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Environmental and correlative significance of a non-marine algal limestone (Westphalian D), Sydney Coalfield, Cape Breton Island, Nova Scotia

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The occurrence of an algal limestone containing stromatolites within the Morien Group (Sydney Coalfield) is reported for the first time. Three distinct morphologic forms of stromatolite (pinnacle, mat and detached) and their stratigraphic variation are described. Variation in clast type and size, biota and elements within the algal limestone is interpreted as evidence for the growth of stromatolites on the shore of an ephemeral, fresh to brackish lake, subject to fluctuating water levels. Pinnacle and mat forms developed on substrate irregularities. A bivalve and ostracode fauna in mudstones and siltstones above and below the algal limestone indicates a correlation with the *Anthraconauta tenuis* chronozone of Britain (Westphalian D) and corroborates on age derived from associated macro- and microflora.

Pour la première fois, on rapporte la présence de stromatolithes dans un calcaire à algues du groupe Morien (houillière de Sydney). Trois types morphologiques de stromatolithes (pinacle, paillasson, détaché) et leur variation stratigraphique sont décrits. On interprète la variation dans la faune, la flore, les éléments, le type et la grosseur des fragments au sein du calcaire à algues comme preuve de la croissance des stromatolithes sur les rives d'un lac éphémère, d'eau douce à saumâtre et sujet à des variations périodiques du niveau d'eau. Les formes en pinacle et en paillasson s'établirent sur les irrégularités du substrat. Une faune de bivalves et d'ostracodes dans les roches argileuses superposées et sous-jacentes au calcaire à algues est corrélative avec la zone chronologique *Anthraconauta tenuis* de Grande-Bretagne (Westphalien D) et confirme l'âge déduit de la macro et la micro flore.

[Traduit par le journal]

INTRODUCTION

Within the non-marine sediments (Bell 1940; Belt 1968) of the Morien Group (Pictou Group) of the Sydney Coalfield (Fig. 1) many limestones occur. These limestones range in thickness from 5 to 45 cm and appear to be restricted to the more central parts of the coalfield. Of all the occurrences, only one limestone was found to contain algal stromatolites. These, together with their associated sediments are described and their environmental significance considered. The presence of a well-preserved bivalve fauna above and below the algal limestone unit provides an opportunity for correlation with the well established bivalve zonation of the British Coal Measures. The investigation also suggests lines for further algal limestone research.

The documented limestone material has been deposited jointly with the paleobotanical collection of the University College of Cape Breton, Sydney, Nova Scotia, and the Institute of Geological Sciences (I.G.S.), Leeds, United Kingdom.

GEOLOGICAL SETTING

The Sydney Coalfield is considered to be of late Westphalian C to early or middle Stephanian age (Fig. 2, inset) on macrofloral grounds (Bell 1938; Zodrow 1982; Gastaldo and Zodrow 1982; Zodrow and Gastaldo 1982), or even Permian on microfloral grounds (Barss and Hacquebard 1967). In general terms the sediments of the Sydney basin reflect cyclic sedimentation under fluviolacustrine conditions within a flood-plain environment (Hayes and Bell 1923; Haites 1951; Belt 1968, Hacquebard and Donaldson 1969). The cyclic sedimentation may be related to contemporary tectonism (Miall 1978 p. 1628).

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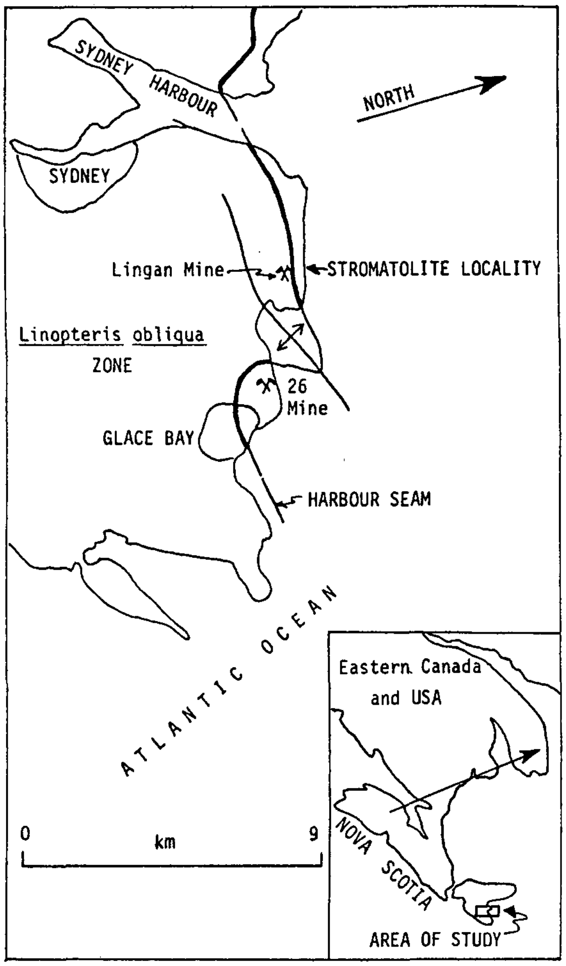


