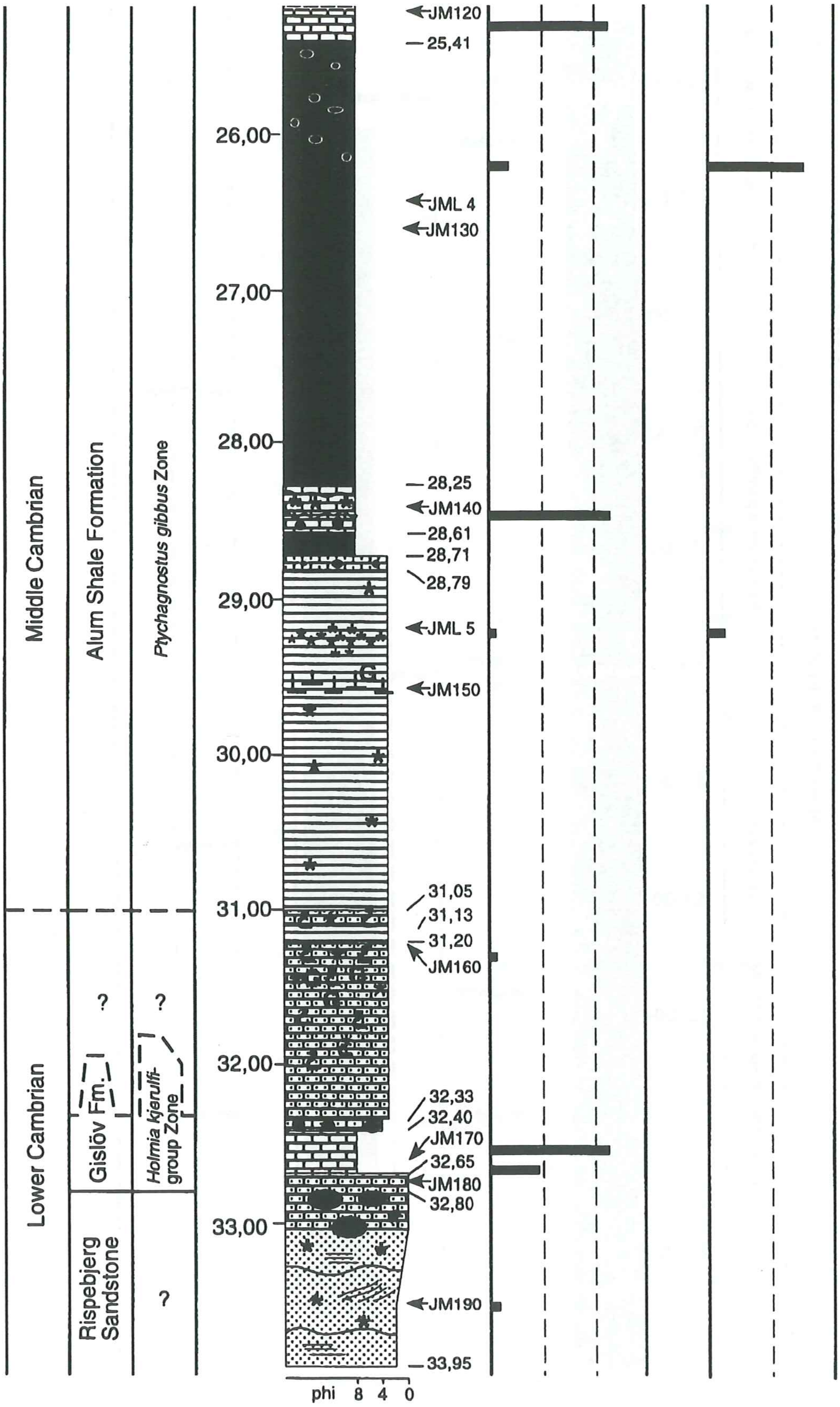


Fig. 3. Core log of Almbacken, showing lithologies, $CaCO_3$ content, TOC and sampling levels for thin sections (JM 20-190) and XRD analyses (JML 1-5). Internal sedimentary structures are not to scale.


