WESTPHALIAN MACROFAUNAS IN NOVA SCOTIA: PALAEOECOLOGY AND CORRELATION.

by

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ABSTRACT

Westphalian non-marine bivalves in Nova Scotia inhabited fresh to brackish temporary lakes. A series of lacustrine facies are identified on the basis of the faunas.

Myalinid genera including the probably pseudoplanktonic *Curvirimula*, and *Naiadites* dominate the middle Westphalian A to early Westphalian B. *Carbonicola* occurs rarely in the late Namurian to to early Westphalian A and is the only reported Anthracosiid. *Anthraconauta* dominates the upper Westphalian C to early Stephanian occurring in a wide range of sediments. The elongate *Anthraconaia arenacea* group range through the Westphalian D and occur in coarser lithologies. Small-shell *Anthraconaia* inhabited ephemeral lake margins.

Cluster and principal components analysis are used to classify the faunas. The method requires the measurement of a small number of linear and relatively uncorrelated morphological variables and allows the construction of reproducable pictographs. Three new morphospecies are described. Principal components analysis is used to study morphological variation with respect to palaeoenvironment.

Consistent morphological trends occur in *Naiadites* and *Anthraconauta* and are considered to have been the product of spat selection and phenotypic changes. With increased turbulence and sedimentation rates, the shell's centre of gravity is shifted towards the anter-umbonal region and the bivalves adopt a semi-infaunal mode of life thus, the morphological changes offer increased stability.

Evolution was inhibited by the absence of marine incursions and progressive environmental change. Such palaeoenvironmental changes that did occur were local. Competition may have been of evolutionary importance in younger communities of *Anthraconaia*.

The bivalves are of limited stratigraphical use as compared to the British faunas. In conjunction with micro- and macrofloral work, the Namurian/Westphalian A and Westphalian C/D boundaries are lowered and a possible Cantabrian stage recognised. A correlation with the British Chronozones is attempted.

DEDICATED TO MY PARENTS AND TO MAUREEN.

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CHAPTER 1

INTRODUCTION

1.1. Background and aims of the project.

The project was initially conceived by Prof. P. McL. D. Duff after periods of fieldwork in several of the Nova Scotian coalfields in the early 1970's (Duff & Walton 1973, Duff et. al. 1982). During the course of sedimentological studies in the Joggins and Sydney coalfields (Figure 1.1), Duff observed the presence of many previously unrecorded shell beds and was quick to recognise their potential stratigraphical and palaeoenvironmental importance. Although early pioneering work on Nova Scotian Westphalian non-marine bivalve faunas had taken place in the early 19th Century (Dawson 1855, 1868, 1878, 1894), they had been largely ignored during the intervening years save for some revision of Dawsons' material (Newell 1940, 1942, Rogers 1965).

The stratigraphical importance of Westphalian non-marine bivalve faunas particularly when used in conjunction with marine and other marker bands, is well known in Britain and NW Europe (Davies & Trueman 1927, Trueman 1946, 1947, Calver 1956 Trueman & Weir 1946-60, Weir 1960-68, George, 1974, Ramsbottom et. al. 1978). Although work on Appalachian and Spanish non-marine bivalve faunas had taken place (Eagar 1970, 1975, in press [1979], in prep. [1983], Eagar & Weir 1971), the faunas of Nova Scotia (the central area in any palaeogeographical reconstruction (see Figure 1.2)) had been neglected.

With these points in mind Duff, in association with Dr. M. A. Calver of the British Geological Survey, proposed the present project.

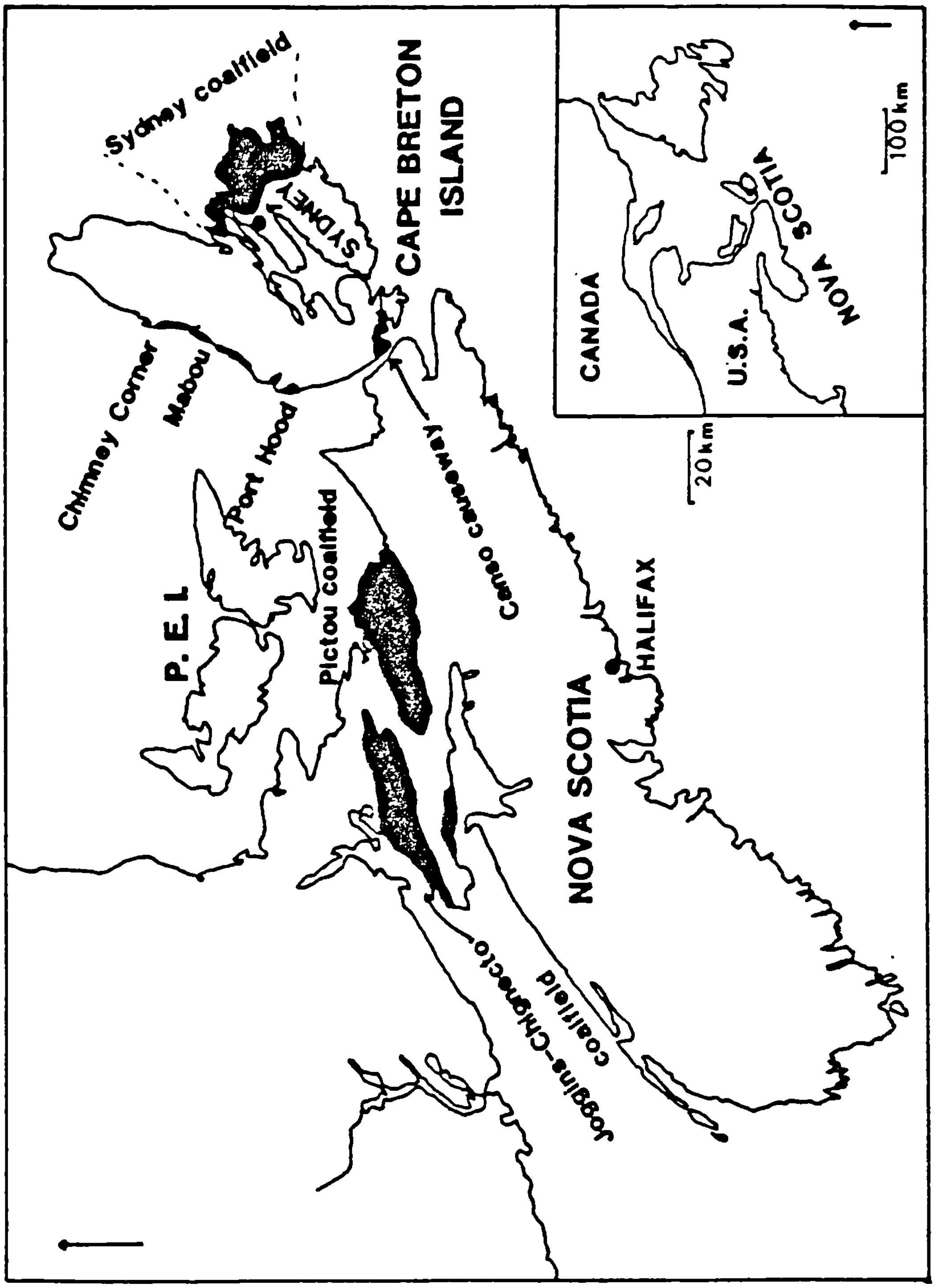


FIGURE 1.1: Nova Scotia, geography and major coalfields.

The initial aims of the project were;

1. To collect, record and study Westphalian non-marine faunas from most of the coalfields of Nova Scotia.

2. To deposit the collection in a suitable repository for further study.

3. To attempt inter- and intracontinental correlation particularly with Britain and the Appalachian area, based on the non-marine bivalve faunas of these areas.

4. To study the palaeoecology of the Nova Scotian faunas.

The initial aims assumed the presence of previously undetected marine bands in the Westphalian of Nova scotia, a premis that was probably more hopeful than realistic considering the continental nature of the Nova Scotian sediments (see Figure 1.2 and Chapter 2). Without marine marker horizons, correlation has proved impossible without reference to macro and microfloras.

In addition, it was quickly appreciated that the naming procedure of Trueman & Weir (1946), though of great stratigraphical value, was illegal. With the now almost universal access to computers and statistical software, a further aim was introduced. Namely, to seek a multivariate statistical technique for use as a classificationary method and in the search for a new and legal system of nomenclature.

1.2. The province of Nova Scotia.

Nova Scotia is situated on the eastern seaboardof Canada (Figure 1.1 inset) and forms part of the Maritime region. The

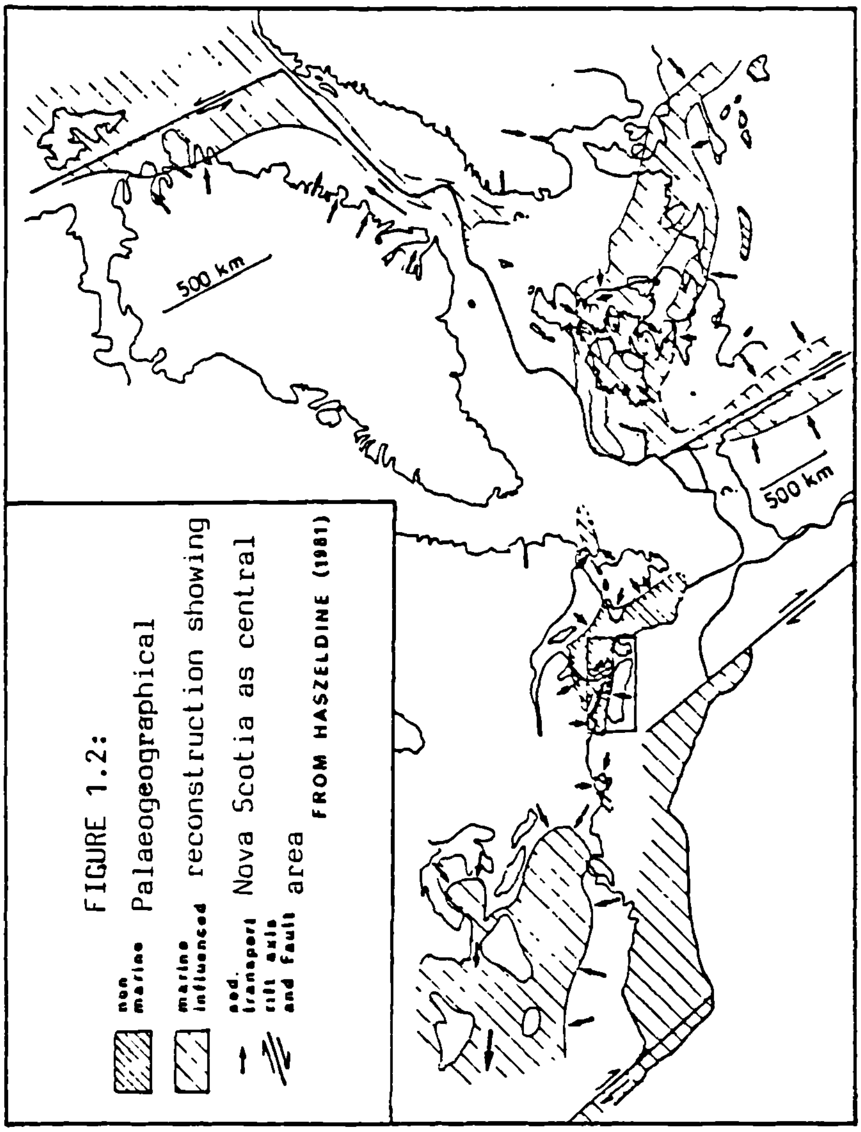


FIGURE 1.2: Palaeogeographical reconstruction showing Nova Scotia as central area

FROM HASZELDINE (1981)

province has an area of 34,280 km and is 580 km in length. Bounded on all sides by ocean, the province is linked to mainland Canada by a small isthmus (Figure 1.1).

Geographically, the province comprises two parts, mainland Nova Scotia and Cape Breton Island to the north east, the Canso causeway being the only link between the two areas. The provincial capital of Halifax lies on the south coast of mainland Nova Scotia whilst the second city of Sydney is situated in the north east of Cape Breton Island (Figure 1.1). Nova Scotia is readily accessible by air, road and sea.

The province was discovered in 1497 when John Cabot planted the English flag at a point near Sugar Loaf Mountain in northern Cape Breton but it was not until 1605 that the first permanent settlement was established. Subsequently, the area has been populated by many European exiles including 50,000 highland Scots displaced by the wholesale clearances of the highlands. Today around 70% of the population is of British descent, 10% French and the other 20% of various European, eastern and African origins.

1.3. Coal and coal-mining in Nova Scotia.

Coal has long been one of the most important mineral products of Nova Scotia and in 194 years of mining some 439 million metric tonnes have been extracted (Hacquebard 1980). By 1985 the demand for coal in Nova Scotia is expected to reach 4.5 million tons annually, 2.7 million for power generation and a possible 1.8 million for metallurgical purposes. The coals have been classified as high volatile 'A' or high volatile 'C' bituminous rank by Hacquebard (1979).

The Nova Scotian coalfields are shown in Figure 1.3. and demonstrated resources amount to 1.8 billion metric tonnes, of which some 90% occur in the submarine part of the Sydney Basin (Hacquebard 1980). Coal mining is operated by the Cape Breton

Development Corporation (DEVCO) for the Canadian Federal goverment and is presently taking place in the Sydney coalfield.

1.4. Fieldwork and study methods.

Three periods of fieldwork totalling seventeen weeks allowed the collection of over 3000 specimens all of which have been examined. Most of these specimens are destined for the British Geological Survey palaeontological collection (prefixed by "GMV"). Others, particularly types and figured specimens will be returned to Canada where they will be housed by the Geological Survey of Canada in their type collection at Ottawa.

During the first field season, several coalfields were visited and reconnaissance studies made involving the collection of any and all faunas recorded, the measuring of sections and visits to Canadian geologists active in the area.

After examination of these initial specimens, the second two field seasons were spent visiting collections housed in Canadian museums and in more detailed collecting and measurement of promising sections.

Study methods involved the use of a Wild binocular microscope with camera lucida attachment in order to accurately draw specimens for measurement. Various statistical methods were applied to such measured shells and these are described in Chapter 3. Ostracodes were studied in a similar way and a scanning electron microscope was occasionally utilised so as to observe surface ornament.

Sediments were studied through hand specimens and the use of a Geological Society of America Rock-color chart (cf. Eagar 1973). The assessment of the darkness or 'greyness' of sediments was attempted in this way and used as an approximation of organic carbon-content. Thin sections were also studied in order to observe internal shell structure and in some cases, the diagenetic history of the lithology.

1.5. Terminology.

The terminology of Spears (1980) was adopted in part when classifying mudrocks thus, a shale is a fissile or laminated rock, whereas a mudstone is neither laminated nor fissile. Rocks containing greater than 40% quartz are termed silts or silty shales. The term muddy shale is used to describe mudrocks containing less than 40% quartz that are fissile or laminated. Carbonate rocks are classified after examination of thin sections, according to Folk (1959).

Colour codes, where given, refer to the grey hues given on the Geological Society of America Rock-color chart (1976). This procedure is adopted following Eagar (1973) and Spears (1980). The colour of the sediment is assumed to approximate the organic carbon-content of the lithology unless otherwise stated (e.g. where the colour is due to a high proportion of finely disseminated pyrite). Due to time considerations, no attempt was made to compare colour codes and the total organic carbon-content of a lithology. Eagar (1973) gives such a correlation for some British Carboniferous mudrocks and on this basis, the colour code is accepted as an approximate measure of organic carbon-content (at least on a comparison basis). The measure is admittedly very approximate, but when taken with other lines of evidence, it serves as a useful environmental indicator (see Chapter 7).

GENERAL KEY FOR FIGURES

FAUNA: Abbreviations

BIVALVES

N - Naiadites
C - Curvirimula
At - Anthracanauta
An - Anthraconaia

OSTRACODES

Carbonita

ev - C. evelinae
ba - C. bairdiodes
in - C. inflata
al - C. altilis
el - C. elongata
se - C. secans
hu - C. humilis
pu - C. pungens
sc - C. scalpellus
sa - C. salteriana
cl - C. clanpunctata
co - C. corrugata

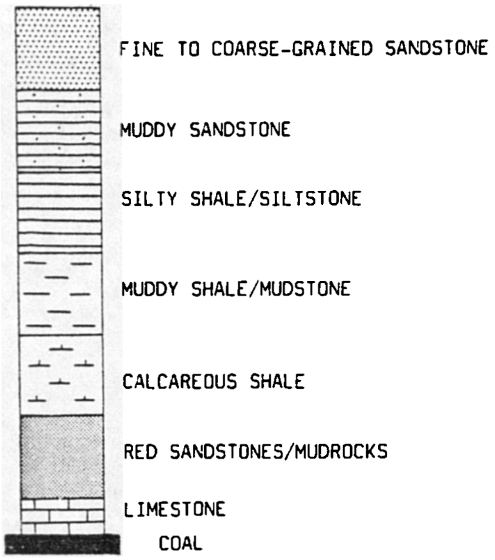
other genera

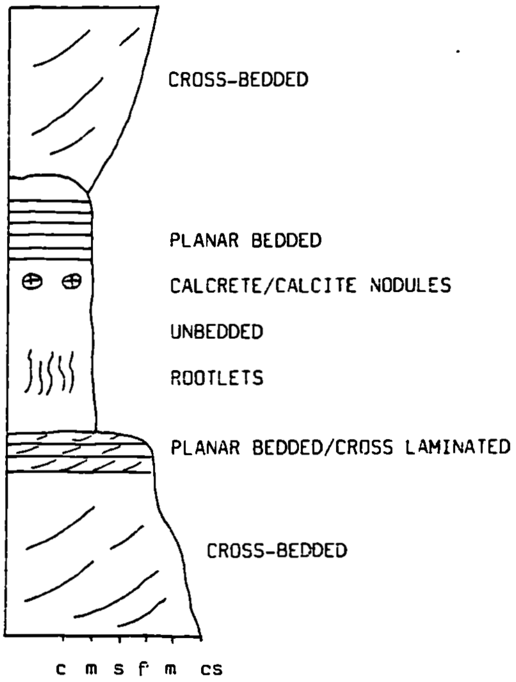
Gt - Gutschickia sp.
G. - Geisina sp.

OTHER FAUNA

6 - Spirorbis sp.
ε - Estheria
L - Leaia sp.
P - Pygocephalus sp.
ψ - plants

LITHOLOGICAL AND BED FORM SYMBOLS.





c - clay
m - muddy
s - silt
f - fine-grained sand
m - medium-grained sand
cs- coarse sand

N X - X -- Colour codes (see text)

FIGURE 1.3

CHAPTER 2

THE GEOLOGY OF NOVA SCOTIA

2.1. The pre-Carboniferous geology of Nova Scotia.

Nova Scotia forms part of the Appalachian region of eastern Canada and North America, an area of complex tectonic and depositional history. Recently, several authors have given syntheses of the geological evolution of the area in terms of plate tectonics (Poole 1967, 1976, Keppie 1970, Schenk 1971, 1978, Williams 1979).

The pre-Carboniferous stratigraphy and geology of Nova Scotia reflects the opening and closing of the Iapetus ocean and the associated Taconic and Acadian orogenies, the result of which was to bring the areas of Nova Scotia together for the first time to form a continental platform area (Figure 2.1.). Thousands of metres of sediment accumulated on this continental platform area in narrow, strike-slip successor basins during the middle Devonian to lower Permian.