Fig. 1 - Sketch map of Sydney Coalfield and its location (inset).

The limestone is exposed on the shore in the Lingan area over an area of 83 by 12 metres (Fig. 1). A 2 cm thick ostracode-rich limestone succeeds the limestone and is followed by a sequence of pale, dark grey mudstones/siltstones and fine sandstones. The sequence is parallel-bedded, dipping at approximately 15 degrees north (into the Atlantic Ocean).

SAMPLING AND ANALYTICAL TECHNIQUES

The algal limestone under investigation is about 20 cm thick and from it an 8 by 8 cm channel sample was cut. The overlying ostracode-rich limestone (Fig. 2) and the seat earth of the stromatolites were also sampled (see results). The channel sample was cut in 2 and 4 cm intervals and, together with the other sampled material, was analyzed for major and minor oxide and boron content using an inductively-coupled argon plasma method and emission spectroscopy, respectively. Insoluble residues from the channel sample were determined in an attempt to associate lithophile elements (Si, Al, Fe), as given by the whole-rock analysis, with minerals (quartz, clay fraction, calcite). Portions of the same samples used for whole-rock analysis, in addition to 45 samples (which included pinnacle-type stromatolites), were micro- and macroscopically examined.

RESULTS

The algal limestone (ALS) is poorly

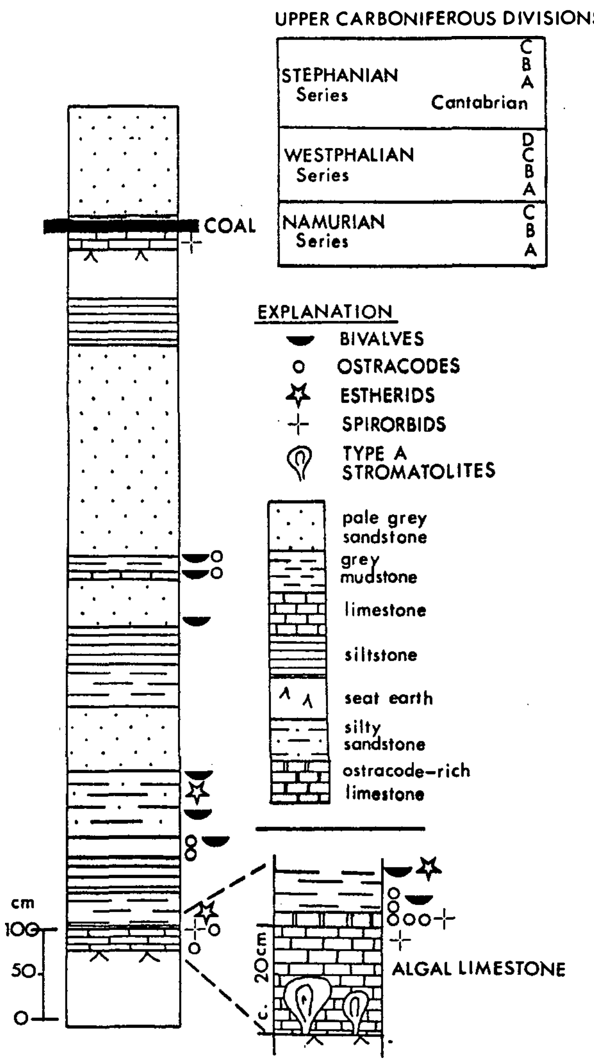


Fig. 2 - Generalized succession of strata at Lingan and Upper Carboniferous series.

bedded and rests conformably on a structureless calcareous siltstone containing autochthonous *Stigmaria* spp. with attached rhizophores. The ALS has a microspar-micritic texture and, because of the presence of stromatolites, fauna and locally derived clasts at the base, cannot be termed a calcrete.