Middle Cambrian
Alum Shale Formation
Ptytchagnostus punctuosus Zone
Hypagnostus parvifrons Zone
Tomagnostus fissus and Ptychagnostus atavus Zone
14,00
15,00
16,00
17,00
18,00
19,00
20,00
21,00
22,00
23,00
24,00
phi
8
4
0
– 14,00
– 14,20
JM80
19,00
19,11
JM100
JML 3
0
25
50
75
0
2
4


Middle Cambrian
Lower Cambrian
Alum Shale Formation
Gislöv Fm.
Rispebjerg Sandstone
Ptychagnostus gibbus Zone
Holmia kjerulfi-group Zone
?
?
?
26,00
27,00
28,00
29,00
30,00
31,00
32,00
33,00
JM120
25,41
JML 4
JM130
28,25
JM140
28,61
28,71
28,79
JML 5
JM150
31,05
31,13
31,20
JM160
32,33
32,40
JM170
32,65
JM180
32,80
JM190
33,95
phi 8 4 0

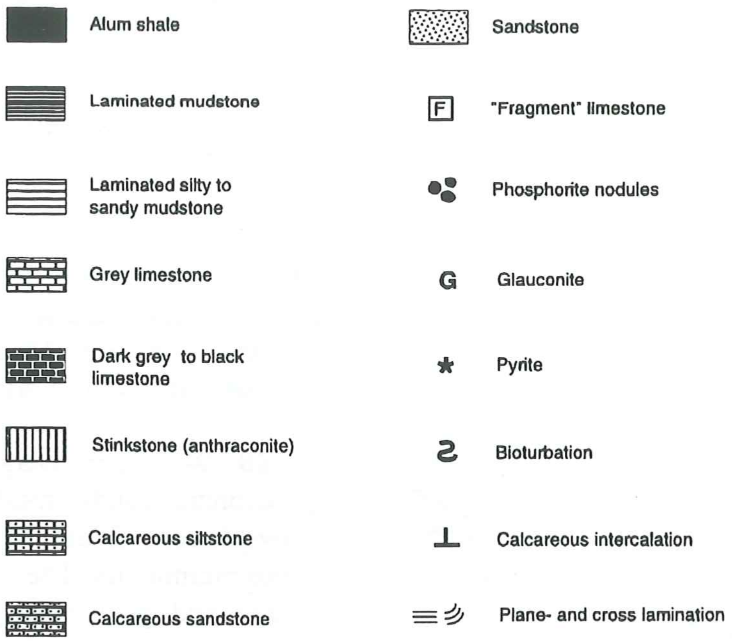


Fig 3. cont´d. Legend

and calcite occur as concretions and fissure fillings.

12.00-14.10 m: Alum shale (black, bituminous, laminated and fissile claystone) with concretions of pyrite. Narrow fissures are partly filled with calcite and pyrite.

14.10-14.20 m: Stinkstone (black, crystalline and bituminous limestone, anthraconite) with calcite concretions.

14.20-19.00 m: Alum shale (black, bituminous, laminated and fissile claystone), consisting of varying lighter and darker laminae with elliptic and horizontally orientated calcite nodules (0.1-1.4 mm) and scattered crystals of pyrite. Narrow fissures are partly filled with calcite. The lower part has slip surfaces partly filled with calcite.

19.00-19.11 m: Stinkstone (black, crystalline and bituminous limestone, anthraconite).

19.11-25.01 m: Alum shale (black, bituminous, laminated and fissile claystone). Some parts are very fossiliferous. The laminae, showing shiftly organic contents, has embedded elliptic and horizontally orientated nodules of calcite (sparite). Pyritic laminae occur, up to 5 mm thick. Narrow fissures are filled with calcite.

25.01-25.41 m: "Exsulans" limestone. The upper 20 cm consists of a dark grey to black crystalline limestone with phosphorite nodules at the extremely fossiliferous top. The recrystallized calcite grains (pseudospar), 20-90 µm across, are separated by thin bitumen coatings (Plate 1b). The pyritic and phosphatic boundary between the two lithologies contains a great number of trilobite fragments and some angular quartz grains (70-90 µm). The middle part (8 cm) is light grey, and consists of recrystallized calcite grains measuring up to 15 µm and separated by a thin bitumen coating. It is very fossiliferous near to the base of the overlying unit (Fig. 4a). The lower 12 cm are medium grey, and are in the upper part very

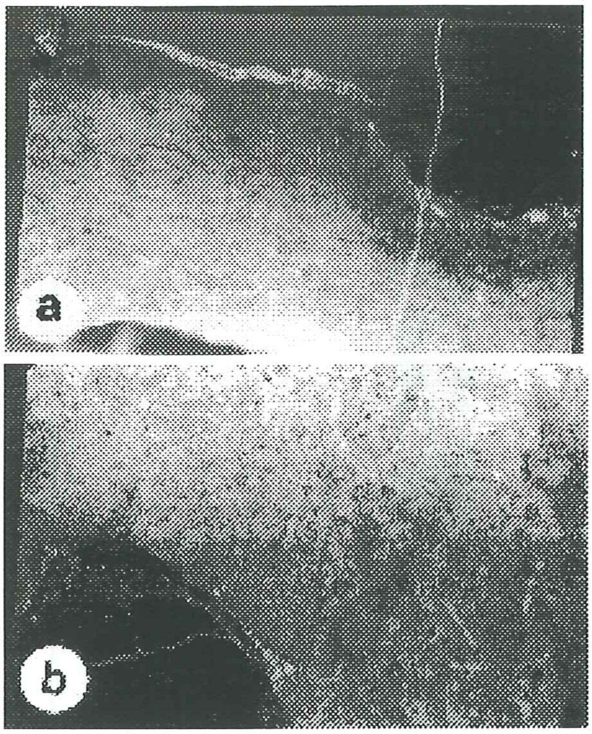


Fig. 4. Polished surfaces. Natural size. a) *Exsulans* limestone at 25.19-25.23 m showing the accumulation of fossils in the boundary between the two different lithologies. b) Rispebjerg Sandstone at 32.80-32.84 m (uppermost part), containing a phosphorite nodule with embedded well rounded quartz grains.