2.1.1. The early evolution of the Avalon Zone.

The only Pre-Cambrian rocks in Nova Scotia are found in the Avalon Zone (Figure 2.1) cropping out sparsely in the Cobequid, Antigonish and Cape Breton highlands (Figure 2.2). The George River Group and Bass River Complex consisting mainly of marbles, quartzites, schists and gniesses are the oldest rocks in Nova Scotia occurring in both the Cobequid and Cape Breton highlands. Younger, less metamorphosed and deformed Pre-Cambrian volcanics and sediments of the Forchu and Georgeville Groups crop out in the

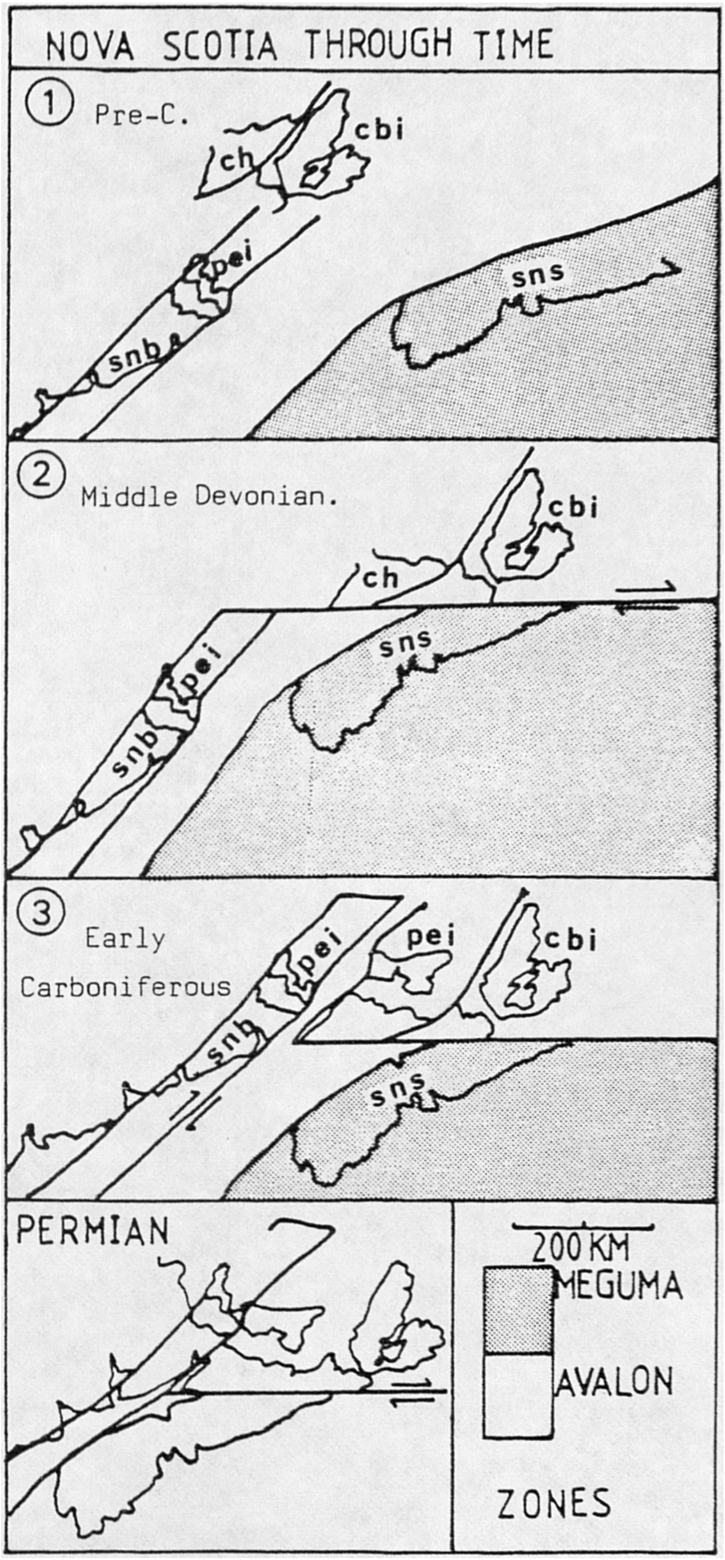


FIGURE 2.1: Tectonic elements and evolution of Nova Scotia. pei - Prince Edward Island, snb - southern New Brunswick, cbi - Cape Breton Island, sns - southern Nova Scotia, ch - Cobequid highlands. (Bujack & Donohoe 1980)

Cobequid and Antigonish highlands (Bujak & Donohoe 1980).

The end of the Pre-Cambrian was marked by folding and faulting of the Cadomanian Orogeny. Nevertheless, the transition into Lower Palaeozoic rocks is mainly conformable in Nova Scotia.

The Avalon Zone formed a stable platform area during the early Cambrian opening of the Iapetus Ocean (Poole 1967, Williams 1979). In the Antigonish highlands, Cambrian and Ordovician volcanics and sediments were deposited in a shallow marine area whereas, in the Cobequid highlands, the oldest Palaeozoics comprise deep water Silurian graptolitic shales. By middle Silurian times, deposition of the Arisaig Group marked a shallowing in both areas and in the early Devonian continental redbeds were deposited. On Cape Breton island, rocks of a Silurian - early Devonian age are absent.

2.1.2. Lower Palaeozoic evolution of the Meguma Zone.

Some distance to the south of the Avalon Zone lay the Meguma Zone, which was restricted to mainland Nova Scotia and separated from the Avalon Zone by a major transcurrent fault. Deposition of Lower Palaeozoics occurred in a deeper water ocean setting allowing the accumulation of upto 13 km of Meguma Group sediments. The Meguma Group is mainly a sequence of turbidites overlain conformably by an Ordovician shale unit. Overlying the Meguma Group unconformably is a unit of mixed sediments and volcanics that include a possible tillite at its base (Schenk 1971). Devonian sediments, deposited in a warm , shallow marine environment follow.

The source area for the offshore Meguma Zone is postulated to have been a low-lying metamorphic terrain to the southeast. The great volume of sediments deposited suggest a provenance area of continental dimensions such as northwest Africa (Williams 1979), which remained against North America after the opening of the present Atlantic Ocean (Figure 2.3).

A Palaeozoic ocean existed between the Avalon and Meguma Zones during this time but no remnants of such an ocean exist (ibid.).

2.1.3. A continental setting for post-orogenic sedimentation.

The closure of the Iapetus Ocean resulted in several phases of folding, faulting, metamorphism and erosion. The earliest phase of folding took place during the Ordovician Taconic orogeny and later folding occurred during the early to late Devonian Acadian orogeny. Following these earth movements, a relatively stable land area was formed composed of pre-Acadian deformed rocks. The Acadian orogeny resulted in the joining of the Avalon and Meguma Zones for the first time, although the exact configuration is postulated to differ from that of modern Nova Scotia in that there was considerable offset along the Cobequid fault (Figure 2.4) (Webb 1969).

A later phase of relatively minor, local tectonism known as the Maritime disturbances, affected a narrow northeastward trending, downwarped area of horst and graben structures (successor basins) that subsided during the Upper Palaeozoic.

The setting for Carboniferous deposition comprised this downwarped area of crust surrounded by basement highs or platforms (Webb 1969). The principal basins, sub-basins and platform areas of Nova Scotia at this time are shown in Figure 2.1 and consisted of the Fundy Basin which was delimited to the northeast by the New Brunswick platform and to the south, by the Meguma platform.

The Fundy Basin formed a complex central zone in which late Devonian-early Permian sediments were deposited. The Fundy Basin

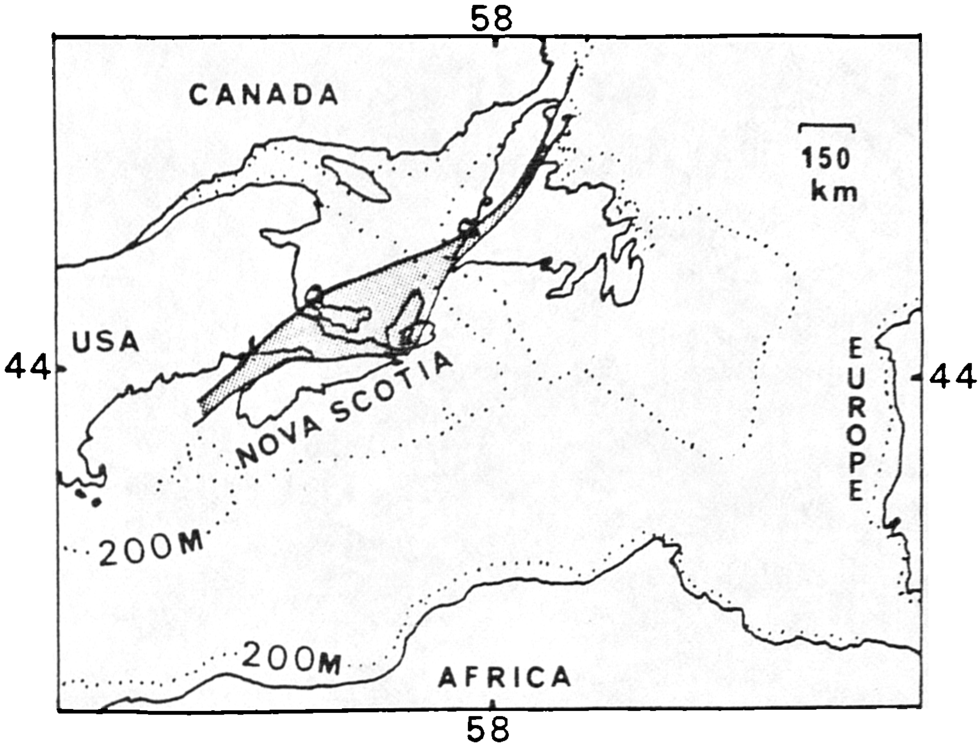


FIGURE 2.3: Late Palaeozoic palaeogeography (note the close proximity of Africa to the Maritime region). From Howie & Barss (1975b).

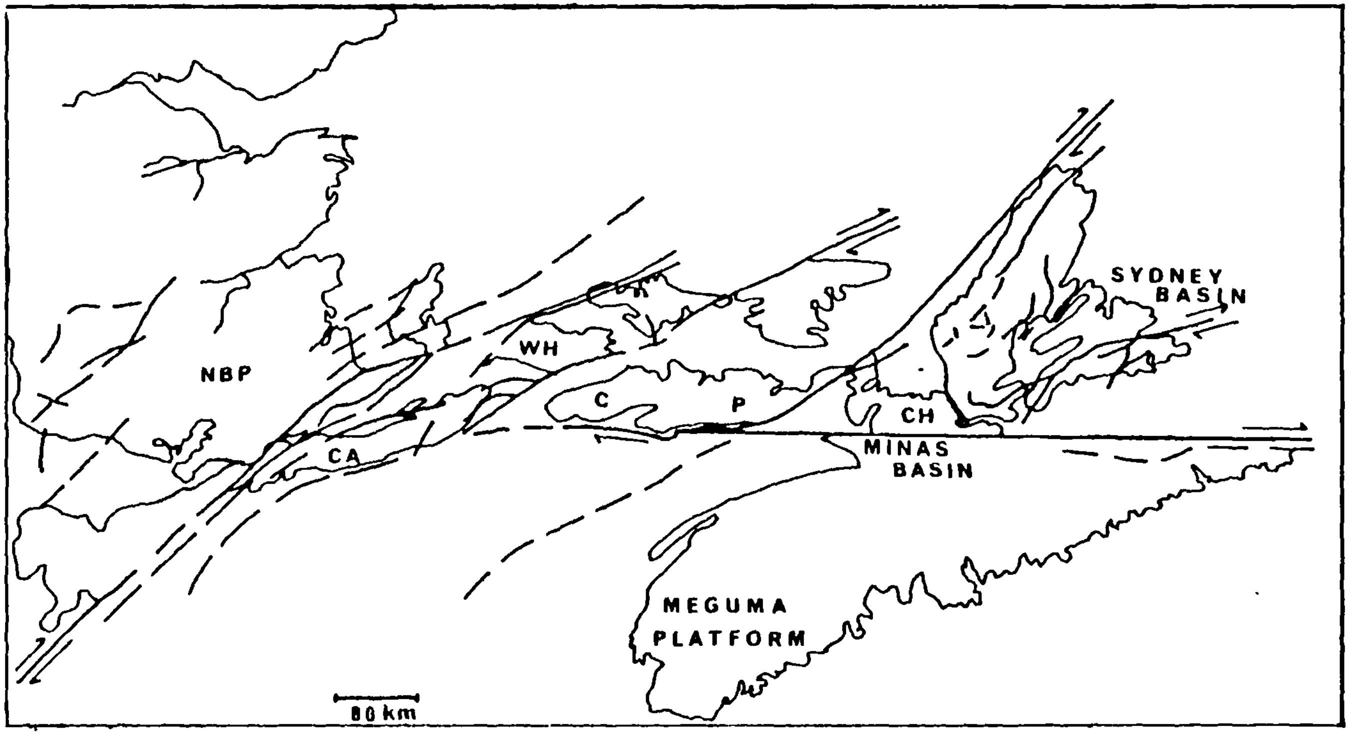


FIGURE 2.4: Webb's (1969) diagram showing offsets along major faults in the Maritime Provinces after the Acadian orogeny. CA - Caledonian highlands, C - Cumberland basin, CH - Cobequid highlands, P - Pictou basin, NBP - New Brunswick platform, WH - Westmorland highlands.

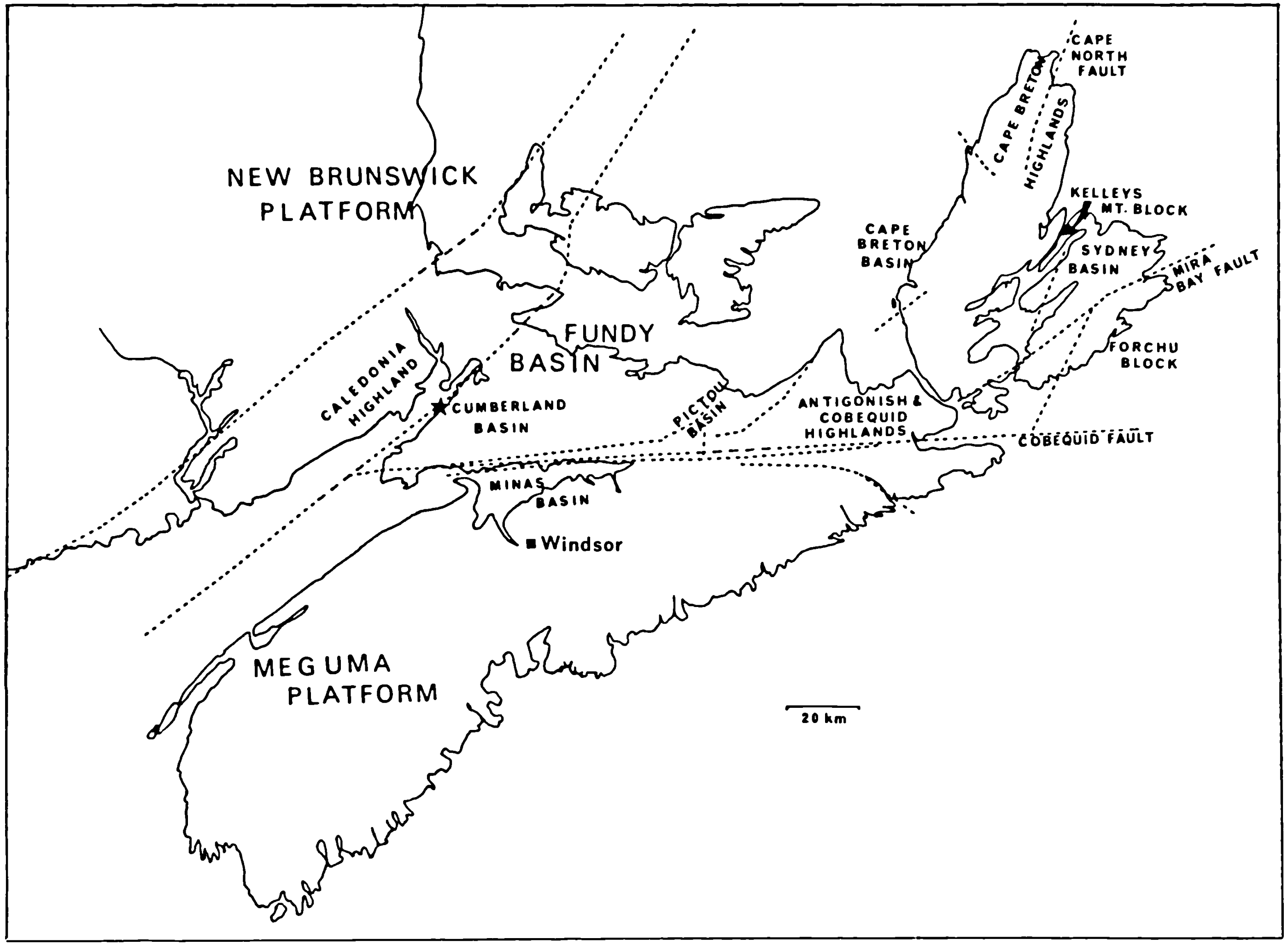


FIGURE 2.2: Map of Nova Scotia showing the major basins, highs and faults referred to in the text. Joggins section indicated with a *.

GROUPS BELL 1944, 1958	SPORE ZONES BARSS in HACQUEBARD (1979)		AGE	OTHER ZONATION		BELT 1965
				BELL (1938)	ZODROW (1982) ZODROW & McCANDLISH (1978)	
	e	*Vittatina*	Lwr. PERMIAN			PICTOU
	d	*Potonieisporites*	STEPHAN-IAN		*L. obliqua*	
PICTOU	c	*Thymospora*	WESTPHALIAN D	*Ptychocarpus unitus*		
	b	*Torispora*		*Linopteris obliqua*		
▨	a	*Vestispora*	C	*Lonchopteris*		
CUMBERL'D	g		B			CUMBERLAND
▨	f					
RIVERSD'LE	e		A			R'SDALE
▨	d		NAMURIAN			CANSO
CANSO	c/b					
	a			BELL (1958)		
WINDSOR			Late VISEAN	E D C B A		WINDSOR
HORTON	g		TOURNAIS'N			HORTON
	f					
	e					
	d					
	c		Late DEVONIAN			
	b					
	a		Mid-DEV.			

TABLE: 2.1

comprised several small sub-basins bounded by strike-slip faults and was divided by local highs (Figure 2.2). Cape Breton Highland to the northeast was composed of extensive areas of uplift and small basins as well as the large Sydney Basin (Figure 2.2).

2.2. Carboniferous stratigraphy.

The Carboniferous of eastern Canada was divided by Bell (1927, 1929, 1944) into six 'series' or Groups mainly on the basis of relative age. However, later work notably by Belt (1964, 1965, 1969), has shown that some of Bell's determinations based on macrofloral and faunal evidence where available, were inaccurate. Palynological work (Barss & Hacquebard 1967) has allowed refinement and revision of Bell's biostratigraphic results and some authors have opted to redefine Bell's groups as lithostratigraphic units (e.g. Belt 1964, 1965, McCabe & Schenk 1982). Table 2.1 shows Bell's groups and Belt's lithostratigraphic equivalents as well as the miospore and floral Zones of Barss & Hacquebard (1967) and Bell (1927, 1938, 1944).

Most authors appear to have retained Bell's original units with some refinement, recognising that they are not chronostratigraphic units. This procedure is followed here.

2.2.1. The Horton Group.

As defined by Bell (1929), the Horton Group included all the rocks of Tournaisian age exposed in the Horton Bluff area, near Windsor, Nova Scotia (Figure 2.2) and was considered by Bell (1927) to be characterised by the plants *Lepidodendron corrugatum* and *Aneimites acadia*. Kelly (1967) redefined the Horton Group as a distinctive rock unit embracing a continental sequence of sediments and volcanics that rest with a major unconformity on the eroded Acadian orogen and are overlain conformably, disconformably and occasionally unconformably by Windsor Group or younger strata.

The type section at Horton Bluff comprises two formations (Bell 1929), a lower Horton Bluff Formation and an overlying Cheverie Formation. The Horton Bluff Formation comprises grey-brownish, conglomeratic quartzose sandstone, siltstones and shales and is unconformable on Ordovician shales. The Cheverie Formation comprises red and grey feldspathic conglomerates, sandstones and shales.

Later work showed that the rocks assigned to the Horton Group range in age from middle Devonian to the top of the lower third of the Viséan and the biostratigraphic zonation based on Hacquebard (1957) and Playford (1963) is shown in Table 2.1.

By middle Devonian times the Fundy and Sydney Basins were subsiding with the New Brunswick, Meguma and Newfoundland platforms, as well as local horst structures, providing terrigenous debris. Coarse piedmont and fluvial sediments were deposited in low-lying areas, each successive rock unit overlapping basement (Howie & Barss 1975a). As the area of deposition expanded, local source areas such as the Cobequid highlands and part of the Caledonian highlands were inundated. Thus, basal coarse facies were replaced by finer sandstone and shale facies as elevated source areas were modified and the environment of deposition changed from piedmont to fluvio-lacustrine (Howie & Barss 1975b).

Later renewed uplift is indicated in some areas with the deposition of red shales, siltsone, sandstone and some salt in an arid to semi-arid climate (Ibid).

In the Sydney Basin, the Grantmire 'formation', a conglomeratic sequence flanking the Coxheath hills and originally included in the Windsor Group by Bell & Goranson (1938), was included in the Horton Group by Giles (1983).