A: Stromatolite Morphologies

1 - Type A, colony comprising pinnacle forms (SH-V structure of Logan *et al.* 1964; see also Logan *et al.* 1974).

Figures 3, 4, 5 and 6

Differential weathering of the ALS shows that the colonies occur as distinct clusters. Reliable measurement shows that one cluster is distributed over an area of approximately 80 by 60 cm (Fig. 3); individual colonies may measure 45 cm in diameter and 16 cm in height. The colonies, oval or domal in shape, are attached to the top of the underlying calcareous siltstone and do not protrude the enclosing ALS. The substrate is over 1 metre thick. Individual stromatolite 'heads' are frequently brecciated and the resultant voids are filled with micrite or, more rarely by sparite. Externally, the 'heads' are nodular and pitted, and coloured brownish-red from ferric oxides. Internally, they comprise pinnacle - shaped stromatolites (Figs. 4 and 5) that grew upward and outward from the area of attachment. Cryptalgal lamination (Monty 1976, p. 195) can be observed with the naked eye and in thin section. The laminations consist of two alternating sets of laminae; a) and b);

a) Orange-brown, radial-fibrous calcite containing abundant fluid inclusions

TABLE 1 - WHOLE-ROCK ANALYSIS OF ALGAL LIMESTONE, ITS SEAT AND OVERLYING ROCKS, AND OF AN 8 cm TYPE A STROMATOLITE COLONY, LINGAN, Nova Scotia

Fig. 2	$CaCO_3$#	C*	OXIDE PERCENT Si	Al	Fe^{3+}	Ca	Mg	Na	K	Ti	Mn	P	LOI**	TOTAL	Boron ppm
Ostracode-rich unit:															
	75.8	2.6	10.65	4.14	3.28	42.44	2.02	0.23	0.46	0.15	0.66	0.64	35.28	99.95	10
2 mm:															
	37.8	--	33.74	13.84	4.63	21.20	1.80	0.36	3.24	0.50	0.25	1.39	18.40	99.35	--
Algal limestone (devoid of Type A):															
top 2 cm	48.8	2.7	20.03	9.48	6.16	27.33	5.50	0.28	1.96	0.33	0.74	0.81	27.88	100.50	20
4 cm	55.5	1.8	19.07	8.08	4.20	31.11	3.35	0.19	1.56	0.34	0.61	0.70	29.70	98.91	20
4 cm	63.7	2.2	16.09	6.55	3.40	35.67	2.69	0.28	1.35	0.26	0.55	0.72	32.01	99.57	10
4 cm	56.8	1.9	13.37	6.40	5.20	31.79	5.60	0.28	1.44	0.24	0.78	0.51	33.49	99.10	10
bottom 4 cm	51.3	1.7	14.88	6.91	5.91	28.75	6.91	0.19	1.19	0.24	0.81	0.32	33.06	99.17	10
Seat earth:															
	11.6	1.1	69.20	11.20	2.47	6.53	0.92	0.05	2.20	0.90	0.15	0.01	7.03	100.66	50
8 cm diameter Type A stromatolite:															
outer 2 mm	90.3	1.3	2.48	0.30	1.59	50.60	2.37	0.06	0.15	0.04	0.31	0.16	42.01	100.07	10
inner 7.8 cm	87.9	0.9	2.61	0.42	2.37	49.23	3.20	0.21	0.12	0.04	0.41	0.09	41.26	99.96	10

#Based on all CaO present, but maximum excess of 7% CO_2 from carbonates indicates the presence of other carbonate minerals. *Organic carbon. **Loss on ignition at 900°C. -- not determined.

Precision: ±1-2 per cent for oxides; ±(5-10) per cent for boron. Standards used: USMBS(88A) dolomite, SAMIV, SAMI, SY2(seyenite), and MRGI.