fossiliferous (similar to the overlying unit, see Fig. 4a). In the lowest part pyrite concretions occur. The entire limestone is dissected by a narrow fissure filled with calcite.

25.41-28.25 m: Alum shale (black, bituminous, laminated and fissile claystone). Phosphorite nodules (up to 1 cm across) occur in the upper part. Quartz grains (15-30 µm) are common, together with clay minerals and elliptic, horizontally orientated nodules of sparitic calcite. Nodules (60 µm) consisting of crystalline calcite surrounding pyrite crystals with a rim of spherical calcedon (?) crystals occur. Narrow fissures are filled with calcite.

28.25-28.61 m: "Fragment" limestone (packstone), with a high content of pyrite (c. 20% in pointcount) and hardgrounds. Phosphorite nodules occur in the lower part. Fossils occur in abundance and consist mostly of micritized and pyritized trilobite fragments (Plate 1c), which are orientated in all directions. Sparse, angular quartz grains occur, 50 µm across. Pyrite concretions occur at the upper boundary. The limestone is dissected by an unfilled fissure whose walls are coated with calcite crystals, up to 5 mm across. Crystalline calcite occur as narrow fissure fillings.

28.61-28.71 m: Dark grey to black laminated and fissile mudstone.

28.71-28.79 m: Medium grey calcareous siltstone with phosphorite nodules.

28.79-31.05 m: Dark grey, laminated and glauconitic sandy mudstone with sparitic intercalations (Plate 1d). The unit is partly more bituminous. The angular to subangular quartz and glauconite grains (50-100 µm) occur in a clay matrix or are cemented by sparry calcite. Clay minerals and phosphorite grains occur as well. Pyrite is abundant. At 29.30-29.37 m a concretion of weathered pyrite occur. Narrow fissures are filled with crystalline calcite.

31.05-31.13 m: Pyritic and calcareous clayey sandstone. Unfossiliferous and bioturbated.

31.13-31.20 m: Dark grey, glauconitic sandy mudstone.

31.20-32.33 m: Pyritic and calcareous clayey sandstone. The upper part is intensively bioturbated. Unfossiliferous. The lower part is more calcareous. The angular to sub-angular quartz grains (50-100 µm) occur partly in a clay matrix, partly in a sparry calcite cement (Plate 1e). Crystals of pyrite and grains of glauconite are abundant. Quartz veins and fissures filled with calcite occur.

32.33-32.40 m: Medium grey pyritic silty limestone with phosphorite nodules.

32.40-32.65 m: Wackestone, with a fossil content consisting mostly of trilobite fragments. Two-thirds of the fossil fragments

Table 1. Percentage values of pointcount. Dark and light lithologhy of the (JM 20)- and (JM 120) samples are marked with (d) and (l) respectivley.

Sample	JM 20 (l)	JM 20 (d)	JM 120 (d)	JM 120 (l)
Micrite	89.3	94.6		
Microspar				65.6
Pseudospar			90.0	
Calcite	3.6	0.3	6.0	9.6
Fossil	5.0	4.6	2.6	21.6
Pyrite	2.0		1.3	1.6
Phosphorite				1.3

Sample	JM 140	JM 170	JM 180
Micrite	35.3	68.3	58.3
Calcite	9.0	1.3	2.3
Fossil	33.3	16.6	1.0
Phosp. fossil	1.0		
Pyritized fossil		6.6	
Quartz		0.6	36.6
Pyrite .	19.6	6.6	1.6
Phosphorite	1.6		

Sample	JM 130	JM 150	JM 160	JM 190
Sparite	2.3	12.0	40.3	
Calcite	1.6		0.6	0.6
Clay	84.6	52.3	12.6	
Quartz	10.0	29.0	42.6	89.3
Pyrite		0.3	1.5	0.6
Phosphorite		0.9		
Glauconite		4.6	4.3	4.0
Clay mineral	1.0	0.6		
Feldspar				

are pyritized. Crystals of pyrite and sparse, subrounded to rounded quartz grains (0.7 mm) occur (Plate 1f).