Thickness of the Group is regionally highly variable ranging in thickness from a few tens of metres to 3,290 m in western Cape Breton Island. In the deepest part of the Magdalen Basin the Group is thought to be greater than 4000 m thick. The great variation in thickness is believed to reflect the instability of the underlying basement (Howie & Barss 1975b).

2.2.2. The Windsor Group.

Bell (1929) proposed the term 'Windsor Group' for a sequence of soft marine sediments occurring in the Windsor area which Belt (1965) modified to a chronostratigraphic stage, and defined as the Windsorian. Kelly (1967) retained the lithostratigraphic unit as a partly or wholly marine sequence of strata that conformably or unconformably overlies the Horton Group and overlaps Pre-Carboniferous rocks.

Bell (1929) divided the Group into two main zones and five subzones (Table 2.1) based on brachiopods and corals indicating a middle to upper Viséan age. Mamet (1970) however, working on foraminifera, suggested a late Visean to early Namurian age.

In the type area the group comprises red sandstones, red and a few grey siltstones, limestone and minor dolomite and gypsum. Salt is absent from the type area. The Group overlies the Horton Group and is unconformably overlain by sediments of the Pictou Group. Outside of the type area, the Windsor Group generally comprises thick members of massive to poorly bedded red and mottled siltstone, shale and sandstone interbedded with gypsum, anhydrite and salt. Evaporites are mainly restricted to Bell's subzone B whereas carbonates tend to characterise subzones C to E

(Bell 1929, Howie & Barss 1975b).

The sea entered the area from the north in middle to late Visean times transgressing Horton Group clastics and locally the basement. Rapid stagnation occurred due to poor circulation and high evaporation rates at a palaeolatitude of 8°S (Schenk 1969), allowed only limited organic activity in shallow peripheral areas; cryptalgal laminites spread accross the low-lying Horton basin fill. Reef-like mounds of euryhaline faunal assemblages fringed islands and steep shorelines (Geldsetzer 1983).

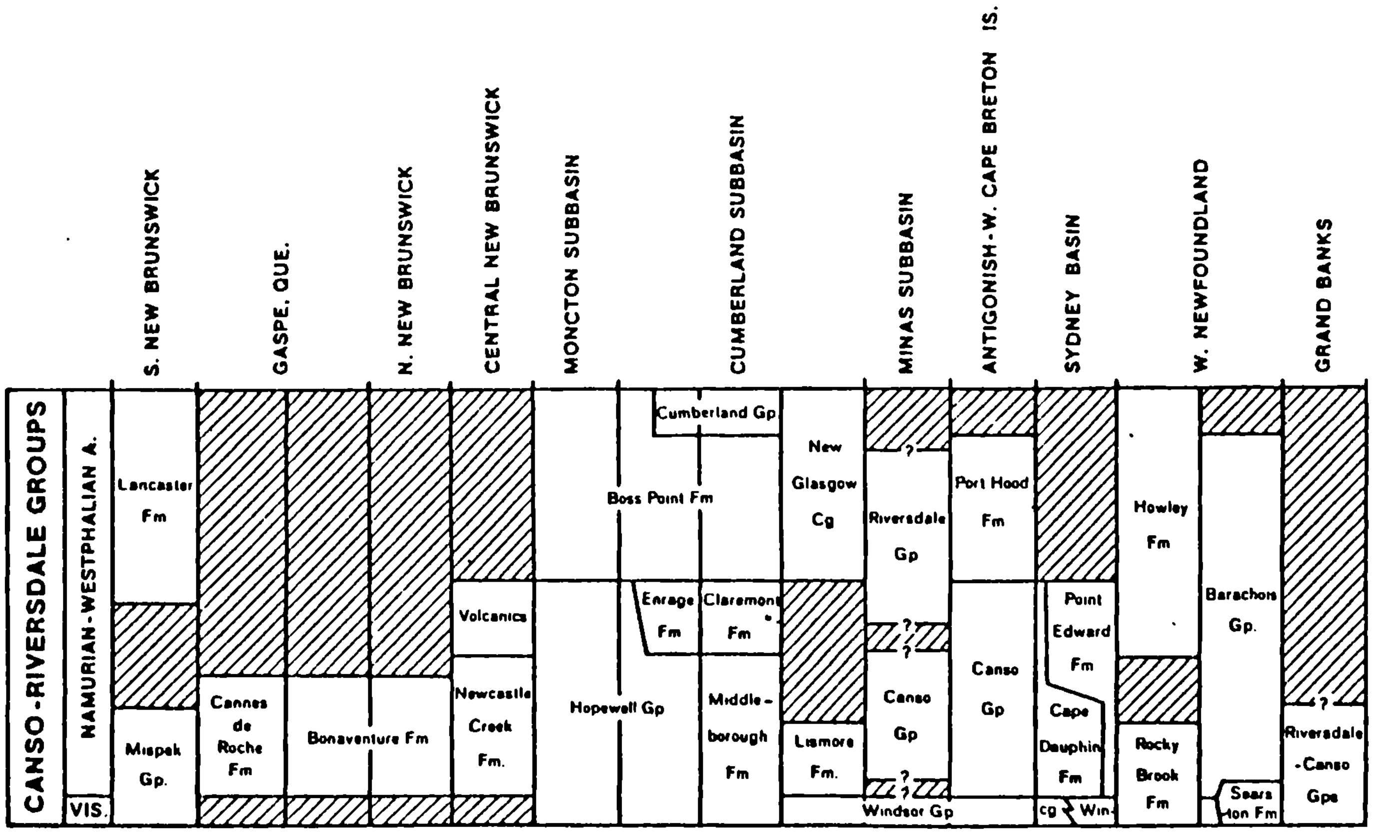
Continued stagnation allowed the accumulation of vast quantities of evaporites but a gradual return to normal salinities led to the deposition of carbonates containing echinoderms.

Giles (1981) recognised five transgressive regressive cycles in the Windsor Group and was later able to redefine the upper and lower boundaries of the group on this basis (Giles 1983).

2.2.3. The Canso-Riversdale Groups.

Bell (1944) proposed both the Canso and Riversdale Groups. The Canso Group was defined as a sequence of Namurian A non-marine, red and grey shales and sandstones that overlie marine Windsor Group or older non-marine rocks. The Riversdale Group was described as a sequence of Westphalian A continental deposits between Canso and Cumberland or younger strata. However, the Canso Group has not been recognised outside its type area in the strait of Canso and correlatives usually bear local formational names (Table 2.2). The Riversdale type section does not contain any diagnostic fossils and has faulted upper and lower contacts though spores from the section suggest it may prove to be a correlative of the Canso Group (Hacquebard 1972). In other areas the Riversdale is characterised by the plants _Neuropteris smithsii_ and _Whittleseya desiderata_, abundant _Curvirimula_ and the first

TABLE 2.2: THE CANSO-RIVERSDALE GROUP AND ITS CORRELATIVES (from HACQUEBARD (1979)



appearance of the Naiadites modiolaris group (Bell 1944).

The confusion surrounding the definition of these two Groups led Belt (1964) to propose the Mabou Group which would include all formations overlying the Windsor Group and underlying the Cumberland or Pictou Groups. Several authors have however, chosen not to adopt Belt's terminology on the basis that the Canso and Riversdale Groups can be recognised using miospores (Hacquebard 1972). Thicknesses of the Canso-Riversdale Groups have been greatly affected by movement of Windsor evaporites and in George bay the Groups have a combined thickness of 3000 m.

Regional and local uplift associated with the Maritime disturbances expelled the Windsor sea giving place to fluvial-lacustrine deposition. The Canso Group is mainly an offlap sequence deposited in areas of relatively low relief where coarse clastics were generally absent and a semi-arid climate is envisaged (Howie & Barss 1975b). Towards the end of Canso deposition, sandstones were deposited more commonly, indicating a period of renewed uplift of the source areas. This continued during deposition of the Riversdale Group, the Fundy Basin being divided by the Cobequid and Caledonia highlands (Figure 2.2) into a series of subbasins.

2.2.3.1. Moncton-Cumberland Subbasin.

In the western part of the Cumberland subbasin the Canso-Riversdale Groups are represented by three formations; the Shepody, Enrage and Boss Point Formations (McCabe & Schenk 1982). A gradual change in facies characteristics occurs in the lower Maringouin Formation of the Windsor Group into the Shepody Formation (ibid.) with fining-upward sandstones becoming thicker and coarser and the volume of overbank deposits decreasing upwards (ibid.). The base of the Enrage Formation represents a sudden environmental change with much lower sandstone thicknesses and

LOGAN 1845	FLETCHER 1908	BELL 1914		COPELAND 1959		
	SECTION I	CUMBERLAND GROUP (BELL1944)	SHULIE FORMATION	FACIES D	RED SANDSTONE/SILT.	
DIVISION 1						
DIVISION 2	SECTION IX SECTION X			FACIES C	NORTH RED SSTN. & SHALE	SOUTH RED CONGL. & GR. SSTN.
DIVISION 3	SECTION XI		JOGGINS FORMATION	FACIES B	COAL - BEARING ZONE	
DIVISION 4						
DIVISION 5				FACIES A	NORTH RED- GREY SHALE, SST. & CONGL.	SOUTH RED CONGL. MINOR SSTN.
DIVISION 6			BOSS POINT FORMATION			

TABLE 2.3 : SECTIONS AND FORMATIONAL NAMES USED FOR THE JOGGINS SECTION.

more dominant floodplain sediments. According to McCabe & Schenk (1982), the rivers which deposited the upper Shepody sediments were large and at least 8 m deep, and the coarsest material (apart from intraformational clasts) is of a medium sand suggesting a distant source area. These authors noted that in the basal part of the Enrage Formation, pebbles upto 100 mm long occur and suggest a closer source area in the Caledonia highlands. Relatively rapid uplift of the Caledonia highlands at the end of Shepody times is thought to have blocked the route of the earlier Maringouin/Shepody river system providing coarser sediments to the western side of the basin.

Much of the Enrage Formation is composed of caliche deposits suggesting that the Caledonia highlands had been eroded fairly rapidly but were still of sufficient relief to divert the easterly flowing Maringouin/Shepody river system (ibid.).

The Boss Point Formation in its lower part is similar to the uppermost Shepody Formation and McCabe & Schenk (1982) suggest a return to the original drainage pattern with the Caledonia highlands no longer a positive area (Figure 2.2). In the upper parts of the Boss Point Formation thin lake deposits, crevasse splays and thin coals were deposited in a fluviolacustrine environment. Laming & Lawson (1963) reported the occurrence of thin bituminous shales with Carbonicola and nodular limestones.

In a number of small basins on the north west coast of Cape Breton Island, rocks of a similar facies are present (Port Hood Formation) and contain thicker coals and better developed crevasse splays than the Boss Point Formation (Gersib & McCabe 1981). Deposition in a meandering river with a swampy floodplain in which lakes were formed by channel abandonment and subsidence of the floodplain area was proposed (ibid.). Crevasse splays built out into lakes and onto floodplain areas.

2.2.3.2. The Minas Subbasin.

To the south of the Cobequid highlands and fault, deposition occurred in the narrow Minas basin. The basal West Bay Formation is separated by a marked unconformity from the overlying Parrsboro Formation.

The West Bay Formation is locally intensely deformed and folded comprising a fine-grained, early Namurian sequence of siltstones displaying symmetrical ripples, desiccation structures and thin beds of ferroan calcite interpreted by McCabe et. al. (1980) as being indicative of a playa lake environment.

The basal conglomerate of the Parrsboro Formation, which is roughly equivalent to the Boss Point Formation (McCabe & Schenk 1982), is red and consists entirely of clasts of the underlying West Bay Formation. The conglomerate was interpreted by Pluim (1980) as being deposited in braided rivers from the east. There is an increasing lacustrine component upwards, higher parts consisting of sandstones and siltstones (ibid.).

McCabe et. al. (1980) considered that the deposition of the West Bay and Parrsboro Formations occurred in an extensional basin formed at a curve in the major strike-slip Cobequid fault (see Figures 2.2 & 2.3) during the upper Namurian to early Westphalian.

2.2.3.3 Antigonish-Cape Breton and Sydney Basins.

Canso-Riversdale strata are represented in the Antigonish-Cape Breton subbasin by the fluvial Pomquet Formation (McCabe & Schenk 1982) which in the Canso Strait and in western Cape Breton Island is split by the lacustrine Emery Brook Formation.

In the Sydney Basin, the Canso-Riversdale Groups are represented by 213 m of red and green shales with minor sandstones and freshwater limestones of the Point Edward Formation (Giles 1983).

2.2.4. The Cumberland Group.

The Cumberland Group is restricted areally to the Cumberland subbasin, to a narrow belt north of the Cobequid mountains and eastward, in the Stellerton gap. Two further small areas of outcrop occur in southwestern New Brunswick. The type section is along the eastern shore of the Chignecto bay (Figure 2.2) beginning 5 kilometres north of Joggins and continuing for about 45 kilometres southwest.

Bell (1944) recognised the Group by a marked rarity of pecopterids, sphenopsids and Neuropteris obliqua, and considered the floral assemblage to indicate a Westphalian B age. Miospore work by Hacquebard & Donaldson (1964) tended to confirm Bell's findings.

At the type locality, the group rests with an apparent conformity on the Boss Point Formation but Bell (1944) recognised that the basal beds become progressively younger inland. Copeland (1958) recognised four facies in the type section which roughly correspond with divisions made by Logan (1845, Table 2.3). Facies A and B consist of channel sandstones, crevasse splay sandstones, lacustrine sediments and rooted floodplain rocks as well as coals upto 1.5 m thick. Duff & Walton (1973) interpreted the Joggins section as representing a delta plain which built out north eastwards between the Caledonia and Cobequid highlands towards the Fundy Basin. However, the sediments were more likely to have been deposited in a fluviolacustrine setting with meandering rivers crossing a swampy floodplain (see Chapter 5).

In south western New Brunswick, the Tynemouth creek Formation of Westphalian B age crops out along the coast and comprises siltstones, sandstones and conglomerates displaying an overall coarsening upward character. Plint & Poll (1982) interpreted the sediments as being alluvial deposits.

In the Stellerton gap, the group consists of red sandstone with a basal conglomerate which is exposed adjacent to the Cobequid mountains and is believed to be locally derived (Nova Scotia Department of Mines & Energy, pers. commun. 1982).

Regional uplift occurred during late Westphalian A and B times in a warm, temperate climate (Howie & Barss 1975a,b). In early Westphalian B times, the Cobequid highlands were providing coarse clastics and the western part of the Cumberland subbasin, north of the Cobequid highlands, was subsiding due to flowage of Windsor salt (ibid.). The Cumberland Group is unknown on Cape Breton Island.

2.2.5. The Pictou/Morien Group.

The group was established by Bell (1944) for sediments in the Tatamagouche syncline of the Cumberland subbasin, the Pictou Group and its lateral equivalents (Morien Group in the Sydney coalfield and Stellerton Group in the Stellerton area). After regional uplift and a change in tectonic style, the rocks were deposited in large wide basins (Haszeldine (1981)). The Pictou Group is characterised by an absence of Naiadites and the entrance of the Anthraconauta phillipsii group.

The type section in the River John area comprises 2250 m of brownish-red, soft quartz sandstones, arkosic grits, thinly bedded and massive sandstones alternating with red shales and muds. The basal bed is a 2 m thick conglomerate that rests with an unconformity on Riversdale strata (Bell 1944, Howie & Barss

1975a).

Barss & Hacquebard (1967) recognised five miospore zones (Table 2.1) ranging in age from the Westphalian D to Stephanian in the Pictou area and from late Westphalian B to lower Permian in the Sydney coalfield. Bell (1938) divided the Pictou/Morien Group into three macrofloral zones of Westphalian C and D age. These were emended by Zodrow and others and suggestions made that a Stephanian stage could be recognised (Zodrow & McCandlish 1978, Zodrow 1982 - Chapter 7).

In the Pictou Basin, the group reaches a thickness in excess of 2700 m (Calder 1979). Sedimentation occurred in a narrow restricted, intermontane trough with the depocentre migrating eastwards through time, although subsidence was slow. Coarse material was deposited close to basin margins and finer material towards the centre.

The Sydney Basin is bounded to the south by Pre-Carboniferous rocks of the East bay and Forchu blocks and on the northwest by Kellys mountain block (Figure 2.2). Both margins are major fault boundaries. The base of the Morien Group is exposed at numerous localities and comprises a cobble conglomerate fining upwards into sandstones (Giles 1983).

In the Sydney coalfield a maximum thickness of 2050 m is reached in the Glace Bay area (Gray & Gray 1941). Dilles and Rust (1983) described the lower parts of the Morien Group in the Port Morien area as alluvial recognising two facies associations. The first is a sandstone association in the lower parts of the succession and deposition on a distal sandy braidplain was envisaged. The second comprises an alternating facies association of fining-upward sandstone sequences and coal-bearing, mudstone sequences; this was deposited in a meandering alluvial system.

Duff et. al. (1982) working in the western part of the coalfield, found evidence for northeasterly trending palaeocurrents, a conclusion which Rust et. al. (1983) confirmed for the coalfield as a whole. Three facies assemblages have been recognised by those authors in a preliminary paper, these comprise; a pebbly sandstone assemblage with thin pebbly sandstones characterised by a paucity of mudrocks, a sandstone assemblage and an alternating assemblage.

In New Brunswick, Pictou Group sediments are known in the southwestern portion of the central Carboniferous basin with a basal lithofacies attributed to a braidplain environment. An upper lithofacies is attributed to deposition on a semi-arid, alluvial plain with isolated channel facies (Le Gallais 1982).

2.3. Post-Carboniferous evolution of Nova Scotia.

During Permian - Triassic times, the area formed part of a hot, arid desert zone in Pangea. The oldest Triassic rocks are redbeds of the Wolfville and Blomidon Formations which were deposited in a fluvial to lacustrine environment. Deposition was interrupted by the development of a rift valley system associated with the opening of the modern Atlantic ocean.

Basaltic lavas of the North Mountain Basalt were extruded overlying older rocks in the Cobequid fault area of the bay of Fundy (Figure 2.5) in late Triassic times.

Younger rocks are not found in onshore Nova Scotia but small, early Jurassic inliers occur along the bay of Fundy containing thin cherts and limestones. Cretaceous and Cainozoic sediments are found offshore and often reach great thickness.

2.4. Late Palaeozoic palaeogeography.

In the middle Devonian the final collision of Gondwana with the northern continents produced the Acadian orogeny. Late Acadian palaeogeography cannot be known due to a scarcity of rocks of an appropriate age in the area. However, the Acadian plate convergence was sufficient to produce a range of mountains which are estimated to have reached a height of 4 kilometres in New England (Bradley 1982). Late Devonian sediments and volcanics are preserved in only a few isolated, fault-bounded basins and were derived from nearby elevated areas.

During late Devonian-early Permian times sedimentation was widespread and probably continuous on a regional scale. Locally, sections are punctuated by unconformities and are nowhere complete (Kelley 1967).

Basins formed adjacent to major northeasterly - easterly trending, high angle faults that juxtapose dissimilar basement blocks (Bradley 1982). Many of these faults (Figure 2.3) are believed to be of Upper Palaeozoic age (Webb 1969) and show considerable dextral movement. Offset on northeasterly trending faults is reported to be as much as 160 kilometres in Newfoundland and 200 kilometres in New Brunswick (Bradley 1982) and along easterly trending faults, as high as 225 kilometres (McCabe et. al. 1980). Extensional pull-apart basins were formed by this movement in which sediments were rapidly deposited. Source areas were a series of uplifted blocks and more stable platform areas outside the plate boundary zone.