Fig. 3 - Colonies of Type A stromatolites. Scale bar is 19 cm.

as well as occasional quartz silt, ostracodes and spirorbids. The laminae rarely exceed a thickness of 8 mm, and

b) Darker micritic layers containing relatively more quartz silt, ostracodes and spirorbids (than layer a). Algal filaments (Fig. 6) have been observed in this layer but are of unknown affinities. The layers vary in thickness from 1 to 5 mm and are often discontinuous. Bituminous films (50μm thick) frequently separate the two sets of laminae.

A chemical analysis of an 8 cm diameter Type A stromatolite (Table 1) shows comparatively low lithophile elements (quartz and probably clays) and concomitantly high carbonate contents.

2 - Type B, mat (LLH-C structure of Logan *et al.* 1964; Logan *et al.* 1974).

Figures 7 and 8

Mat forms, up to 3 cm in length and 2 mm high occur within the lower part of the ALS (Fig. 8). The mats form a thin crust over the top and sides of substrate irregularities and extend away from their area of attachment (Figs. 9 and 10). Their microstructure is similar to that of Type A.

3 - Type C, detached forms

Figures 10 and 11

Small oncolites (Figs. 10 and 11) occur within the main mass of the ALS and are rarely more than 10 mm in diameter. Stromatolite growths totally encase lithoclasts, ostracodes and spirorbids. Quartz silt appears to be totally absent from the encasing growths. Laminations are similar to both Types A and B.

B: ALS and Ostracode-rich limestone Lithologies

Chemical analyses of 10 samples from the algal limestone, its seatearth, overlying rocks and an 8 cm Type A stromatolite colony are presented in Table

1. Figure 7 shows the stratigraphic variation of the chemistry and faunal constituents. The ALS contains large and small clasts of seatearth, ostracodes, micrite peloids, micrite and birdseye micrite. Other clasts comprise spirorbids, plant debris, fish remains and angular stromatolite fragments. Large lithoclasts (2-4 cm in diameter) are restricted to the basal 8 cm of the ALS. Stratigraphic variation in the abundance of clast types in both the ALS and the ostracode-rich limestone is illustrated in Figure 7. Results of chemical analyses (Table 1) can be interpreted in conjunction with petro-

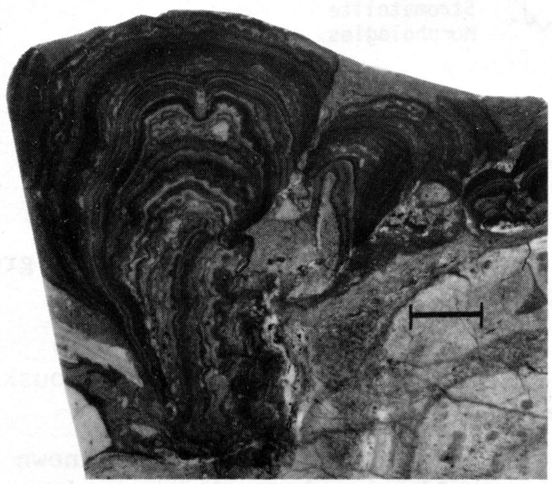


Fig. 4
Type A morphology attached to an oncolite, note brecciation and subsequent infilling. Polished surface. Scale bar 10 mm.

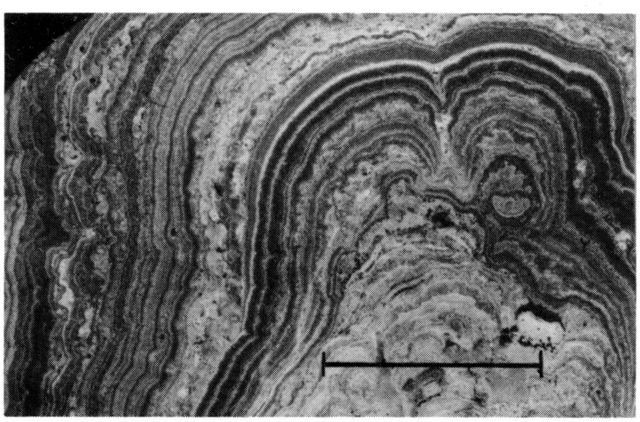


Fig. 5
Detail of alternating lamination of Type A morphology. Photonegative of a thin section. Scale bar 10 mm.