32.65-32,80 m: Arenaceous limestone. The upper part is a light grey arenaceous calcilutite. The lower part is a calcareous quartz arenite. Pyrite is rather abundant. The subrounded to rounded coarse (up to 0.7 mm) quartz grains are mixed with angular to subangular (50-100 μm) ones in a micritic matrix (Plate 1g). Pyrite crystals and a phosphorite grain with embedded, angular quartz grains of silt size are present.

32.80-33.95 m: Rispebjerg Sandstone. The upper part is a pyritic and calcareous quartz arenite with phosphorite nodules (up to 7 cm across) and glauconite grains. Large well-rounded quartz grains (up to 1 mm across) occur in both the nodules and the matrix (Fig. 4b). The lower part of the unit is a quartz-arenite with planar and cross lamination, and pyrite in abundance. The subangular to subrounded quartz grains (0.1-0.4 mm) are generally cemented by quartz overgrowths, rarely by sparite (Plate 1h). It is mature and well sorted (Fig. 5j) with sparse feldspars and glauconite grains.

The XRD analysis showed that the dominating clay mineral is illite. It is the only clay mineral that has been identified in the samples, except for one sample (JML 3) where chlorite also was detected. The TOC in the shales increases slightly upwards in the succession.

Discussion

Facies interpretation

The lowermost part of the Almbacken core, the mature and well-sorted Rispebjerg Sandstone, suggests a deposition in a shallow marine environment probably in a nearshore area. The upwards increasing grain size in this interval indicates an increasing energy level. The large quartz grains occurring in the uppermost part of the Rispebjerg sandstone and the lower part of the superimposed arenaceous calcilutite in the Almbacken core, are also occurring in the corresponding unit of Bornholm (only the Rispebjerg Sandstone, de Marino 1979). They are interpreted by de Marino (1979) as inherited from an older sedimentary bed due to the good roundness and occurring together with finer material. The phosphorite nodules and glauconite grains suggest a low sedimentation rate. de Marino (1979) suggests that micrite has been replaced by phosphorous from sea water forming phosphorite in the Rispebjerg Sandstone of Bornholm. The quartz grains are not occurring in contact to each other and the grain content decreases gradually, therefore the mix of large quartz grains and lime mud must be due to bioturbation. The following wackestone indicates a calm environment, and like the arenaceous calcilute, bioturbation. The silty limestone with phosphorite nodules indicate a higher energy level and a break in the sedimentation. The intensively bioturbated clayey and sparitic sandstone, showing an upward increasing pyritization and clay content together with a decreasing calcium carbonate content, may indicate a gradual change to more reducing conditions. This lithology is in the close to Almbacken located Hardeberga section II only 35 cm (Troedsson 1917) thick compared to over 1 m in Almbacken. The alterations between bioturbated sandstone and laminated sandy mudstone in the upper part is due to a change in the water environment (anoxia?) for organisms causing the bioturbation. The redox boundary seem to have been situated below the sediment-water interface in the clayey sandstone and fluctuating above and below the interface in the sandy mudstone (which has a variable content of calcium carbonate and organic content). The alterations between the two lithologies and the local differencies in bed thicknesses of the clayey sandstone also suggest that the change in the environment is lateral and not a basinwide change with time. The occurrence of glauconite in both lithologies suggest a slow depositon in a shallow marine environment. The calcareous siltstone with phosphorite nodules suggests a slow sedimentation rate aswell, perhaps slower than the underlying lithology. It is followed by a short interval of laminated mudstone. The highly fossiliferous ”Fragment” limestone is formed in a rather high energy environment according to the high degree of broken fossil fragments. The phosphorite nodules in the lowermost part together with the following hardgrounds indicate a low sedimentation rate in a shallow marine environment. Hence, the fossil fragments have been accumulated and reworked over an extended time. The high degree of pyritization could have been taken place below the sediment-water interface during the following anoxic alum shale deposition (reducing conditions in pore water in the bed during alum shale deposition).