According to Bradley (1982), the area had a diachronous two-stage history of subsidence: earlier rapidly subsiding basins with shifting depocentres giving way to a period of thermal subsidence in large, wide basins which progressively onlapped basement. The Pictou/Morien Group, showing subsidence rates one third those of the Westphalian A and B (Figure 2.6) is an example

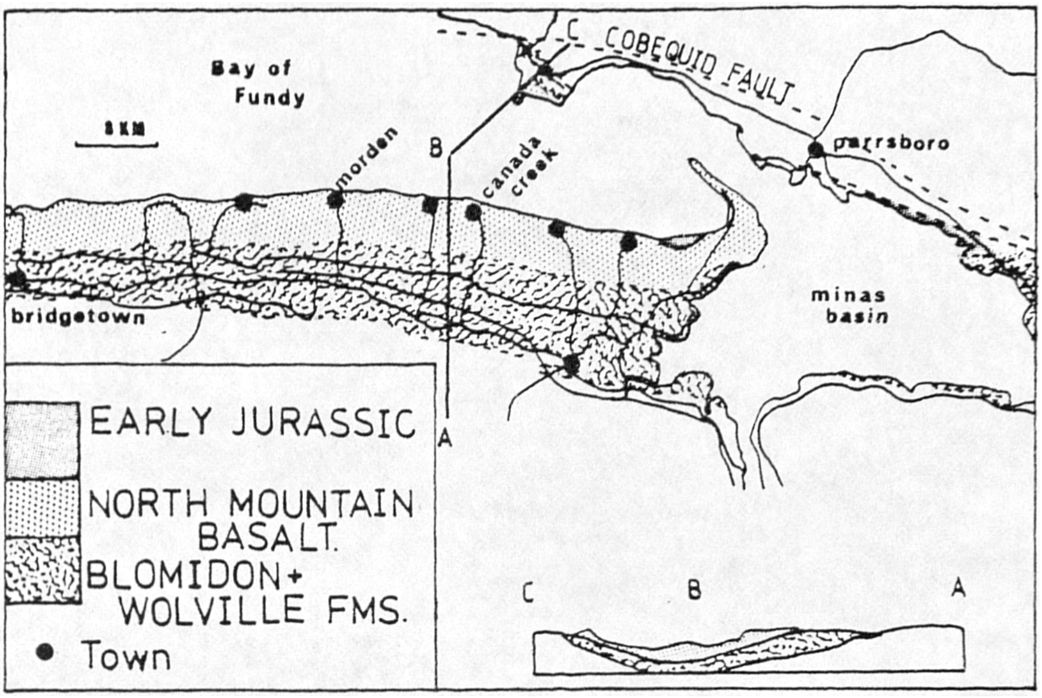


FIGURE 2.5: Post-Carboniferous rocks in the Bay of Fundy (after Bujack & Donohoe, 1980).

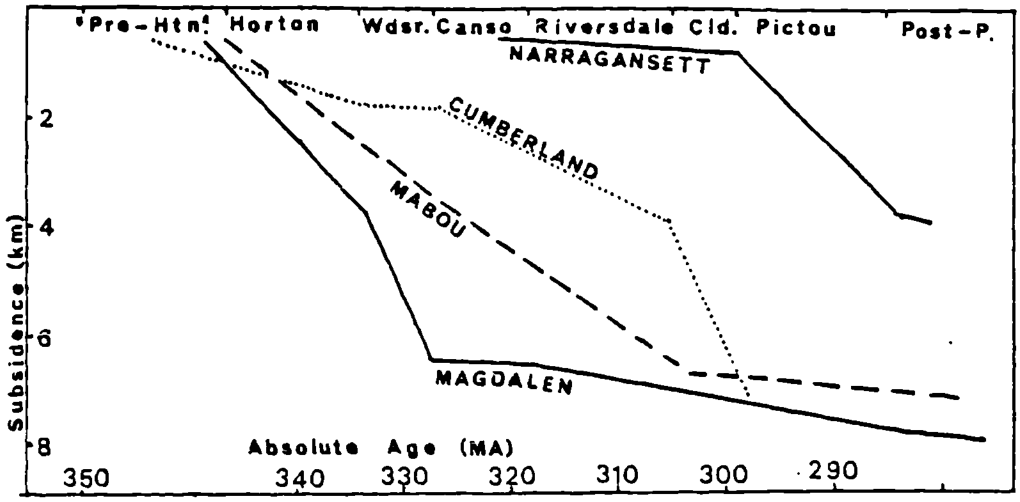


FIGURE 2.6: Subsidence curves for the Carboniferous basins of Nova Scotia (after Bradley, 1982).

of this (Poll 1973, Haszeldine 1981).

Figure 2.7 shows a palaeogeographical reconstruction of the northern continents at this time (Haszeldine 1981). In Britain deposition was fluvial, lacustrine and deltaic within the Pennine miogeosyncline. Sedimentation was locally dominated by block and basin tectonics. Marine influence was spasmodic but mainly occurred during the Westphalian A and B times, a sea lying to the southwest and a continental influence to the north (Calver 1968, Haszeldine 1981).

In Spain, small east-west trending basins formed in the Namurian C and marine carbonates and clastics were deposited upto Westphalian A times. Later sedimentation was non-marine and mainly took place in the form of alluvial fans with some marine bands. Stephanian sediments were more continental being deposited in fresh to brackish water (Eagar in prep. [1984]). Sedimentation took place in basins adjacent to dextral strike-slip faults in a similar way to those in Nova Scotia (Hewerd & Reading 1980).

In eastern U.S.A. marine influence was important in early Westphalian times with a sea lying to the southwest (Haszeldine 1981).

Nova Scotia apparently lay within a continent and coal deposition occurred within an intracontinental setting either in limnic or floodplain dominated basins (Hacquebard & Donaldson 1968).

2.5. The coalfields of Nova Scotia.

Figure 2.8 shows the location, age, production and remaining resources of the coalfields of the Maritime Provinces. Coal has been mined for over 190 years in Nova Scotia and although production has fluctuated, reaching as high as 7 million tons in

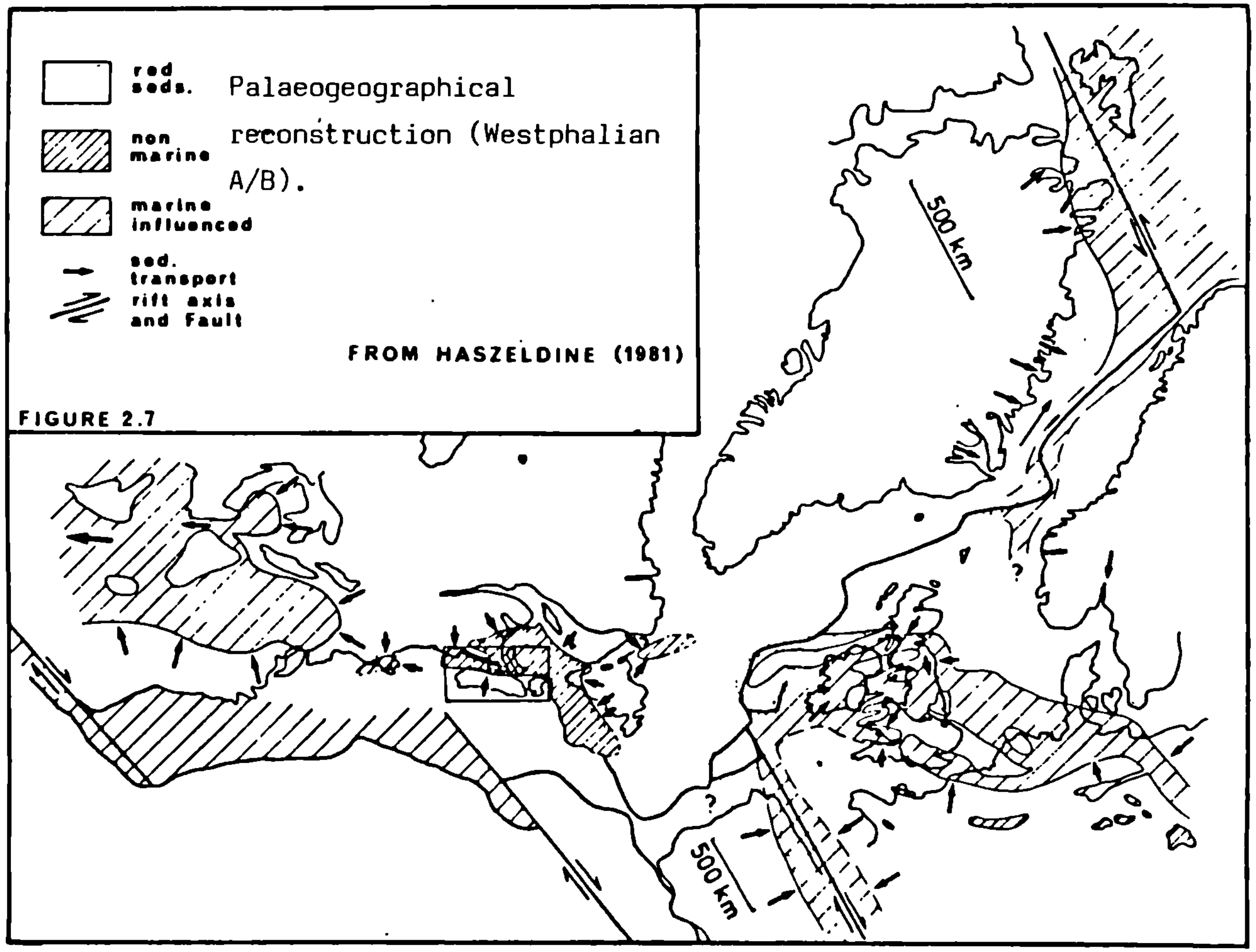


FIGURE 2.7

Palaeogeographical reconstruction (Westphalian A/B).

FROM HASZELDINE (1981)

1940, current production stands at 2.4 million tonnes. During the top production years coal was extensively mined from eight coalfields, the Sydney coalfield accounting for 77% of the total.

It is anticipated that demand for coal in Nova Scotia will reach around 4.5 million tonnes annually mainly for power generation and for metallurgical purposes (Hacquebard 1980).

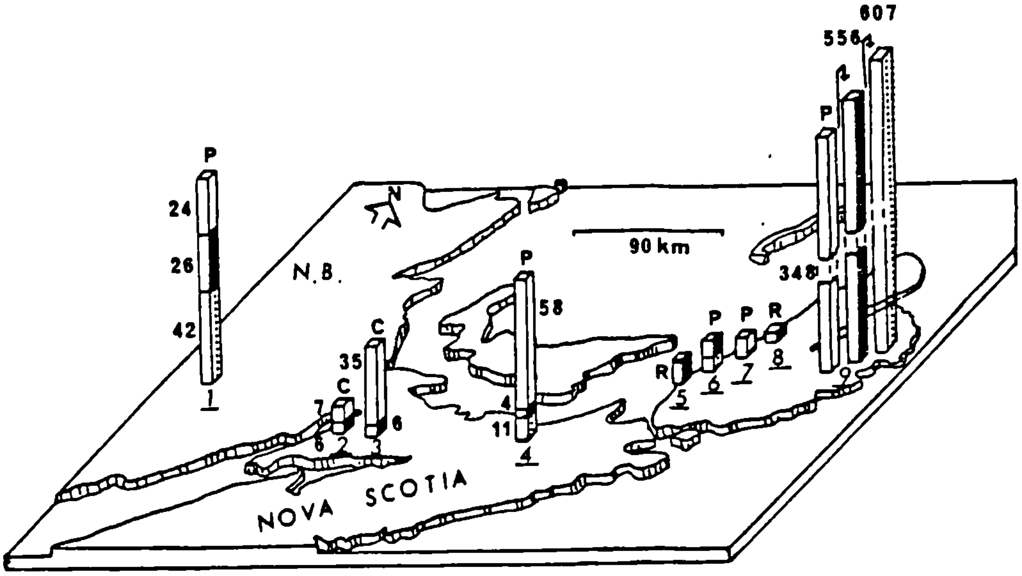


FIGURE 2.8: Coal resources and reserves in Nova Scotia. ⁘ - already mined, ■ - proven reserves, ☐ - calculated resources. *1* - Moncton coalfield, *2* - Joggins - Chignecto coalfield, *3* - Stellerton coalfield, *4* - Pictou coalfield, *5* - Port Hood coalfield, *6* - Inverness, *7* - Mabou Mines, *8* - Chimney corner - St. Rose coalfield, *9* - Sydney coalfield. Figures in Tonnes. R - Riversdale Group coals, C - Cumberland Group coals, P - Pictou Group coals. (From Hacquebard, 1979).

CHAPTER 3

NON-MARINE FAUNAS.

3.1. Introduction.

In Britain, Upper Carboniferous non-marine bivalves inhabitated paralic environments which were influenced by proximity to marine conditions (Calver 1968a). The varying effects of this marine influence can be seen in the nature and distribution of the bivalves and of the Coal Measures fauna in general; there was a progressive lessening of marine influence during the Upper Carboniferous in Britain. In Nova Scotia, the coal measures of this general age were deposited in an entirely continental setting and there is no evidence of proximity to a marine area during the Namurian-Westphalian. It can be expected on the basis of the geological history of the two areas (Chapter 2) therefore, that the non-marine bivalve faunas will be broadly similar in the two areas. The absence of anthracosiids from the Riversdale-Pictou Groups has been reported by previous authors (e.g. Rogers 1965, in prep. [1979], Eagar 1970, 1973); however, questionable Carbonicola are now known from the Boss Point Formation (Riversdale Group) sediments.

The Upper Carboniferous non-marine bivalves were probably tolerant of a range of salinities from freshwater to brackish and Eagar(1947, 1961, p. 147) showed that the ranges of tolerance probably varied between the different genera (Figure 3.1). Salinity though, was not the only factor controlling bivalve distribution. Substrate condition, current activity, oxygen availability and water depth would also affect their distribution. In this way the Coal Measures bivalves were strongly opportunist in the sense of Levinton (1970), with the

FIGURE 3.1: Salinity ranges of the genera in the U.K. (after Eagar 1961 and Calver 1968a). Dashed line indicates range of Curvirimula in the Appalachians (Eagar 1970).

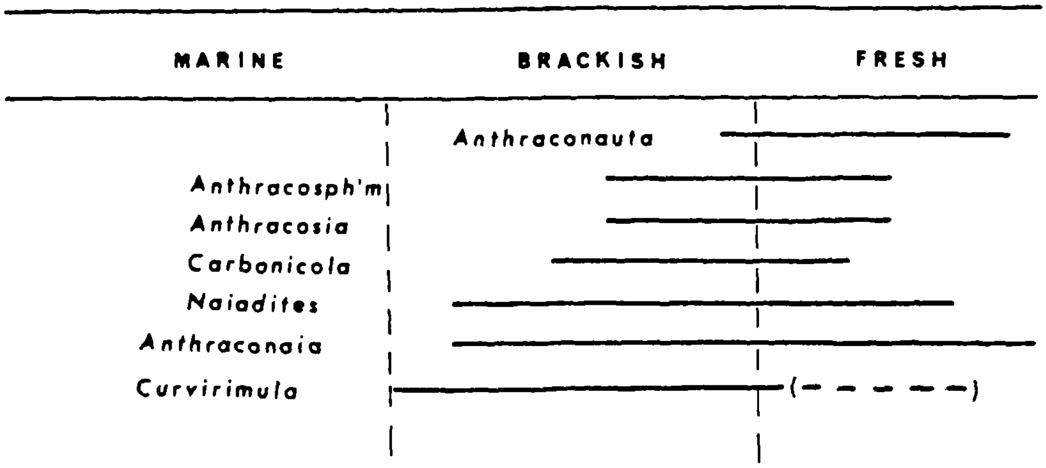
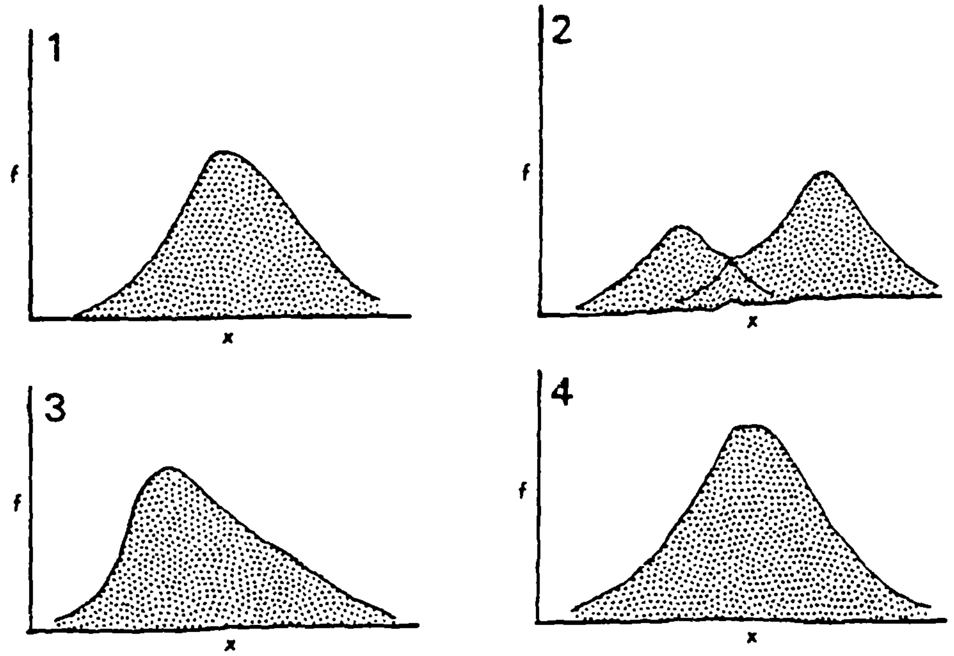


FIGURE 3.2: Frequency diagrams of some measured shell dimension (X mm). 1 - Unimodal distribution, 2 - Bimodal, 3 - Skewed, 4 - Symmetrical.



ability to invade normally inhospitable environments (Eagar 1978).

Detailed examination of these faunas have proved their stratigraphic value and a zonal scheme originally set up by Davies & Trueman (1927) is still utilised in Upper Carboniferous stratigraphy although, with some considerable modification notably in the addition of zonal boundaries marked by marine faunas (see Ramsbottom et. al. 1978). Comparative studies by Eagar (1948, 1977b, 1978) have demonstrated close similarities between modern and Upper Carboniferous non-marine bivalves allowing more detailed palaeoecological conclusions.

Recently (Eagar 1973), attention has turned to an examination of palaeoenvironent in relation to the bivalve Chronozones, which are based on morphological varieties differentiated mainly by shell shape. It has been envisaged that some of the stratigraphic use of these fossils is fortuitous as progressive environmental changes in the British-West European area may have been reflected in shell shape modification. This also appears to have been the case in Nova Scotia.

3.2. History of Research.

Early contributions to the literature on Upper Carboniferous non-marine bivalves are mainly locality listings, often without figure or adequate description of the species catalogued. Confusion appears to have arisen due to the same specimen being named differently on several different occasions. Hind (1894-1896) gave an account of this early literature and went someway towards an ordering of the taxonomy both at the generic and specific level. Important early contributions include those of Sir William Dawson, whose work has direct relevance to this thesis.

Dawson (1860) named six Nova Scotian species (*carbonarius*, *elongata*, *laevis*, *arenaceus*, *ovalis* and *angulata*) which he placed in his new genus *Naiadites* but he described them only in general terms (and was inconsistent with his specific name endings, *Naiadites* being masculine (Weir 1945, p. 322)). Several of Dawson's specimens were sent to Salter at the Geological Survey who had recently proposed the new genera *Anthracomya* (Salter, 1861) and *Anthracoptera* (Salter 1862). In 1863 Salter figured and described some of Dawson's specimens as *Anthracomya elongata*, *Anthracoptera carbonaria* and *A. laevis*, substituting his generic names for Dawson's *Naiadites*. In later editions of "Acadian Geology" (1868,1878), Dawson again figured and described his six species with Salter's names given in brackets and reasons were put forward for not using Salter's names which, according to Dawson, carried implications of salinity. A further edition of "Acadian Geology" (1891) added the species *Naiadites obtusa* and *Anthracosia bradorica*.

At this time in Britain there was some confusion surrounding the generic names given to shells of Coal Measures age previously referred to Unio. King (1844) had mentioned his intention to publish on these shells under the name of *Anthracosia*, but ten years later, no publication having resulted McCoy (1854) proposed the name *Carbonicola*. However, in reference to McCoy's description of the new genus, King (1856) pointed out that this name could not be accepted for his shells, since *Carbonicola* was described as possessing lateral hinge-teeth. Hind's monograph went some way towards clarifying the usage of the name *Carbonicola* in recognising that;

a. King's original publication (King 1844) gave no description or figures of the characteristic features of *Anthracosia*.

b. McCoy's original publication gave a partly erroneous diagnosis and no figures but left no doubt as to which shells were described under the name Carbonicola.

Dawson (1894) later published a revision of all his genera and species, placing the species elongata, laevis, arenacea, ovalis and obtenta in the genus Anthracomya Salter 1861, Naiadites angulatus and Anthracosia bradorica in the genus Carbonicola McCoy 1854, and he redescribed Naiadites carbonarius along with two new species; N. longus and N. mytiloides.