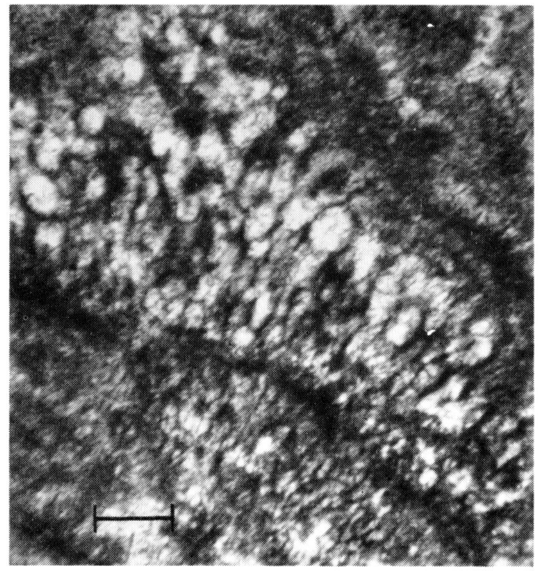


Fig. 6
Algal filaments (of unknown affinities). Scale bar is 0.1 mm. (Photomicrographs).

logical observations. For example, the high spirorbid content correlates with high phosphorous in the upper portions of the ALS and in the basal part of the ostracode-rich limestone ('2 mm' in Table 1), as the shells of spirorbids are phosphatic. Within the ALS, the upward increase in SiO_2 correlates with an upward increase in quartz silt.

The top 2 mm of the ostracode-rich (c. 60% ostracodes) limestone is a calcareous siltstone and has comparatively the smallest lithophile content. Both lithologies are characterized by the presence of plant debris (see C contents, Table 1), abundant coprolites (probably piscine), and spirorbids in a micritic matrix. The ostracode-rich unit is desiccated producing polygons up to 60 cm across. The desiccation marks extend downwards into the top of the ALS and also occur in the first few centimetres of mudstone above.

DISCUSSION

This detailed study of the algal limestone reveals some interesting variation in clast type and size, biota and chemical composition as a function of stratigraphy. These variations and, in particular, the presence of stromatolites provide clues as to the environ-

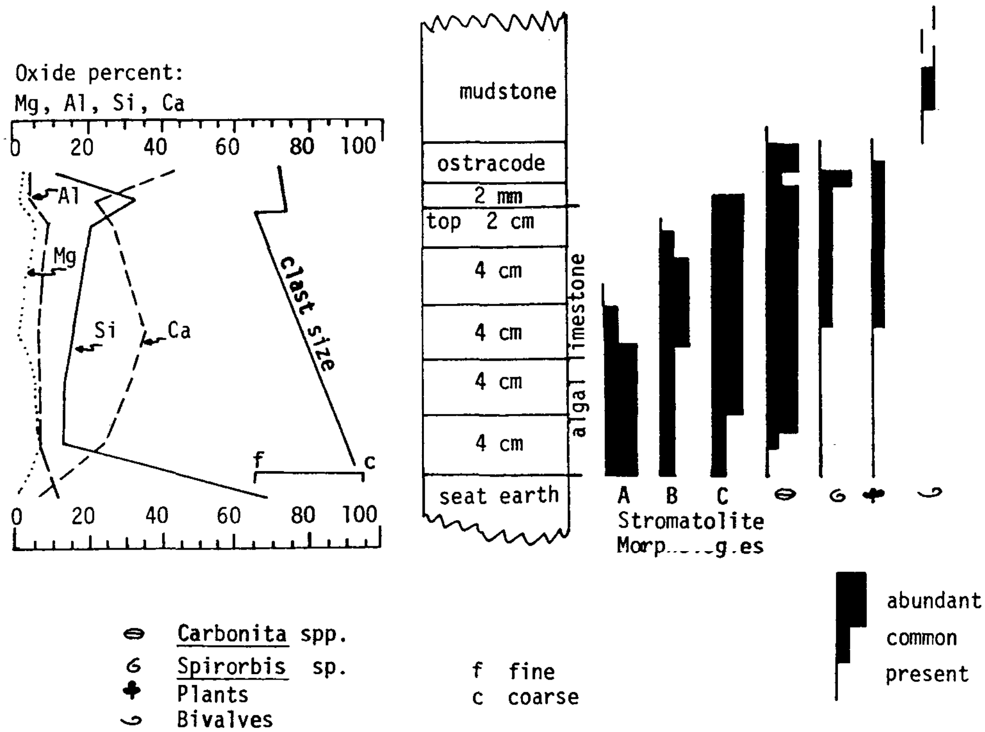


Fig. 7 - Variation of oxides (wt. percent) Mg, Ca, Si and Al, stromatolite growth forms and various clast types in relation to stratigraphy.