The undisturbed lamination and the lack of current induced sedimentary structures in the very fine-grained alum shale in the Almbacken core, suggest deposition below wave-base in quiet water. The units below (the interval Rispebjerg Sandstone to ”Fragment” limestone) and the *Exsulans*- and Andrarum limestones within the alum shale in the Almbacken core are demonstrably of relatively shallow marine origin. Thus, the alum shale is by inference suggested to have been deposited in a fairly shallow marine environment as well. High TOC and amounts pyrite, and the lack of trace fossils suggest anoxic conditions at or right above the sediment-water interface. The water depth during alum shale deposition in Scandinavia is suggested to have been less than 200 m and the sedimentation took place on an epicontinental shelf in an environment with no modern analogues (Thickpenny 1984, 1987). The sedimentation rate of the Middle Cambrian in the Södra Sandby area was very low. Using the same methods as Thickpenny (1984) and including stinkstones and limestones, a depositional rate of approx. 31 mm / 10^3 yr for Almbacken is suggested here (the Middle Cambrian duration from Thickpenny 1984). The slight variation of the organic matter, causing the formation of the laminae, must be due to long-term climatic changes and not by annual variations considering the extended time-span (Thickpenny 1984). The formation of pyrite in the Middle Cambrian alum shales of Scandinavia was TOC-limited due to a very low primary organic production, which perhaps was as a response to a low global hydrospheric oxygen content (Thickpenny 1987). The low sedimentation rate and the poor water circulation allowed long periods of contact between detrital iron minerals and organic sulphur forming the pyrite (Thickpenny 1987). The formation of stinkstone nodules is somewhat less well understood. In the Almbacken core no depositional textures, except for one pyrite laminae, are visible in the stinkstones. Thickpenny (1984) suggests that nucleation on fossiliferous layers on intrabasinal highs was responsible for their origin. Bjørlykke (1973) explains them as remains of continuous limestone beds, that became partly dissolved. Cementation is, by Henningsmoen (1974) and Buchardt & Nielsen (1985), suggested to have been taken place by precipitation of calcium carbonate in pore space of favourable host beds at an early diagenetic stage close below the sediment-water interface. If the water depth was less than the storm wave-base, storm events could be due to the origin bringing oxygenated water to the host sediments (i.e. making host beds favorable for precipation of calcium carbonate in pore space).

The *Exsulans* limestone is, like the Andrarum limestone, relatively uniform in Scania, consisting of a dark grey to black anthraconitic bed and the underlying two different grey lithologhies arranged in irregulary portions (Westergård 1944; Hadding 1958). Correlating the bed in the Almbacken core with the diggings of Steneström (unpublished 1940), the lower two lithologies seem to occur as alternating flat lenses over an extent of a few metres. The silty quartz grains, the occurrence of unbroken fossil fragments and the phoshorite nodules indicate deposition in fairly turbulent water and a shallower environment than the alum shale above and below the *Exsulans* limestone in the Almbacken core. Hadding (1958) considers the *Exsulans* limestone as a thick, extended anthraconite (stinkstone) bed with a matrix consisting of recrystallized calcite grains with bitumen coatings. According to the texture, the uppermost part of the *Exsulans* limestone is similar to anthraconite. The hypothesis of stinkstone as originated at an early diagenetic stage (Henningsmoen 1974; Buchardt & Nielsen 1985) is supported by the different degrees of recrystallization in the limestones discussed above. If the neomorphism in the limestone beds and nodules would be of a late diagenetic origin, they should show the same degree of recrystallization.

The formation of the Andrarum limestone in the Almbacken core could be due to a temporary rising of the redox boundary allowing precipation of calcium carbonate and habitation of benthic organisms. The deposition took place in a very calm environment due to the abundance of well preserved fossil fragments. The very low content of calcium carbonate in the Andrarum limestone of the Almbacken core, due to sampling in two blackish parts of the limestone, indicates temporary rising of the redox boundary within the lithologhy. The lithological development is relatively uniform in Scania (Hadding 1958), and the Andrarum limestone contains a fossil fauna representing a peak in diversity in the Cambrian of Scandinavia (Martinsson 1974).

In Scania, the combined influence of burial to substantially greater depths than all other alum shale areas east of the Caledonian front in Scandinavia during their post-depositional history, and the intrusion of a dyke swarm, has resulted in a general coalifaction (Andersson et al 1985). Thus, the alum shales of Scania has a much lower content of organic matter than the alum shales of other areas (Andersson et al. 1984) and they are classified as thermally postmature (Buchardt et al. 1994; Nielsen & Buchardt 1994). An additional reason to the low TOC in Scania is the higher supply of terrigenous material (Regnéll 1960). The TOC of the Middle Cambrian alum shale in the Almbacken core never exceeds 3% and the calorific value in the Södra Sandby core (boring interrupted in the *Ptychagnostus punctuosus* Zone; Westergård 1944) is lower than in the other cores made in Scania 1941-42. In the Tosterup (Andersson et al. 1985) and Gislövshammar-2 (Nielsen & Buchardt 1994) cores the organic carbon content is, especially in the uppermost Middle Cambrian, much higher than in Almbacken. These data, the lack of dikes in the Gislövshammar area (Nielsen & Buchardt 1994) and the occurrence of a dike very close to the Almbacken drill-site (Steneström 1940) may confirm the high igneous activity in the Södra Sandby-Fågelsång area as responsible for the comparably low TOC in the Almbacken core. However, in Buchardt et al. (1986) samples taken within the same horizons may show a significant variation of organic content and only major trends in values of organic content have a significance in understanding depositional and diagenetic conditions.