The publication in 1894-96 of Hind's " Monograph of Carbonicola, Anthracomya and Naiadites" had the effect of stabilising the nomenclature and was widely used both in Britain and abroad. However, Hind and many of his contemporaries felt that the value of Coal Measures non-marine bivalves for correlation was minimal since the view was held that the Coal Measures had been deposited in more or less isolated basins within each of which the non-marine faunas showed certain local peculiarities of succession.

Hind adopted the practice of lumping together into one species a wide variety of similar but by no means, identical forms. This approach, later shared by Belgian workers Pruvost and Pastiels (Pruvost 1930, Deleers & Pastiels 1947 for example) did not allow for stratigraphical discrimination as the number of recognised species was small. It was not until the publication of the classic paper by Davies & Trueman (1927), with suggestions of a revised nomenclature, that the institution of a zonal sequence of shells became a possibility.

Hind's work however, was of immense value in the controversy as to the marine or non-marine origin of these shells. Hind was of the opinion that the three genera Carbonicola, Anthracomya and Naiadites had occupied a fresh to brackish environment and he recognised marine bands as "discrete horizons carrying a fully marine fauna" in an otherwise non-marine Westphalian A which had previously been regarded in some quarters as qausi-marine overall (Hind 1894-6).

The publication of Davies & Trueman's (1927) paper stimulated increased interest; the emphasis was mainly placed on the extension, clarification and revision of the zonal scheme proposed by those authors. A full account of the literature of this period may be found in Trueman & Weir (1946, pp. ii to v).

Of considerable taxonomic importance was the revision of the three genera documented by Hind. Pruvost (1930) separated the 'species' belonging to the *phillipsii* group from the genus *Anthracomya*, placing them in a new genus, *Anthraconauta*. The 'species' referred to *Anthraconauta* clearly form a distinct group and the revision met with general acceptance. In 1933, Trueman suggested that the genus *Carbonicola* covered a wide range of forms falling into several distinct groups and in Trueman & Weir (1946-68) the genus was revised. Members of the *Carbonicola communis* group were retained in that genus, but the *aquilina* group was assigned to the genus *Anthracosia* King and the more tumid forms of the *turgida* group were placed in a new genus *Anthracosphaerium* Trueman & Weir. In addition, it was found that the name *Anthracomya* was preoccupied and the name *Anthraconaia* was proposed to replace it.

Later, Weir (1960) separated out the *Anthraconauta belgica* group primarily on the basis of its external shell structure of radially curved cracks but also because of its rather different statigraphical range (Table 3.1). This group was referred to the new genus *Curvirimula* Weir.

The Trueman & Weir monograph (1946-68) summarised a great deal of the work on Upper Carboniferous non-marine bivalves which was of stratigraphic, palaeoecological and taxonomic importance and therefore, forms the primary reference.

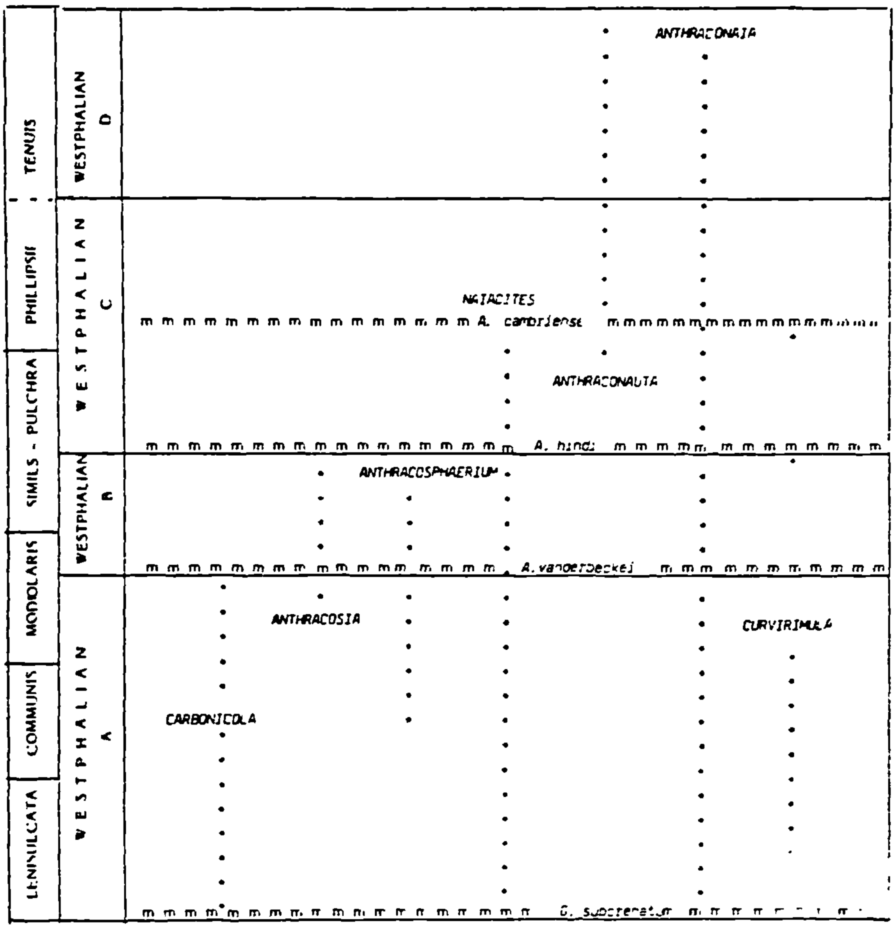


TABLE 7.1: Ranges of the genera of non-marine bivalves in Britain. (After Calver 1956, 1968a, Ramsbottom et. al. 1978 and Cleal 1984).

Of great significance too, since 1947 has been the work of Dr. R.M.C. Eagar (of which the earlier part is summarised by Weir (1968)). The importance of Eagar's work lies in his biometrical approach to the study of variation in a community; an approach pioneered by Davies & Trueman (1927), Wright (1934) and notably, Leitch (1936, 1940, 1942). In addition, Eagar has consistently been able to demonstrate a degree of correlation between shape of shell and the palaeoenvironment in which the bivalves lived. This aspect of his work has been supplemented by research into environmentally related shape and weight changes in Recent non-marine bivalve shells (Eagar 1948, 1977b, 1978).

In the context of this thesis, work by Newell (1940, 1942) is particularly significant. Newell described the hinge and musclature of *Naiadites carbonarius*, the type species from Joggins, Nova Scotia. Dealing with *Naiadites* in his subsequent monograph on Late Palaeozoic Mytilacea, Newell (1942) added to his earlier discussion of *N. carbonarius* and described and figured *N. ohioensis* Morningstar; a form which Rogers (1965) later referred to *Anthraconaia* and which was subsequently rejected as a homonym by Eagar (1975, p. 52).

Rogers (1965) reviewed the type material of Dawson's acadian 'species' in which the 'species' *elongata* was rejected as a *nomen dubium* (Rogers 1963);the 'species' *laevis* and *obtenta* suppressed and the 'species' *Carbonicola sculponeata* and *Curvirimula? corvosa* added. Rogers was able to draw up a tentative homotaxial correlation with the British succession (Table 3.2)

A study of shell shape variation displayed by Upper Carboniferous and Recent non-marine bivalves led Eagar (1973) to formulate two palaeoecological "laws";

> "a. When a decrease in the organic carbon content of a shell-bearing sediment takes place, either on the same horizon or in the sequence above it, and when this decrease

TABLE 3.2: Roger's (1965) correlations.

Group	Chronozone
PICTOU/MORIEN	Phillipsii - Tenuis (upper Westphalian C to Westphalian D).
CUMBERLAND	Modiolaris - Similis-Pulchra (upper Westphalian A to lower Westphalian C)
RIVERSDALE	Communis (middle Westphalian A)
CANSO	Lenisulcata, or possibly part of Namurian stage (lower Westphalian A or lower).

TABLE 3.3: The equations of Leitch (1940).

1: $h = 0.44l + 0.25d - 2.8$
2: $h = 0.54l + 0.26v - 5.2$
3: $h = 0.37l + 0.30d + 0.39v - 8.0$

can be interpreted as resulting from either decreased food supply or increasing sedimentation, or both these factors, then a corresponding decrease takes place in mean size, as measured by length, of the anthracosiid fauna in the band. Decreased organic carbon content is usually accompanied by decreased carbonate in the band.

b. Where increased turbulence in the palaeoenvironment can be reasonably deduced, the growth of the anthracosiid shells associated with the increase is such that a fitted line for height and length of shell shifts significantly in the direction of the H ordinate. The shifted line has either a steeper slope or the same slope as the line for the assemblage in the more tranquil environment. "

Work on fossil non-marine bivalves and trace fossils by Hardy (1970, 1971) and Eagar (1971) led Eagar (1974, 1977a,b,1978) to draw several conclusions on burrowing positions and shell shape in terms of shell function (see also Hardy & Broadhurst 1978) and enabled him to give a functional explanation of his "laws".

Eagar (in press [1979]) also worked on faunas referred to *Anthraconaia* in the Stephanian and 'Autunian' of the Appalachians, Saar and Saale coalfields of Germany, Spain and Portugal. He described several new species including *A. speciosa*, *A. protracta* and *A. altissima* (Eagar 1970, 1973, 1975, 1977a, in press [1979], 1983 and in prep. [1983]). Striking similarities shown by the *Anthraconaia* in N. America, Spain and Germany led Eagar (in press [1979]) to the conclusion that they ultimately be used in a zonal scheme but unfortunatly, much of the critical material came from boreholes in East Germany and provenances were not forthcoming for political reasonings.

Work on Viséan, Namurian and early Westphalian faunas and the recognition of bivalve escape shafts and other trace fossils in these strata resulted in the description of a new genus, *Paracarbonicola* which ranges from the Viséan to the Pendleian of Britain and occurs in the Pendleian of Poland and Czechoslovakia (Eagar 1977a). It was also demonstrated that *Carbonicola* evolved from a marine stock referred to cf. *Sanguinolites* Hind non McCoy in R1 to R2b times; communities of cf. *Sanguinolites* were overwhelmed by prograding delta lobes and tended to escape upwards to colonise the paralic deltaic environment evolving into elongate and streamlined shells of the *Carbonicola bellula* group of the late Namurian- early Westphalian (Eagar 1977a, Eagar *et al.* 1983). Such communities buried by sediment and forced to escape upwards, were termed "refugee communities" by Hardy & Broadhurst (1978).

In 1982 Rogers outlined a method which employed the use of Tchebyschev polynomials to describe the generating curve of a bivalve. One hundred irregularly spaced data points are required to produce stable coefficients. The first six coefficients adequately describe the outline and may be used as shape discriminators. In a further paper, Rogers (in press [1979]) demonstrated the method using *Naiadites* and *Curvirimula* from the Riversdale Group of Nova Scotia, principal components analysis being used for the first time to display the range of variation in each population.

During the same period, Calver[1] published several papers dealing with the distribution of mainly marine but including non-marine, faunas in the British Coal Measures (Calver 1968a,b 1969). Of importance are his two review papers dealing with the stratigraphic and palaeoecological ranges of the non-marine and marginal-marine Coal Measure faunas (Calver 1968a) and a further paper dealing with the Westphalian of Britain (Calver 1969).

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[1] SEE ALSO CALVER (1956) WHICH CONTAINS RANGE DATA OF ALL THE RELEVANT GENERA.

3.3. Use of biometrical and statistical techniques.

Biometrics, "the statistical treatment of quantative morphological data " (Imbrie 1956), is of limited use in taxonomy in general as many important taxonomic characters cannot be efficiently represented numerically (though they may be coded in a binary system). However, the taxonomy of Upper Carboniferous non-marine bivalves is fraught with problems of preservation and usually in any sampled population, only external morphological characters can be fully examined. Hinge structures, ligament details and musclature tend to be missing or imperfectly preserved in all but the rarest of cases. For this reason, and because of their extensive morphological variability, the use of statistics in the study of these fossils is perhaps inescapable.

Much can be learned about the variation of a single measured character through the use of frequency distributions and whether that variation is unimodal or bimodal, symmetrical or skewed (Figure 3.2) can prove to be significant. However, many morphological relationships are better expressed if two measured characters are handled at a time. The scatter diagram is an example of such bivariate analysis and can be used to identify ontogenetic trends most usefully.

Davies & Trueman (1927) studied variation in exactly this way making use of frequency distributions, scatter diagrams and correlation coefficients (Figure 3.3). It was this particular method of study and their conclusion that " so wide are the limits of variation in three or four (measured) characters, that members of a species-group occurring side by side in the same band may differ to an extent which might appear to justify reference to several species, if the intermediate forms were unknown " (Davies & Trueman 1927, p. 218), which led to the special binomial system of nomenclature described later.

FIGURE 3.3a: Davies & Trueman's (1927) frequency diagrams used to illustrate the variation in communities of <u>Carbonicola</u> in the Brynamman district (continuous lines) and at Bonville's court, Pembrokeshire (broken lines).

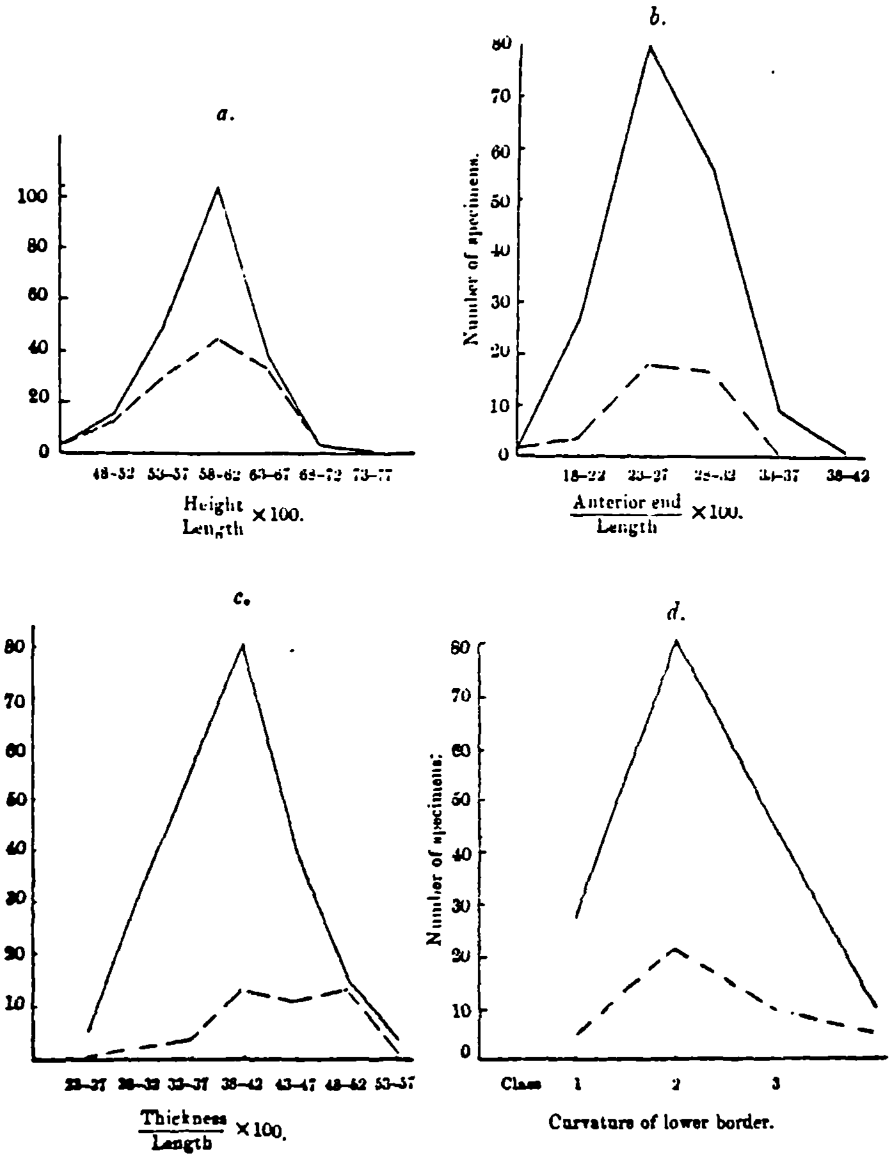
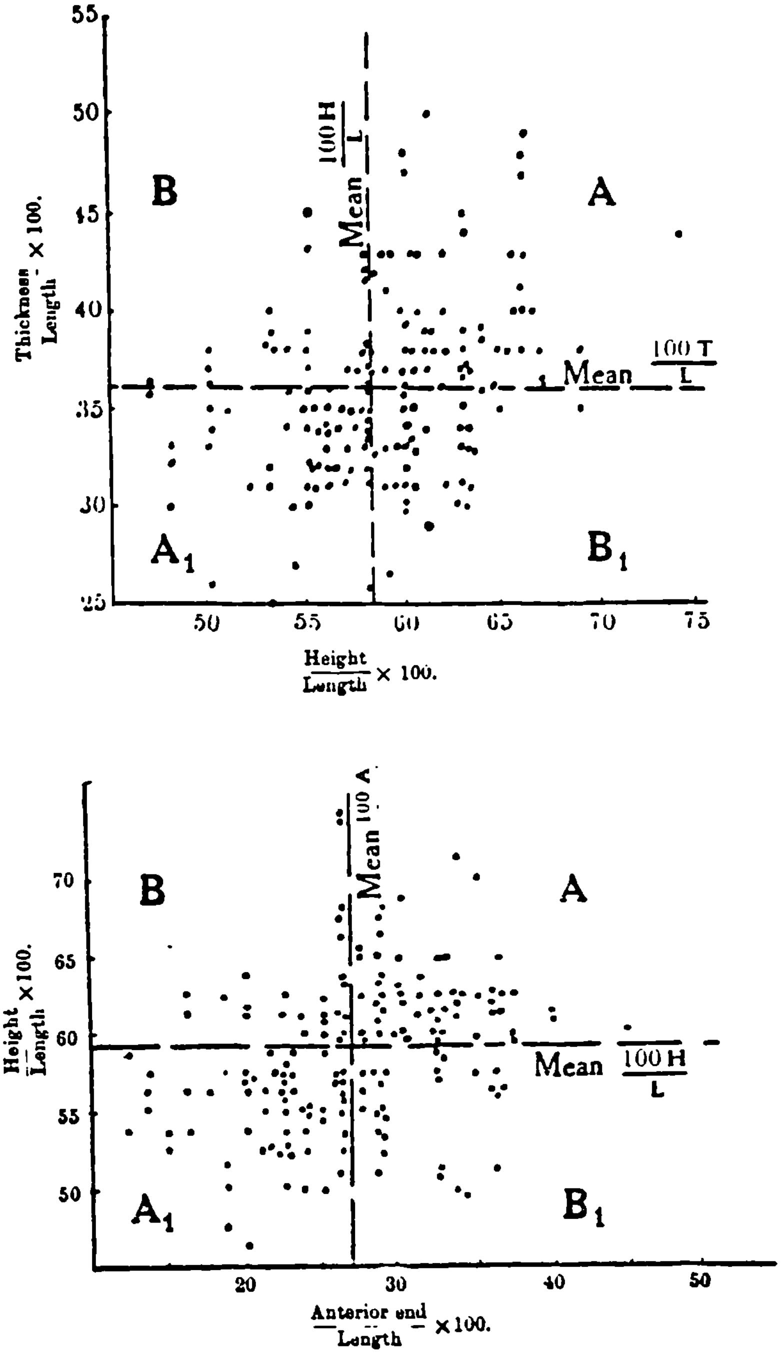


FIGURE 3.3b: Scatter diagrams used by Davies & Trueman (1927) to display the variation in an assemblage of Carbonicola from above the Lower Vein in the Brynamman district.



Other authors (e.g. Deleers & Pastiels 1947, Eagar 1947, 1948, 1951) followed similar techniques and it became common practise to express the dimensions of the type specimens and figured specimens as ratios over length.

3.3.1 Ontogenetic variation and the regression line technique.

The growth of a bivalve is allometric (Figure 3.4) and when a sampled population is measured in terms of for example height and length, the resulting scatter plot shows a similar allometric growth curve which can be said to represent the average path by which the adult form was attained. The amount of variation normally increases with growth in such a case owing to the tendency for the absolute amount of variation to be proportional to size (Imbrie 1956, p.228). The equation of such a line can be expressed mathematically as;

$$Y = bX^{a}$$

where X and Y are variates, a is the growth ratio and b is the initial growth index.