ment of deposition through comparison with modern stromatolites and their environments (Gunatilaka 1975; Horodski and Von Der Haar 1975; Monty and Hardie 1976). Recent studies show that small changes in environment produce large changes in stromatolite morphology. As alga is a primary source of food for many organisms, the environment in which the stromatolites accumulated must have been unusual, restricting fauna to a small number of ostracodes, spirorbids and fish.

It is suggested that the ALS was deposited in a fresh to slightly brackish lake. This interpretation is supported by:

a) The presence of *Carbonita* spp.; *Spirorbis* sp., and a small amount of plant debris (Calver 1968, p. 156-7; Pollard 1969; Bless and Pollard 1973, p. 21),

b) the absence of a hypersaline-tolerant fauna and of evaporite minerals or their pseudomorphs (Hudson 1970), and

c) the low boron contents (Bouska *et al.* 1977).

However, stromatolites are known from hypersaline and marine environments (Horodski and Von Der Haar 1975; and from the Carboniferous of Nova Scotia, Schenk 1969).

It is suggested that Type A forms were initiated on an irregular calcareous siltstone substrate, possibly near the fluctuating lake shore resulting in alternate periods of wetting and drying. Periodic emergence, desiccation and brecciation of the stromatolite heads may explain the presence of large locally derived angular limestone clasts.

Formation of the algal limestone may have occurred through the destruction of the algal stromatolites, a process described for the freshwater calcareous marshes of Florida by Monty and Hardie (1976, p. 453). Type B growth forms developed on substrate irregularities. Increasing water turbulence may have been a contributing factor to the decrease in Type B forms with a concomitant increase in Type C forms. The decrease in large, locally-derived clasts, Ca content and a corresponding increase in quartz silt, plant debris with attached spirorbids and ostracodes towards the top of the limestone may indicate greater water depth and current activity. Proximity to shore or a decrease in turbulence may provide an alternative explanation. The upward decline of the stromatolites through the ALS may be related to the increasing quartz sand content indicating increasing clastic input and current activity in the lake. The final phase of siltation of the lake is represented by the ostracode-rich limestone. The overlying mudstones and siltstones containing a restricted fauna, reflect the reintroduction of clastic-dominated, floodplain conditions.

The faunal assemblage above and below the ALS comprises; *Anthraconauta phillipsii (*Williamson*); A. tenuis* (Davies and Trueman*) senso lato;* rare *Anthraconaia* aff. *arenacea* (Dawson); *Carbonita* spp. dominated by *C. evelinae* (Jones and Kirkby*); Spirorbis* sp.; *Lioestheria* sp.; and *Leaia* spp. This assemblage provides a tentative correlation with the Upper Coal Measures of Britain (Rogers 1965; Calver 1968, p. 149).

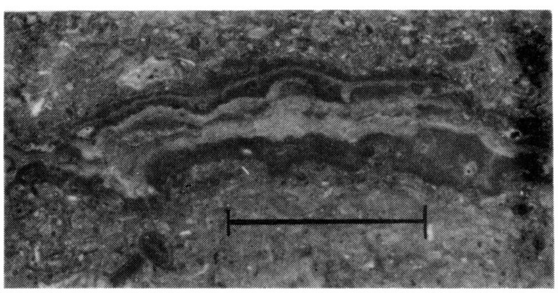


Fig. 8
Type B morphology attached to a calcareous substrate. Polished surface. Scale bar 10 mm.

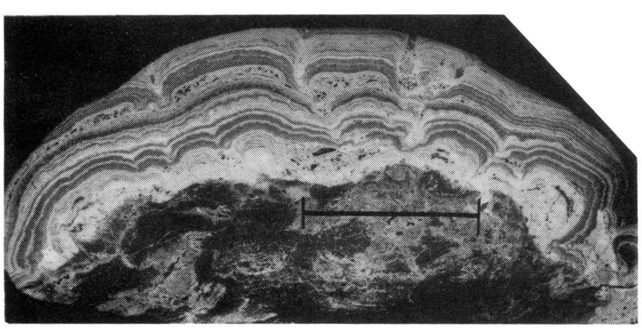


Fig. 9
Detail of alternating lamination of Type B morphology. Photonegative of a thin section. Scale bar 10 mm.