The calcium carbonate content in the alum shales of Scania are in general much higher (up to 11%) than in other areas (as a rule below 0.5 %, rarely exceeding 1-2%; Hessland & Armands 1978) and the Almbacken core shows no exception (2-7%). A high calcium carbonate content favoured the preservation of fossils in the alum shales of Scania (Bergström & Gee 1985). In other areas, where the calcium carbonate is largely restricted to the stinkstone beds and lenses, fossils generally occur only in these lithologies, especially in the highly kerogenous parts of the alum shale (Bergström & Gee 1985). The dominating clay mineral in the Middle Cambrian alum shales is illite, with minor amounts of chlorite (Andersson et al. 1985), as confirmed in the Almbacken core.

Stratigraphy and provenance

The Middle Cambrian succession is, at least from a petrographical point of view, very uniform in Scania. The Södra Sandby core of Westergård (1944) and the Almbacken drill core give a total thickness of the Middle Cambrian in the Södra Sandby area of c. 34.6 m, which is the known maximum in Scania. It thins out to the southeast; the Middle Cambrian is 19.9 m in the Andrarum 1 core (the thickness is uncertain, because the core is tectonically disturbed; Westergård 1944), c. 17 m in the Tosterup core (Andersson *et al.* 1985), 18.6 m in the Gislövshammar core (Westergård 1944), c.18.8 m in Gislövshammar 2 core (Nielsen & Buchardt 1994) and only c. 3 m on the island of Bornholm (Berg-Madsen 1985). The three limestone beds in the Middle Cambrian of Almbacken core (the Andrarum, *Exsulans* and "Fragment" limestones) occur in all known sections in Scania, except in the "Andrarum 1" core (Westergård 1944), where the "Fragment" limestone is missing. However, the core interval is tectonically disturbed, and the "Fragment" limestone occurs in the nearby situated Forsemölla section.