However, collecting bias more usually means that only a relatively small part of the total size range is sampled and the resulting growth line displays so little curvature or the variation is so large (or both), that the underlying allometric relationship cannot be convincingly demonstrated. Under these circumstances, the equation of the growth line can be readily approximated to that of a straight line;

$$Y = aX + b$$

where a is the slope of the growth line, b is the intercept on the Y axis, and the ratio X/Y will normally vary with growth.

In accepting this approximation there are several statistical techniques by which a straight line can be drawn through a scatter of bivariate data such that the best fit is obtained. These methods are reviewed by Imbrie (1956, pp.230-235) who argues that the Reduced Major Axis method is to be preferred over other methods in dealing biometrically with problems of relative growth.

When using regression line techniques, it is necessary to give some value of how well the fitted line 'fits' the data or a value of correlation between the two variates. The correlation coefficient (r) is a measure of the strength of linear correlation. The coefficient varies between one and zero where a value of one indicates a perfect correlation. Both positive and negative values for r may be obtained. Where an increase in one variate is associated with an increase in the other, the value is positive.

The use of regression line plots has allowed the comparison of sampled bivalve populations (e.g. Eagar 1973) and also palaeoecological studies (e.g. Eagar 1971, 1973, 1977). Collections of bivalves from an in-life or near-life position in lithologies that can be inferred to have been deposited under different conditions can be examined in this way.

Through such work, Eagar (1973) was able to formulate his two palaeoecological laws and was able to discriminate between "invading" and "established" faunas. In "invading" faunas, shells tend to be elongate, having a low H/L ratios, short anterior ends and low obesities. They characterise silty to sandy sediments commonly showing evidence of comparitively rapid deposition and episodes of turbulence. In contrast, "established" faunas are characterised by more oval shells with greater H/L ratios, longer anterior ends and greater obesities. Their shells tend to form

FIGURE 3.4.

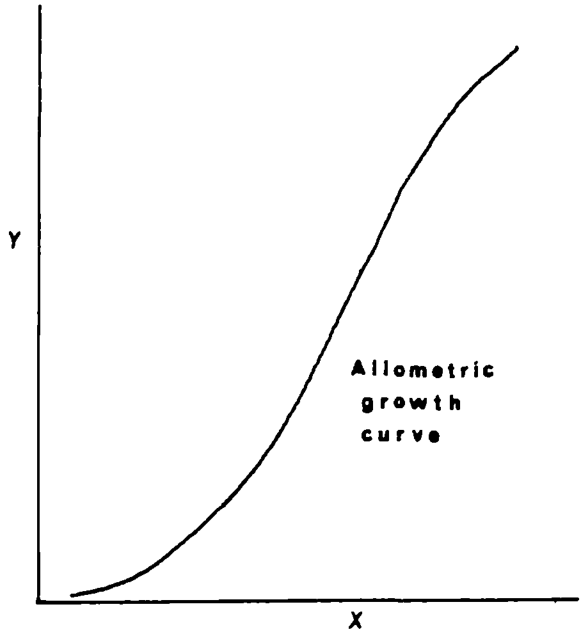
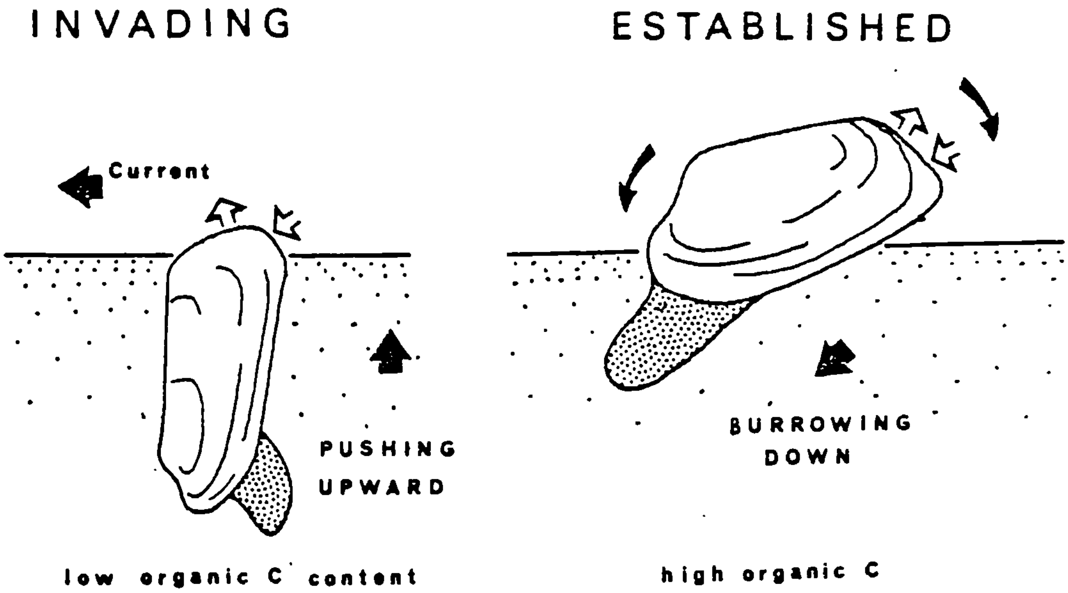


FIGURE 3.5: Eagar's invading and established faunas (Eagar 1977a)



prolific accumulations in shales and mudstones typically rich in organic carbon. In invading faunas there is commonly direct evidence of a steeply-burrowing or steeply inclined living position, whereas in established faunas, a shallow-burrowing or ploughing position has been deduced (Figure 3.5).

3.3.2. Early multivariate analysis.

Prior to the advent of computers and readily available software, nearly all the fundamental work done on shell assemblages included only bivariate analysis. An exception is the work of Leitch (1940) who worked on 55 measured shells from above the musselband Coal of the Scottish Central coalfield. In this analysis, the standard dimensions of height and length were supplemented by the addition of d and v (Figure 2d of Leitch 1940). The results of the multivariate analysis were used to express the dimensional range and pattern of the fauna in three statistically derived equations (Table 3.3).

The equations gave the best estimate of height in terms of length, v and d, so that they are representative of the variation within the assemblage. For example, an observed value of height which differs from the calculated one by more than twice the standard error of H differs significantly from its dimensional criteria. The three equations were used by Leitch to distinguish this critical fauna, referred to *Anthraconaia salteri*, from a somewhat similar one from higher measures.

More recently, Rogers (in press [1979], 1982) has outlined a method which employs the use of Tchebyschev polynomials to describe the generating curve of a bivalve with a straight hinge-line. One hundred irregularly spaced data points (x,y) are required in order to produce stable coefficients. The first six coefficients were found to be adequate to describe the outline and may be used as shape discriminators. Rogers (in press [1979]) demonstrated the method using *Naiadites* and *Curvirimula* from the

Riversdale Group of Nova Scotia. Principal components analysis was used for the first time to display the range of variation in each sampled population.

3.4. The Trueman & Weir system of nomenclature.

Any collection of Upper Carboniferous non-marine bivalves from a single horizon may prove to be statistically homogeneous and probably represents a single, potentially interbreeding biospecies.

Trueman (1924) recognised the potential stratigraphic value of these fossils believing that " a palaeontological classification *must be such that a name is available to designate* every recognisable form which characterises a horizon" (Trueman 1924). Trueman's concept was applied in Davies & Trueman (1927) who demonstrated the past existence of a series of continuously variable and potentially interbreeding populations and proposed a special system of binomial nomenclature. Later adopted by Trueman & Weir (1946), it was the subject of several later papers of a defensive nature (Leitch 1951, Eagar 1952, 1956, Weir 1968, pp.37-45).

This system of nomenclature uses generic and varietal names for individual specimens. However, later workers referred to the latter as "specific" names, a practise which often caused confusion.

The system is based on the comparison of individual specimens with types which are named and described on the basis of morphology only. The type was often chosen from a stratigraphically useful morphological variety and may have been part of a past community of reproductively isolated forms. The same community may contain other named and described morphotypes and a single presumed biospecies may contain a number of named and described morphological varieties. Using this special system; which bears no relation to the concept of biospecies, individual communities can be distinguished from one another in space and time through the recognition of morphological varieties and their relative numerical strengths. Thus, the system of nomenclature provides results which are of great value to the stratigrapher.

The use of the varietal or "specific" name was limited by Trueman & Weir (1946) to forms "practically identical" with a named morphotype and a system of figured and measured specimens was used to limit the amount of variation allowable for the varietal name to be prefixed by 'aff' or 'cf' as the case might be (Figure 3.6). The prefix 'cf' however, was used in two different ways in this system. For specimens which are "not known to be related to the holotype, although possibly showing greater similarity to it in some features, the use of the prefix 'cf' is recommended". The prefix 'cf' may also be used in naming poorly preserved specimens (Trueman & Weir 1946, p. xxi).

With the use of trinomial nomenclature and the revision of the International Code for Zoological Nomenclature (International Code 1961) in which both varietal and form names are recognised but only within a named species, the special system of nomenclature described above has become both out of date and illegal. As early as 1951, Sylvester-Bradley pointed out that the taxonomic unit in the "New Systematics" is the interbreeding population and any individual member of the community is a morphological variety. Sylvester-Bradley regarded Trueman & Weir's overlapping 'species' as chronological subspecies.

Recently the use of trinomial nomenclature has been reconsidered (Eagar in press [1979]) but for specimens practically identical with the morphotype the shorthand form of, for example, *Anthraconauta phillipsii* is substituted for the longer *A.* sp. var. *phillipsii*. For forms requiring a prefix such as 'aff', the terminology *A* sp. aff *A. phillipsii* is used. This is undoubtedly

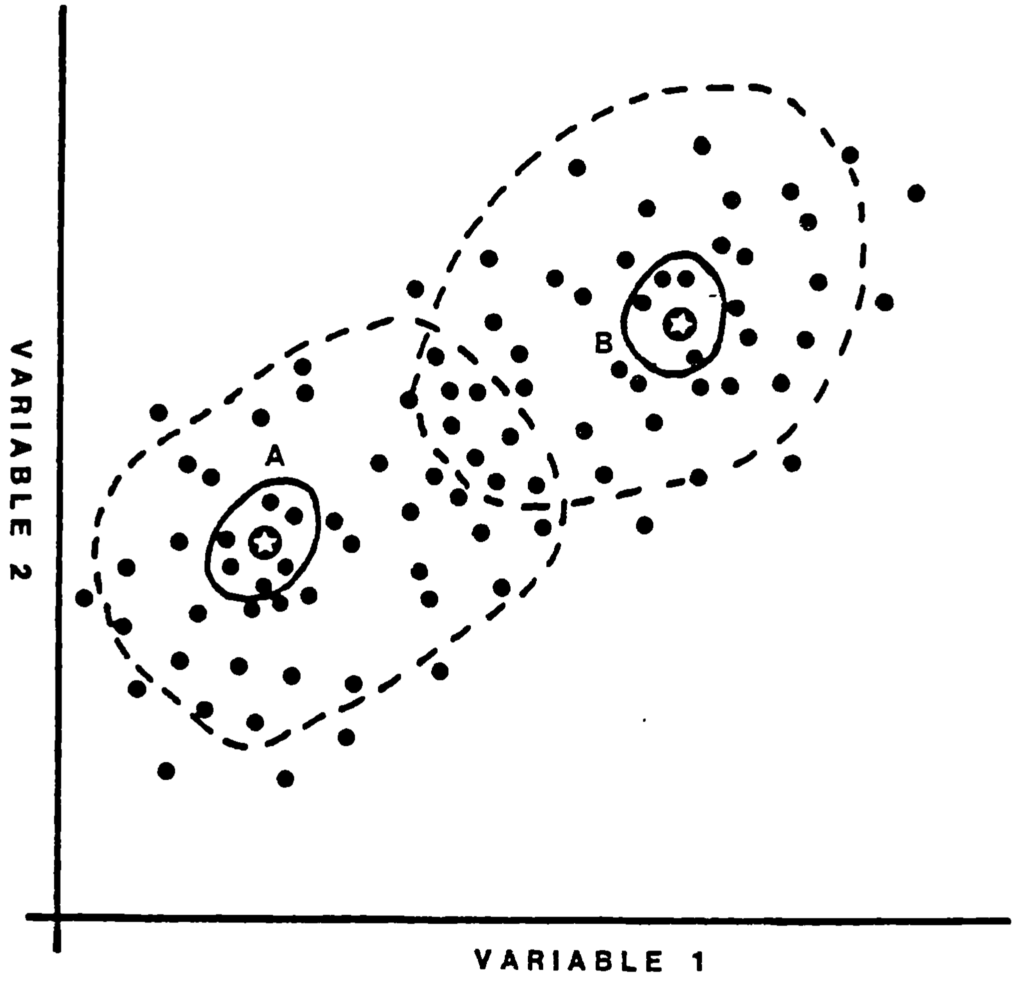


FIGURE 3.6: Trueman & Weir's (1946) diagram showing the limited amount of variation around two morphotypes ✪ for which the prefix 'aff' may be used. Note overlap.

legal, but a full revision of the system of nomenclature must inevitably take time.

3.5. The use of cluster analysis in the study of Westphalian non-marine bivalves.

Early in this study, the subjectiveness involved in the recognition of morphological varieties and the illegality of the system of nomenclature in use were recognised. To this end, a multivariate statistical technique was sought which by as objective means as possible, fulfilled the following criteria;

1. The method should be able to discriminate between groups of shells of similar external morphology to produce a phenetic classification.

2. The method should require the input of the minimum number of measurable shell dimensions.

3. It should allow the choice of a near-modal morphotype for naming and description where and when required.

4. The method should be one which allows the pictographic representation of variation within both the sampled population and within the selected morphotypes by as objective means as possible.

Cluster analysis combined with principal components analysis (PCA) was identified as such a method and a readily available software package in which several clustering methods were offered together with PCA, was used in this study (CLUSTAN, Wishart 1978).

3.5.1. Cluster analysis.

The process of clustering consists of arriving at one or more partitions of a set of objects (operational taxonomic units or OTU's in the terminology of Sneath & Sokal 1973). Reviews of the many different clustering methods and an explanation of similarity/distance coefficients may be found in Sneath & Sokal (1973), Everitt (1974) and Swann (1982).

For taxonomic purposes, an agglomerative hierarchical method is most usually used. Such a method begins with N entities and successively fuses or clusters individuals and/or groups of individuals so as to decrement the total number of entities on each successive clustering cycle. The method finally arrives at a single cluster which contains all N entities. The technique may be viewed according to Everitt 1974, as an attempt to find the most effective step, in some defined sense, at each stage in the progressive synthesis of the population. Once made, fusions are irrevocable.

All agglomerative techniques work in a similar fashion and begin with the computation of a similarity or distance matrix between the entities. Sneath & Sokal (1973, p.116) defined a similarity matrix as a "quantification of the resemblance between the elements in two columns of the data matrix representing the character states of the two OTU's in question". The end product of all the methods is a dendrogram or phenogram (where phenetic relationships are depicted) which shows the successive fusion of individuals (Figure 3.7). Appendix B describes several agglomerative hierarchical clustering methods.

3.5.2. Choice of method.

Ward's method (Ward 1963) was chosen for all analyses and the choice of this method was influenced by Swann (1982) and Wishart (1978). The other methods described in Appendix B all tend to

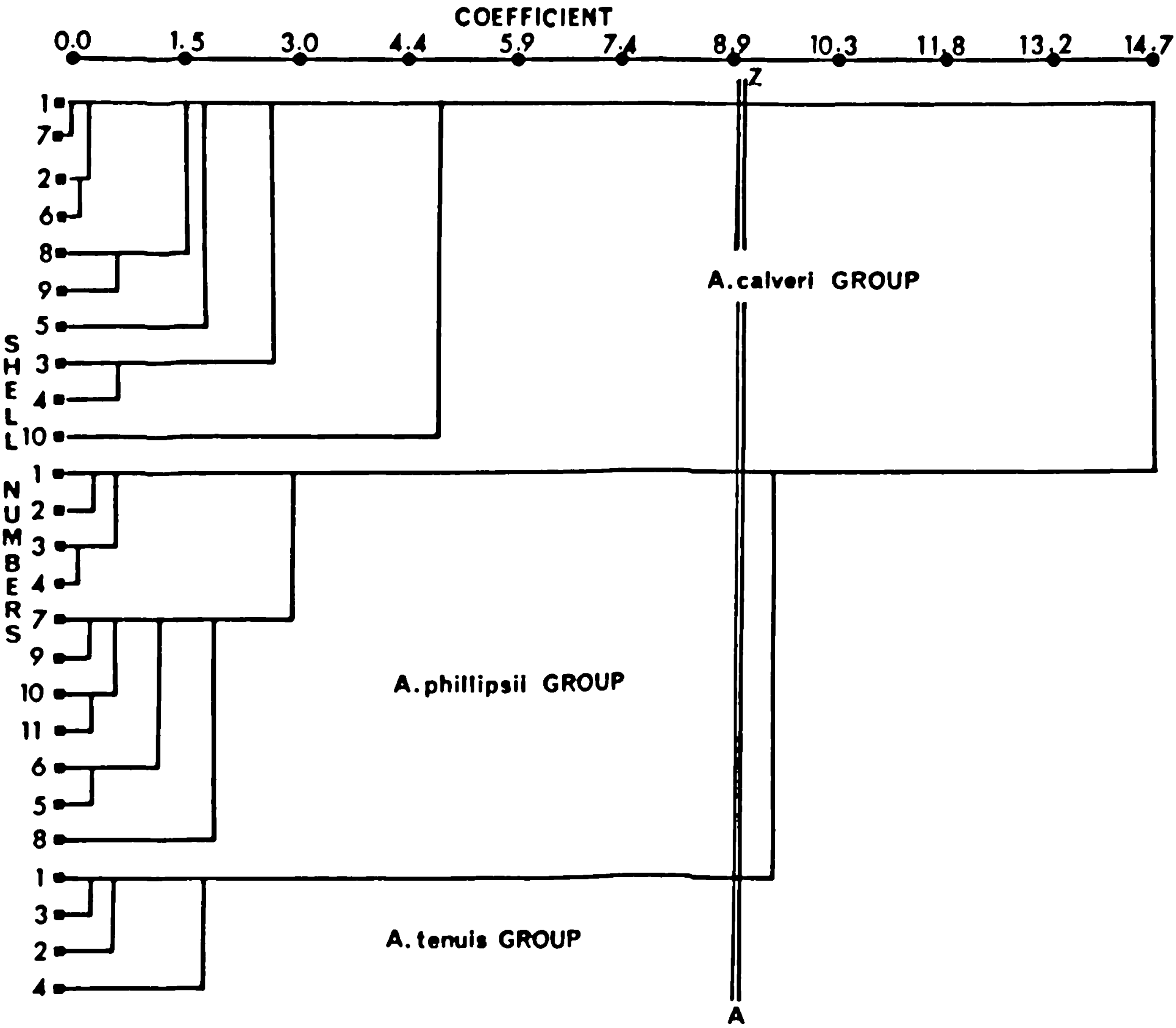


FIGURE 3.7: An example of a phenogram

have inherent faults and drawbacks whilst Ward's method gives, perhaps the best results.

3.5.3. Principal components analysis.

Following Rogers (1982), for each cluster analysis undertaken, a PCA was also run. PCA is a common ordination technique solving a symmetric correlation matrix for its eigenvectors and eigenvalues (Fordham & Bell 1978). The method has the advantage of producing a small number of components from which much greater information can be obtained than from a similar number of measured characters.

3.5.4. Application.

In order to apply cluster analysis to the study of non-marine bivalves for taxonomic or palaeoecological work, several points require consideration;

> Generic differentiation - Any classification scheme which utilises a numerical method such as cluster analysis is essentially phenetic and because of the difficulties mentioned earlier, the data set used in an analysis will not include any information regarding the internal features of the shell. For this reason, generic differentiation must proceed in the usual way through examination of the material and through comparisons with descriptions, plates and type specimens. No attempt was made in this study to utilise cluster analysis for generic classification thus, shells subject to analysis were always of the same, predetermined genus.
>
> Such a practise is considered to be realistic and practical since the aim of the exercise was to examine inter- and intraspecific variation.