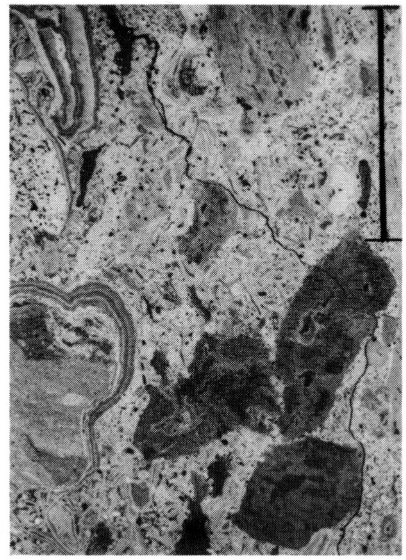
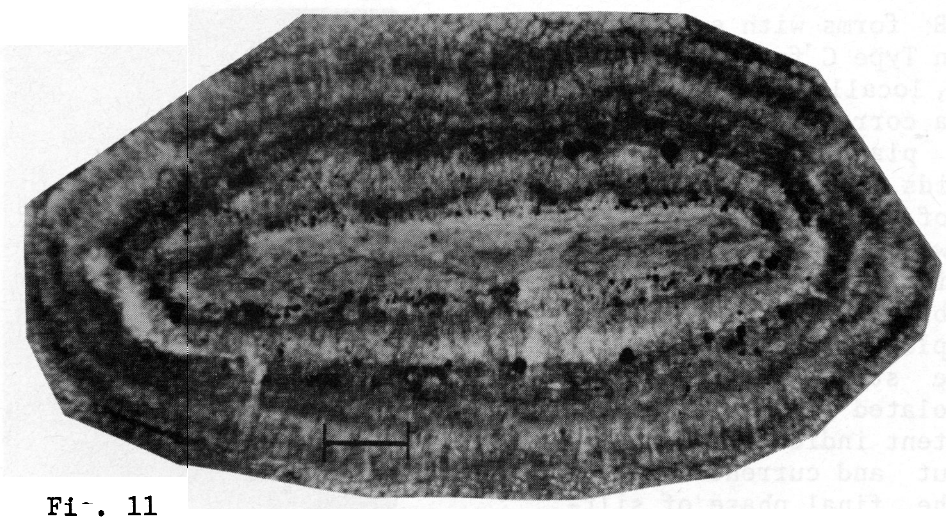


Fig. 10
Photonegative of algal limestone containing large irregular siltstone and micrite clasts occasionally encrusted with Type B morphologies. Matrix contains abundant Type C morphologies in grain to grain contact. Scale bar 10 mm.

Specifically, the occurrence of a form comparable to *A. tenuis* suggests a correlation with the *tenuis* chronozone of Britain (Westphalian D). This hypothesis is supported by the rare occurrence of *Anthraconaia* aff. *arenacea* which is similar to the elongate *A. prolifera* (Waterlot - a form typical of the Upper parts of the European Coal Measures), and *Leaia* spp., which is considered by Calver (1968) to characterize the British Westphalian D. It is of interest to note that Pollard and Wiseman (1970) recorded algal lenses from the North Staffordshire Coalfield, England, at a level approximately equivalent to that of the occurrence of the algal limestone in the Sydney Coalfield.



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Type C form encrusting an ostracode fragment. Scale bar 0.1 mm. Photomicrograph.

This investigation suggests that the occurrence of algal stromatolites in the Sydney Coalfield is indicative of ephemeral lacustrine conditions in a generally fluviatile environment. The presence (or absence) of stromatolites from the other limestone units found in the area does not preclude a marine origin for them but faunal information yields no evidence of marine, or even near marine conditions.

Future research will concentrate on the identification of algal filaments, stromatolite carbonate textures and fluid inclusions. Data on limestone geochemistry is also under investigation in an attempt to characterize facies using trace elements along the lines suggested by Veizer *et al.* (1978).

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