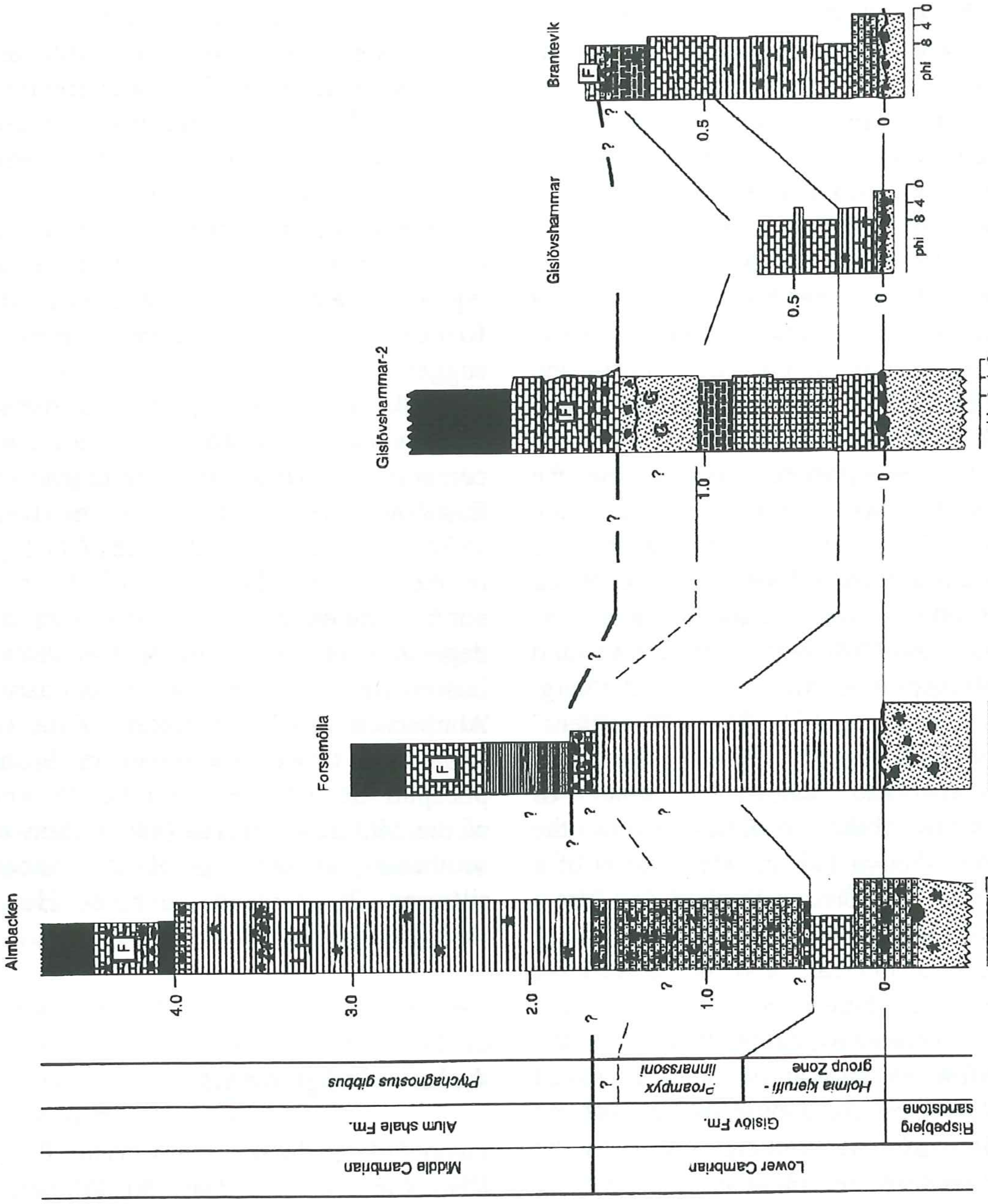


Fig. 5. Correlation of the uppermost Lower to lowermost Middle Cambrian in Scania. The Forsemölla, Gislövshammar and Brantevik sections are drawn from Bergström & Ahlberg (1981), and the Gislövshammar-2 log from Nielsen & Buchardt (1994). The size of fossil fragments are excluded in the grain size scale. Locations are shown in Fig. 1. Note the wider scale shown in the Brantevik section. For legend see Fig. 3.

The lowermost Middle Cambrian and uppermost Lower Cambrian show more local differences in Scania compared to the superimposed strata, because deposition took place in shallower marine environments. A correlation of the sections of Almbacken, Forsemölla, Gislövshammar and Brantevik is shown in Fig. 5. The lowermost part of the Almbacken core (the interval Rispbjerg Sandstone-the sandy mudstone) are, with slight varations of bed thicknesses, analogue with the closely located Hardeberga section II of Troedsson (1917), later examined by Hadding (1927, 1958) and Bergström & Ahlberg (1980). The biozonation is not complete due to the lack of fossils in some lithologies, mainly in the phosphoritic and glauconitic silt- and sandstones. The Rispebjerg Sandstone, with an erosional surface and phosphorite nodules, and the overlying *Holmia kjerulfi*-group Zone are distinguished in all sections while the *Proampyx linnarssoni* Zone is only occurring in the Brantevik (type section of the Gislöv Formation) and Gislövshammar sections and cores. (Bergström & Ahlberg 1981; Ahlberg, personal information). The "Fragment" limestone rests directly on the glauconitic, phosphorous and calcareous sand- or siltstones in these localities while the Forsemölla section has an intercalation of a grey shale. The biozonation of the strata around the Lower-Middle Cambrian boundary in Scania is unclear, and no correlative sediments to the Hawke Bay regression have so far been reported in Scania. Preliminary, the Lower-Middle Cambrian boundary is placed at the top of the glauconitic and phosphatic units (Bergström & Ahlberg 1981). In the Almbacken core the boundary is even more unclear, due to the lack of fossils in the rocks between the *Holmia kjerulfi*- group Zone and the "Fragment" limestone (except for a few unidentified lingulate brachiopods in the sandy mudstone, Per Ahlberg personal information).

During late Early Cambrian to early Middle Cambrian times the Bornholm area was probably uplifted (Vejbæk et al. 1994) and this is a probable explanation to the southeasterly decreasing thickness of the strata in Scania. de Marino (1980) concluded that the Gislöv Fm at Brantevik and Gislövshammar shows a transgressive-regressive shift in a shallow marine to tidal flat environment with presence of celestobaryte in the lower part of the glauconite-arenite at the former locality indicating evaporitic tendencies. This shift is distinguished in Almbacken aswell but no celestobaryte or other evaporitic minerals have been observed. On Bornholm the *Exsulans* limestone, and the equivalent Kalby clay, rest directly on the Rispebjerg Sandstone (Berg-Madsen 1981) suggesting a long erosional phase. Additionally, the fairly large glauconite grains in the "Fragment" limestone at Brantevik and the contents of quartz and glauconite grains in the Exsulans limestone of Bornholm (Hadding 1958) compared to the absence of such grains in the corresponding beds of Almbacken, confirm the difference in water depth during deposition and in the thickness of strata. The Lower-Middle Cambrian boundary of Almbacken should be placed, if the top of uppermost Lower Cambrian in Scania is phosphoritic and referring to bed thicknesses of the Middle Cambrian (which thins to the southeast), at the top of the calcareous siltstone (28.71 m in the core). However, further examinations are needed.