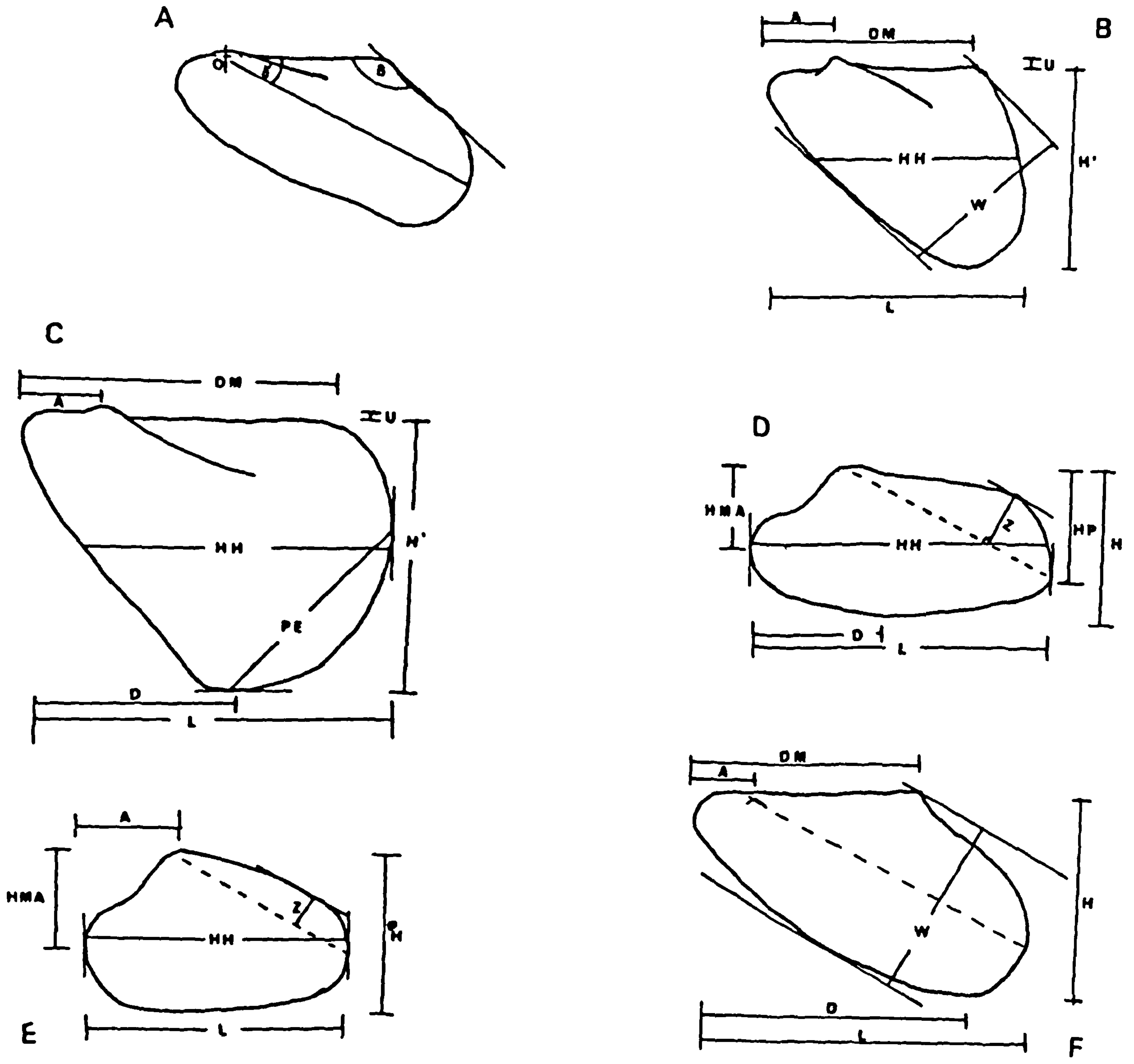


FIGURE 3.8: Measured shell dimensions and orientation (see also Table 3.5).
A - orientation of a shell for measurement and Trueman & Weirs' (1946) angular dimensions γ and β. B - Measured shell dimensions on Curvirimula, C - Naiadites, D - Carbonicola, E - Anthraconaia, F - Anthraconauta.

Preservation - For reasons that will be explained later, the use of cluster analysis due to the number of measurements required as input parameters, does not need perfect preservation. Imperfect shells on which the measured characters may be measured or reasonably estimated through careful examination of growth lines, may still be used in an analysis. Shells with ragged margins may also be utilised through measurement of the latest whole growth line, providing the point of origin of growth (Figure 3.8) can be accurately determined.

A problem is encountered in the analysis of both crushed and uncrushed shells where the obesity of the uncrushed shells is large. This problem was not fully investigated however, most Nova Scotian shells are either crushed or partially crushed such that this problem did not arise or was considered to affect the measurement of characters by only a small amount.

Care must be taken at all times to ensure that the shells were not subject to strain such as would result in deformation (e.g. Raup & Stanley 1978, p.75).

Orientation of shell for measurement - Before a bivalve can be accurately measured it must be correctly orientated. Following Rogers (in press [1979], 1982) the shells were positioned with their straight dorsal margins horizontal (Figure 3.8).

Measurement technique - All measurements were taken from drawings produced with the aid of a Wild microscope and camera lucida attachment at low magnification (X6.4) and are subject to a slight distortion (1 %). A graduated calliper was used to measure the drawings and measurements were made to the nearest 0.1 mm. Measurement was found to be accurate to well within 1 mm which is considered to be within the desired range.

Selection of shell dimensions for measurement - Originally as many as 24 measurable characters both linear and angular, were measured on each shell or valve. A correlation matrix of the characters was generated for each of the genera and scrutinised for interdependency (e.g. Table 3.4). Character measurements were systematically rejected on this basis to arrive at a set of near-uncorrelated characters (see Sneath & Sokal 1973). In view of the high correlations found to occur between angular and linear shell dimensions (Table 3. 4), all angular shell dimensions were rejected from consideration. The shell dimensions used for each genus varied according to the overall morphology of the shells (e.g. the depth of the anterior lobe is important in Anthraconaia but not in Anthraconauta - Figure 3.8 and Table 3.5).

Ontogenetic variation - In order to eliminate the effects of ontogentic variation as far as possible, all measurements were expressed as ratios over length and obvious juveniles were not considered. This simple method of size/growth stage elimination was mentioned by Sneath & Sokal (1973, p.170) and investigated by Fordham & Bell (1978, p.131) who found that size was "indeed eliminated" in this way.

An alternative method involves the input of the parameters as measured without recourse to ratios. The first principle component is then considered to represent growth stage/size variation and is removed from consideration. This method undoubtedly removes the unwanted size/growth stage variation but probably also removes an unknown amount of morphological variation as well thus, this method was not used in favour of the simpler ratio technique.

Minimum number of individuals which may be used in an analysis - Cluster stability to some extent depends on the

TABLE 3.4: An example of interdendency of variables (in this case - <u>Anthraconauta</u>)

	H/L	A/L	DM/L	D/L	W/L	α	β	X1/L	X7/L	X17/L
A/L	+		+	+	+	+++	+++	+++	++	+++
DM/L	+	++		+	+	++	+++	++	++	+++
D/L	+	+	-		+	++	++	++	++	++
W/L	++	+	++	-		+++	+++	+++	++	+++
α	+++	+++	++	++	+++		++	++	+++	++
β	+++	++	+++	++	+++	++		++	++	++
X1/L	+++	++	++	++	+++	+++	++		+++	+
X7/L	+++	+++	++	+++	++++	++	+++	+++		+++
X17/L	+++	++	++	++	+++	++	++	+++	+++	

SIX LINEAR SHELL DIMENSIONS USED IN ANALYSES = L, H, A, DM, D & W.

+/- = low correlation (0.0-0.30), ++ = moderate correlation (0.3-0.65)

+++ = high correlation (0.65-1.00). X_1-X_{17}/L are measurements of lines drawn from the umbo to the shell margin at 10° intervals.

TABLE 3.5: Measured shell dimensions and phenon-line for each genus.

GENUS	LINEAR SHELL DIMENSIONS	PHENON-LINE LEVEL
CARBONICOLA	L, H, A, HMA, D, HH, HP, Z	6.5
NAIADITES	L, H , A, DM, D, HH, U, PE	6.5
CURVIRIMULA	L, H , A, DM, HH, U, W	9.5
ANTHRACONAIA	L, H, A, HMA, Z, HH	6.5
ANTHRACONAUTA	L, H, A, DM, D, W	10.5

EXPLANATION:

L = Total length of the shell measured at a right angle to the straight dorsal margin (or to a horizontal tangent taken of the point of maximum depth on the ventral margin.

H- Maximum height measured at a right angle to L.

A-Length of the anterior end measured parallel to length.

HMA-Height of anterior end. ie Length from dorsal margin to point of maximum anterior protrusion (see. *Figure 3.8) measured perpendicular to length.*

D-Length from anterior end of shell to point of maximum downwraping of the ventral margin (cf. Leitch's 'd' (1940).

HH-Length of shell measured at half height.

U-Height of the umbone(s) measured parallel to Height.

PE-Measured length from maximum downwarped part of ventral magin to point of maximum posterior extension (see Figure 3.8) to represent a measure of posterior expansion.

DM-Length of the dorsal margin measured parallel to length.

W-Width of the shell. Distance between two tangents drawn parallel to the angle (Figure 3.8).

HP-As HMA but for posterior.

Z-A measure of the sloping of the dorsal margin found by measuring the distance shown in Figure 3.8. (*Carbonicola* and *Anthraconaia)* number of individuals used in an analysis. When too few individuals are clustered (e.g. less than 15), then those individuals placed on the peripheries of clusters may in fact be unstable. The addition of further individuals results in the replacing of a few previously positioned individuals. This probably occurs as the variation in the sampled population is not fully represented by the small number of individuals used in the analysis. The addition of further individuals allows gaps to be filled thereby increasing the error sum of squares value (Appendix B) of the cluster and thus, enabling some of the peripherally placed individuals to be more suitably placed.

The maximum number of individuals that can be used in an analysis is only limited by the capabilities of the software package.

3.5.5. The display and assessment of results.

The results of cluster analysis are displaced in the form of a phenogram (Figure 3.7). The phenogram is divided into clusters by means of the selection of a phenon-line (Sneath & Sokal 1973) the positioning of which is left to the operator. In this study the phenon-line was placed at an error sum of squares value (or similarity level) so as to divide the phenogram into a number of clusters which represented morphological varieties. The phenon-line was therefore placed differently for different genera as the number of morphological varieties recognised in each genus varies according to their stratigraphic usefulness. Table 3.5. shows the error sum of squares levels used for each genus.

The positioning of the phenon-line was also governed by the need to identify stratigraphically useful morphological varieties and to identify new morphological varieties. In order to find the error sum of squares level for each genus, a series of analyses were made using test data (usually measurements of the plates in

Trueman & Weir (1946-68)). Once obtained, the same phenon-line was used in each analysis of shells assignable to the same genus.

The phenogram is a two-dimensional representation and much information is lost. Sneath & Sokal (1973) recommend the combined use of phenograms and PCA plots. PCA plots show the variation of the shells in three dimensions and can be produced either as stereopairs (Figure 3.9) or as a two-dimensional representation (Figure 3.10). In this thesis, both the phenogram and PCA plot are reproduced in Appendix A.

Previous work on these faunas has made much use of the pictograph (Leitch 1951, Eagar 1953, 1964 and 1973, Broadhurst 1959, Bless & Pollard 1973). Pioneered by Leitch (1951) and further developed by Eagar (1972), the pictograph was intended as a means of description and used to supplement biometrical work. At its simplest, the pictograph shows the relationship between shells. To some extent however, admittedly - by all users of it - it is a subjective procedure, individual workers compiling pictographs according to their own experience. Eagar (1972) has defined the pictograph and loosely defined certain rules for their construction, but the pictograph as used previously must always be subjective.

The use of cluster analysis and PCA however, allows the construction of objective pictographs in that given the same results, any worker would construct the same pictograph. These reproducible pictographs are constructed through the combined use of a phenogram, which links the most similar individuals in an analysis and a PCA plot, which shows variational trends in terms of the measured characters. Thus, the pictograph remains an ideal way of illustrating variation within a sampled assemblage and is here produced by placing drawings of the shells in their relative positions on a two-dimensional PCA plot and linking the most similar by inspection of the phenogram.

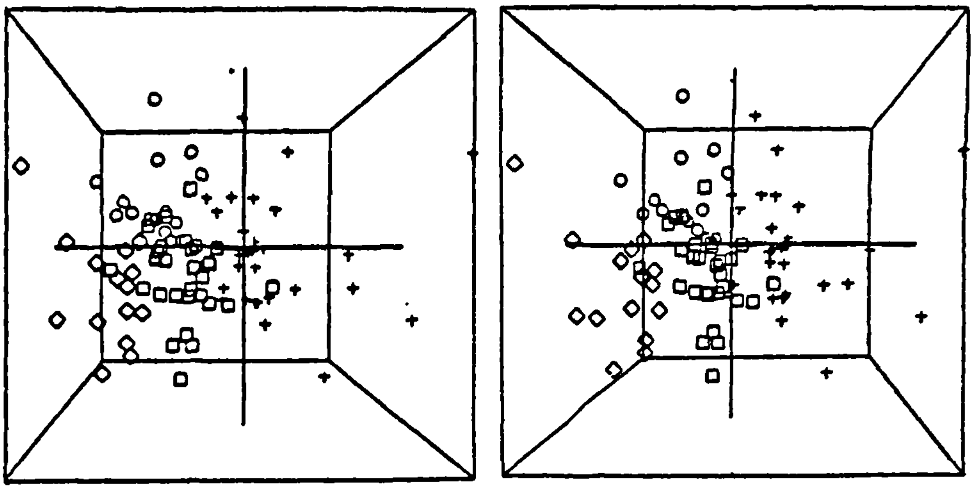


FIGURE 3.9: An example of a PCA plot produced as stereo-pairs.

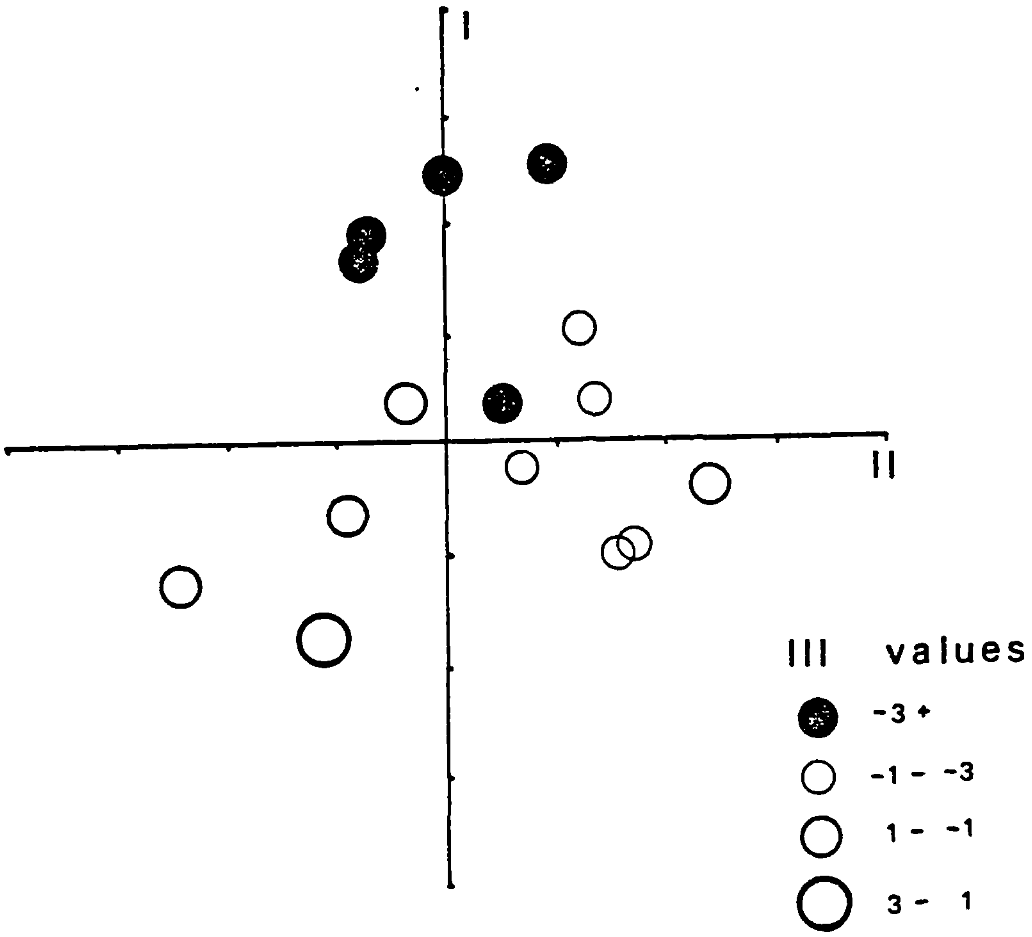


FIGURE 3.10: An example of a two-dimensional representation of a three-dimensional PCA plot.

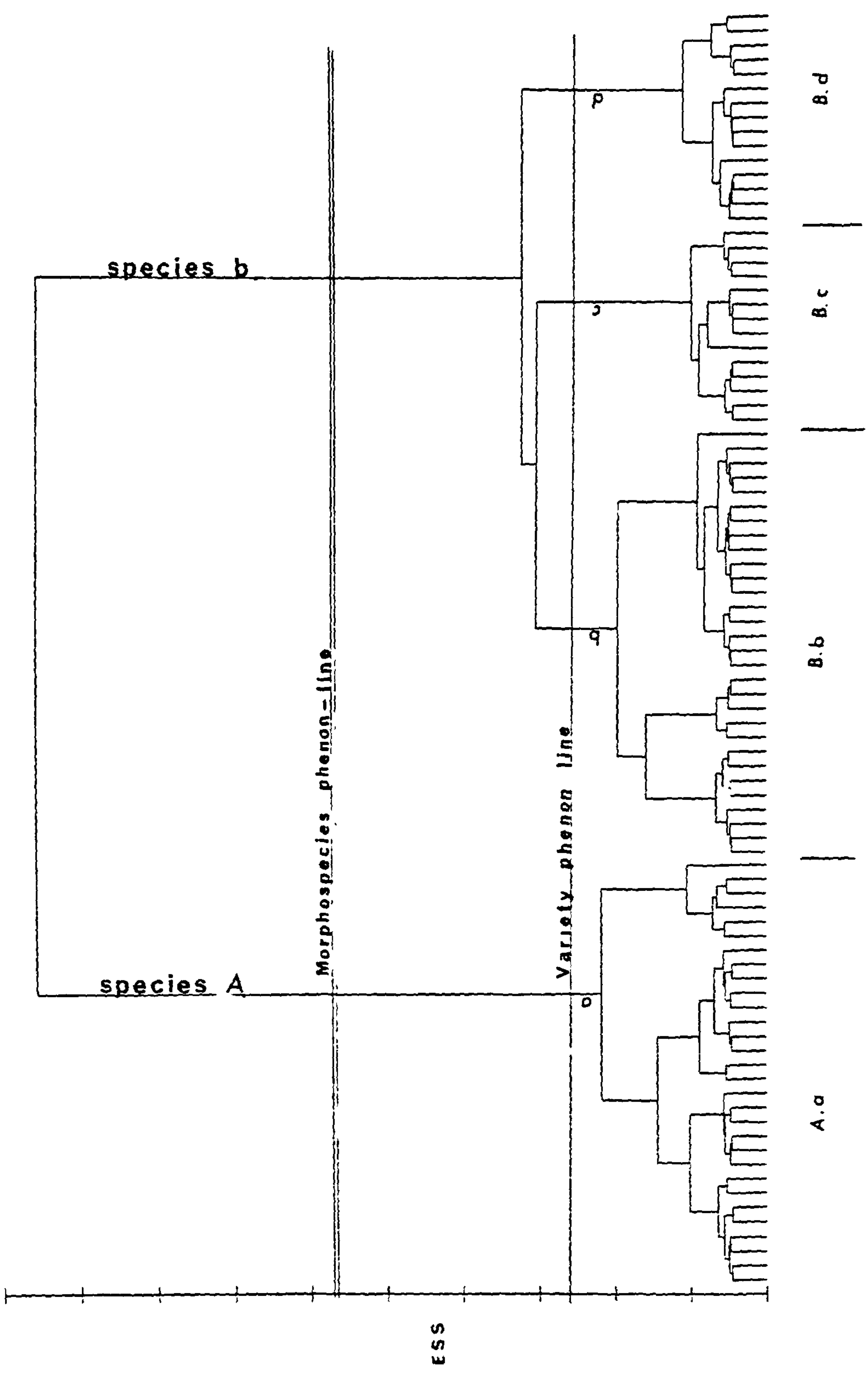


FIGURE 3.11: Phenogram split into morphospecies and morphological varieties by the use of two phenon-lines.