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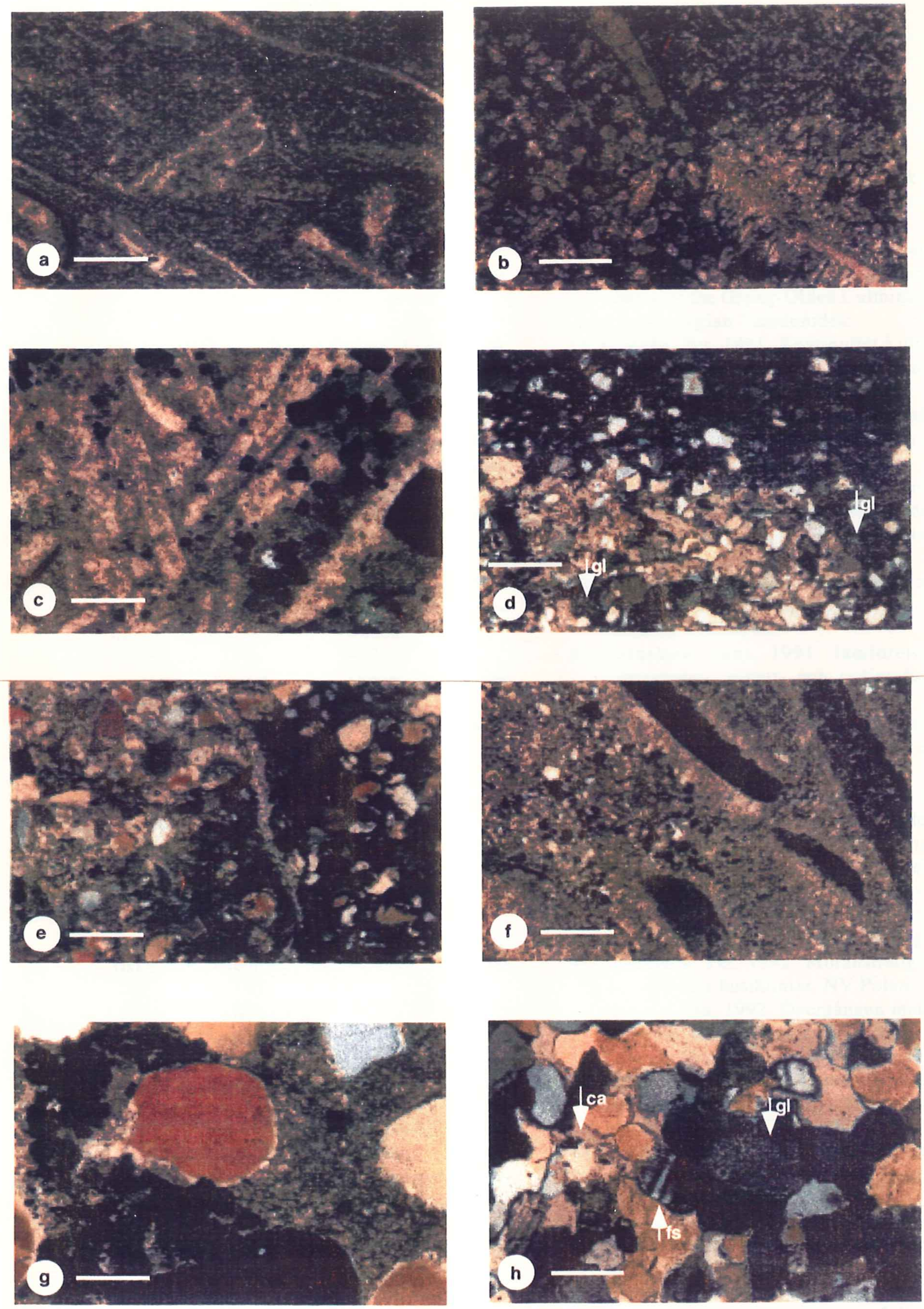
Plate 1.

Micrographs. Scale bars are 200 µm. a) Andrarum Limestone (JM 20), the edge of the darker lithologhy, consisting of accumulated fossil fragments in a micritic matrix. b) *Exsulans* Limestone (JM 120), dark grey to black lithology, consisting of recrystallized calcite grains (pseudospar) with thin bitumen coatings. Note the columnar cements on the fossil fragments. c) Pyritic "Fragment" limestone (JM 140). Note the micritized and pyritized fossil fragments. d) Glauconitic sandy mudstone (JM 150), with a calcareous (sparry) intercalation in the lower left. Note the glauconite grains (gl). e) Calcareous sandstone (JM160), consisting of quartz grains partly in a clay matrix and partly cemented by sparry calcite. Note the stylolite. f) Wackestone (JM 170), with pyritized fossil fragments. g) Arenaceous limestone (JM 180), consisting of coarse and well-rounded quartz grains in a micritic matrix. h) Rispebjerg Sandstone (JM 190) showing quartz grains cemented by quartz overgrowth. Note the glauconite (gl) and feldspar (fs) grains. Calcite cement (ca) also occurs.



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