Utilised in this way, the results of cluster analysis combined with PCA can provide systematic and stratigraphic information. The clusters produced represent morphological varieties and intracluster variation can be readily assessed. Furthermore, a new morphological variety brought to light by this method can be adequately described through statistical, descriptive and pictographic means. Morphotypes can be selected from the mode of a cluster.

Should cluster analysis be performed on shells from different stratigraphic levels, then the morphological varieties present and their relative numerical strengths can be rapidly assessed providing results of potential stratigraphic importance.

3.5.6. Trinomial nomenclature.

There are two ways in which this numerical approach to taxonomy may allow the timely introduction of trinomial nomenclature. Neither of these methods have been utilised in the present work as it was felt that work should take place on classic British material first. Such work is in progress using Leitch's (1940) classic Anthraconaia salteri assemblage (Eagar & Vasey, in prep.).

The first method would simply involve the introduction of another phenon-line on the phenogram. As before a phenon-line would be inserted at a reasonably high similarity level in order to divide the phenogram into clusters considered to represent morphological varieties. A second phenon-line would then be inserted at a somewhat lower similarity level to divide the phenogram into a number of clusters which would be considered morphological species (Figure 3.11). Such a method is outlined by Sneath & Sokal (1973, pp. 294-6).

An alternative method would be to use the principle that a biospecies is statistically homogenous. Thus, the biospecies present in the sampled assemblage would be identified prior to cluster analysis through the use of bivariate and univariate statistical tests. Such a method may not be workable in reality, particularly if the two biospecies overlap statistically in several measured characters (Figure 3.12).

Whichever method were to be used, work should proceed with extreme care allowing for the fact that there are many problems involved (e.g. no data on internal characters, homeomorphy and so on).

3.5.7. The analysis of ecological data.

In order to attempt an assessment of shell-shape changes associated with changes in the palaeoenvironment (e.g. see Eagar 1978), PCA was used. In these analyses, the same measured shell dimensions were used as morphological parameters however, a further parameter(s) was added to reflect change in the environment.

Increased sedimentation rates and current activity are reflected by coarsening and a decrease in organic carbon-content of the sediment. A host of other sedimentological data such as cross-lamination and sole marks may be used as additional evidence for these environmental changes. Evidence may also be gained through examination of the fauna itself (disarticulation, fragmentation) (Eagar 1960). In order to attain some approximate measure of these palaeoenvironmental changes a value was given to grainsize (Table 3.6) or to the colour of the lithology (reflecting organic carbon-content).

Eagar (1973) has shown that the greyness of a lithology obtained by matching shades of grey on the U.S. Geological Society of America Rock-color Chart (1980) approximates the amount of organic carbon in a shale.

TABLE 3.6: Grainsize codes used in PCA analyses.

1	Sandstone
2	Muddy sandstone
3	Siltstone/ silty shale
4	Muddy siltstone
5	Mudstone/Muddy shale
6	Claystone/Clay shale

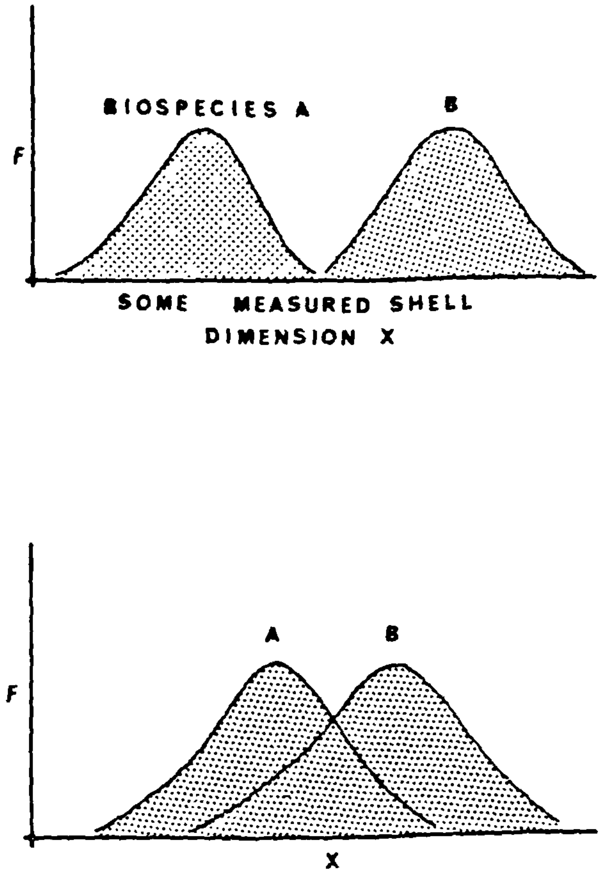


FIGURE 3.12: Overlapping biospecies.

Usually, grainsize and 'greyness' of a sediment display a high degree of interdependence such that a coarser shale is paler in colour and vice-versa. As the amount of clastic material entering a lake increases then the relative proportion of organic material decreases. In this case one of the environmental measures will adequately suffice and more usually 'greyness' was chosen as it is a less arbitary measurement (with set standards). However, in instances where the colour and grainsize of the lithologies did not correlate, both measures were used.

It is recognised that both of these measures are rather approximate however, when taken with other lines of evidence such as those measured earlier, they serve as a useful indicator of the palaeoenvironment in which the faunas lived. It is crucial that the sampled population be an in-life or near-life assemblage in order for the morphological changes observed to be considered phenotypic or caused through natural selective processes (or both).

With the input of this further parameter, a PCA plot shows certain shell-shape trends along with the general trend of the palaeoenvironment (e.g. towards heavier and coarser sedimentation and increased current activity - see Appendix A). A form of a pictograph may be constructed from which the overall morphological trends and that of the palaeoenvironment may be observed (e.g. Figure 7.5). The results of such analyses have shown much agreement with the findings of Dr. Eagar (Chapter 7).

3.6. Associated Coal Measures faunas.

Bivalves are the most important element of Coal Measures faunas for both stratigraphic and palaeoecological work except in some intermontane basins, where they may be scarce or even absent. Other elements of the fauna such as ostracodes (Pollard 1966, 1969, Bless & Pollard 1973), arthropods, fish and vertebrates may be of value in a supportive role (Calver 1968a).

3.6.1. Arthropods.

Ostracodes occur both in bivalve-bearing beds and separately in cannelly shales to calcareous beds. In Britain two genera of ostracodes are important in the Coal Measures; Carbonita and Geisina. Geisina is commonly found in association with marine bands and was probably tolerant of near-marine conditions (Pollard 1966, Calver 1968a). The species Geisina arcuata is characteristically found in the Westphalian A but is generally absent in higher Measures, reappearing only in association with marine bands.

Carbonita ranges throughout the Coal Measures and is rarely found associat-ed with marine fossils probably preferring a less saline habitat (Pollard 1966, p.676). There is some evidence that different species of Carbonita were restricted ecologically (Pollard 1966, 1969, Bless & Pollard 1973) and stratigraphically (Anderson 1970). However, most workers consider Carbonita to be of little stratigraphic use. It is possible that Carbonita was more sensitive to environmental changes than some genera of bivalves allowing their use in a supportive role (e.g. Eagar, in prep [1983]).

In Nova Scotia, Carbonita is common throughout the Coal Measures occurring with or without bivalves in finer-grained lithologies. Geisina however, is known only from a single locality in the Riversdale Group and was reported by Copeland (1957) as "Sansabella reversa".

Conchostracans, such as 'Estheria' and Leaia, occur in the British-European paralic Coal Measures. 'Estheria', a name broadly applied to a group of conchostracans, have tolerated a wide range of conditions though it is probable that different forms had slightly different ecological and stratigraphic ranges

(Raymond 1947, Copeland 1957). Modern conchostracans, such as *Cyzicus* inhabit the bottoms of pools and shallow lakes on all the main continents, obtaining their food by filter feeding (Calver 1968a).

The carapaces of '*Estheria*' occur in a variety of sediments, but are most common in canneloid or carbonaceous rocks (*Ibid.*). There is a tendency for these fossils to occur at discrete horizons for which reason they are often of local stratigraphic use and may correspond to marine bands (Ramsbottom *et*. *al*. 1978).

Leaia (which differed from '*Estheria*' mainly in the presence of two or three radial carinae) is characteristically a later Westphalian fossil, though it occurs sporadically in the lower parts of the Westphalian. Revision of the Leaiadidae attempted by Raymond (1947) and Novojilov (1958) resulted in numerous genera being proposed for the species previously referred to *Leaia* on the basis of surface ornament.

Other arthropod fossils such as *Prestwichinella* and less commonly, *Pygocephalus* and *Arthropleura* occur sporadically in the Coal Measures. *Anthrapalaemon* and *Pygocephalus* often occur in mussel-bands (Calver 1968a), commonly accompanied by ostracodes and fish remains. Frequently occurring tracks and trails have been associated with *Arthropleura* which is thought to have been terrestrial, rather than an aquatic form by Van Der Heide (1951, p.44).

3.6.2. Serpulid worms.

Spirorbis sp. is the only worm definitely known from the Coal Measures (Calver 1968a). The coiled tubes are consistently present in the main mussel-bands attached to non-marine bivalves, commonly on shells of *Naiadites* and *Anthraconauta* and rarely on *Anthraconaia*, *Curvirimula* and *Carbonicola*. *Spirorbis* sp. is also locally found attached to plant debris and to locally firm, calcareous substrates.

Trueman (1942) summarised evidence for regarding the association of *Spirorbis* with certain bivalves as a commensal relationship offering the worm a firm anchorage as well as feeding advantages from inhalent water currents.

Spirorbis sp. appears to have a wide salinity tolerance occurring rarely with marine fossils and has no value as an environmental indicator although its common association with certain genera of non-marine bivalves may be of significance with regard to the bivalves mode of life.

3.6.3. Fish and other vertebrates.

Fish remains are common throughout the Coal Measures and most often occur in form of isolated scales and teeth. They are of little use either stratigraphically or palaeoenvironmentally. Fish may however, have provided the means for the propagation of non-marine bivalve communities. The modern mussel is propagated in the gills of fish (Eagar 1977b) and in the absence of other obvious means of propagation in the Carboniferous, it is suggested that this may well have been a suitable propagatory mechanism.

Vertebrates such as primitive amphibians and pelycosaurs are known from the Coal Measures but little is known of their stratigraphic range or indeed, palaeoecology. In Nova Scotia, several amphibian fossils have been found in upright sigillaria fossil tree stumps (Carroll 1967) where they appear to have been trapped by sudden sediment influx.

CHAPTER 4

FAUNAS OF THE RIVERSDALE GROUP

The Riversdale Group defined by Bell (1944), has already been described in general terms in Chapter 2. More detailed descriptions of the local successions are given in this Chapter. Coal reserves for each of the areas are given in Figure 4.1.

Faunas are described from each locality in turn and shell variation is discussed in general terms. Brief interpretations and some correlations based on homotaxy are suggested were appropriate, though these are considered in greater detail in Chapter 7.

4.1. Faunas of the Boss Point Formation (Riversdale Group).

A small section of the Boss Point Formation was examined for fauna along its type section on the east coast of Chignecto Bay, north of Lower Cove (Figure 4.2.). The Boss Point Formation is considered to be of Westphalian A age on palynological (Barss, in Belt 1965), macrofloral (Bell 1944) and faunal grounds (Copeland 1957, Rogers 1965) and according to Copeland (1959) passes conformably upwards into the Cumberland Group of Joggins.

Logan (1845) was first to note the presence of several shell beds in the section between South Reef and Dogfish Reef (Logan's Division 6, see Figure 4.2) which represents the upper part of the Boss Point Formation. Figure 4.3 shows Logan's measured section (Logan, in Poole 1908) which comprises thick fining-upward channel sandstones, crevasse splay sandstones, floodplain and lacustrine deposits, and thin coal seams. Thick crossbeds, pebbly sandstones

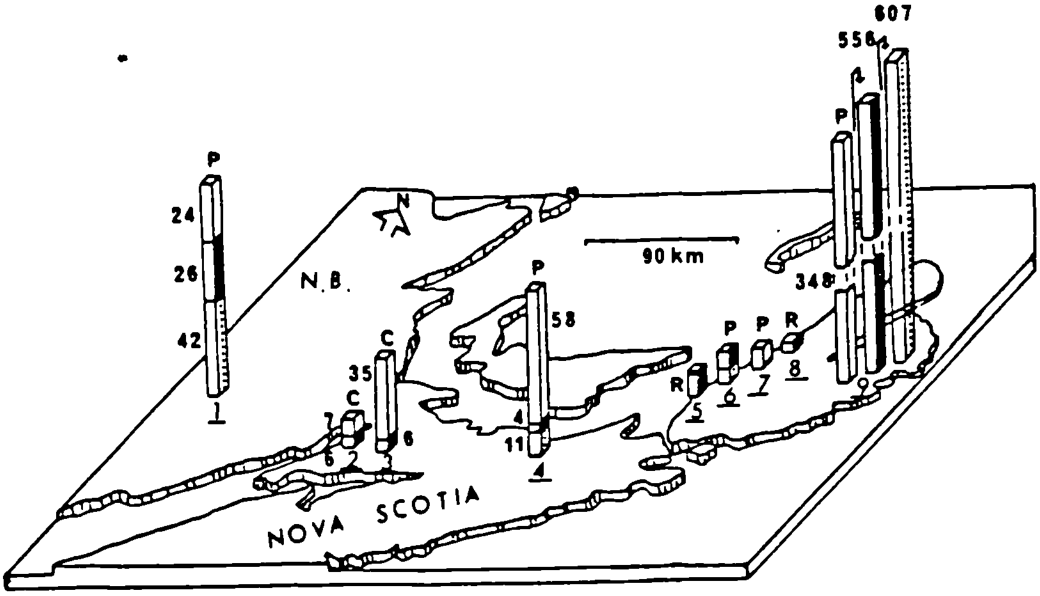


FIGURE 4.1: Coal reserves in Nova Scotia.
∴ - already mined, ■ - proven reserves, ☐ - calculated resources. *1* - Moncton coalfield, *2* - Joggins - Chignecto coalfield, *3* - Stellerton coalfield, *4* - Pictou coalfield, *5* - Port Hood coalfield, *6* - Inverness, *7* - Mabou Mines, *8* - Chimney corner - St. Rose coalfield, *9* - Sydney coalfield. Figures in Tonnes. R - Riversdale Group coals, C - Cumberland Group coals, P - Pictou Group coals. (From Hacquebard, 1979).

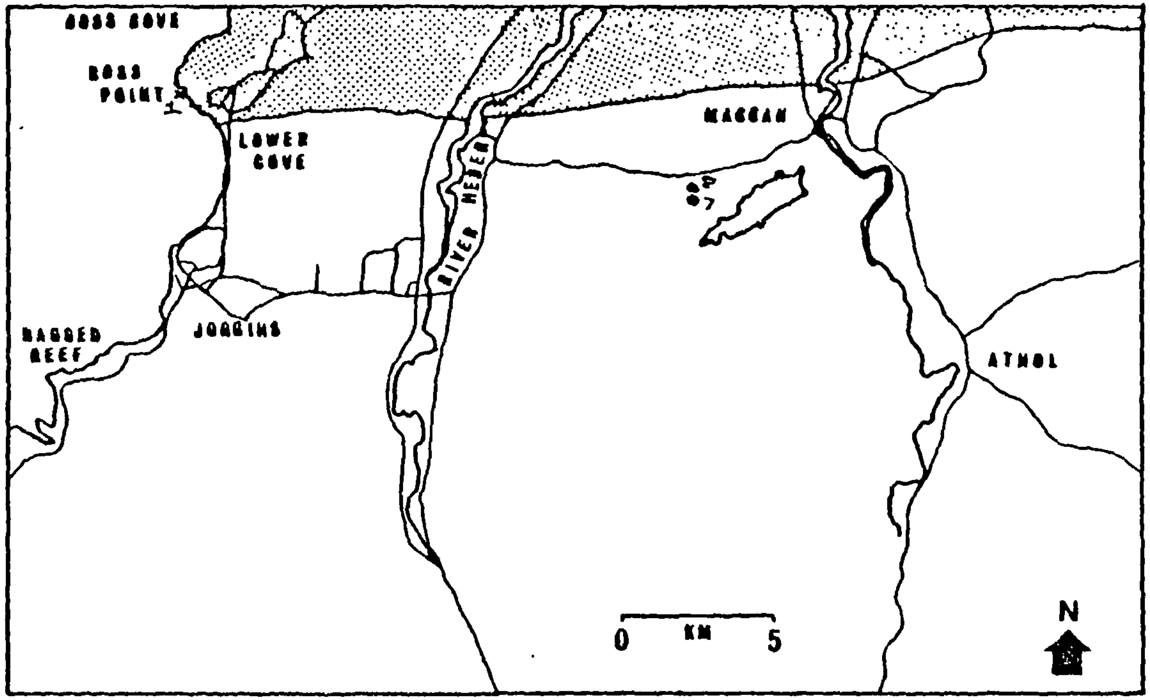


FIGURE 4.2: Sketch map of the Joggins-Boss Point area. Shaded areas repesent the Boss Point Formation, all other area = Cumberland Group. • BOREHOLE.
X ~ LOCALITY.

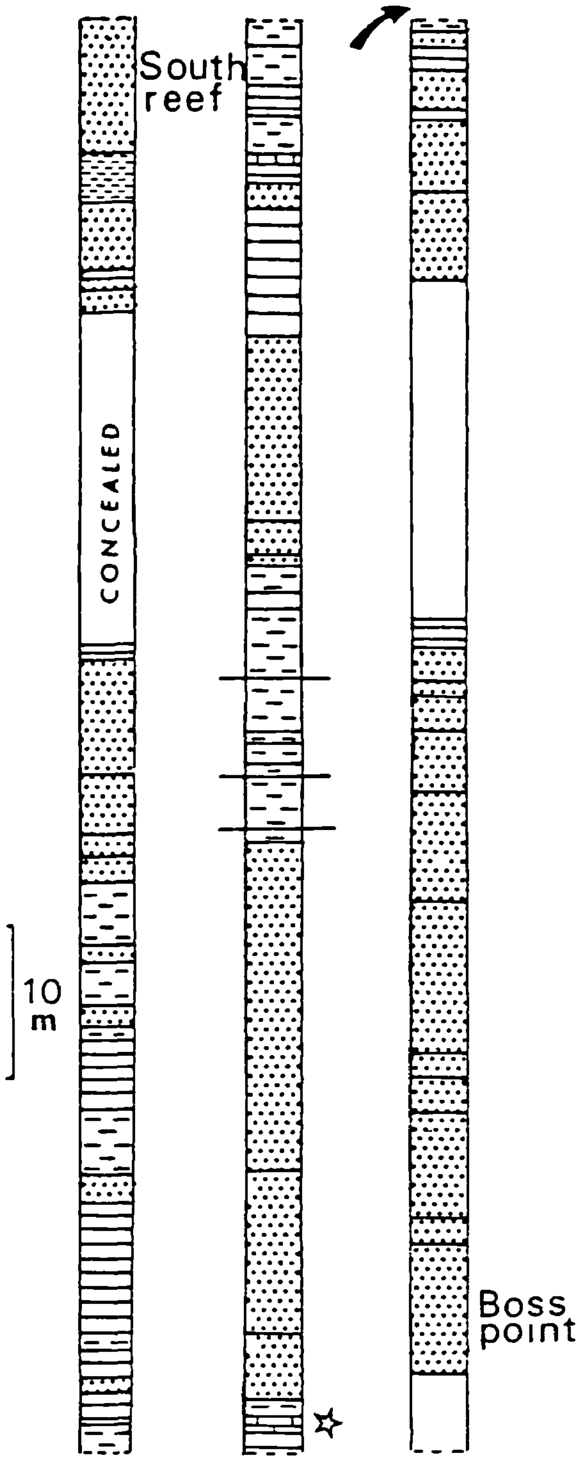


FIGURE 4.3: Logan's section of his Division #6 of the Chignecto shore section (from Poole, 1908). Represents the section from Boss Point to South Reef. Star represents location of Carbonicola? eagari Bed.

and channel thicknesses are suggestive of large, deep meandering rivers.

Lakes of local extent formed on the floodplain through differential subsidence and/or a rise in the level of the water table. Others may have formed through channel abandonment. Crevasse splays built out onto floodplain areas and rarely, into lakes. McCabe & Schenk (1982) gave the ratio of floodplain deposits to channel sandstones as 80:20 in the Boss Point area.

4. 1. 1. A Curvirimula spp. fauna at Dogfish Cove.

A thorough search of the Dogfish Cove area (Figure 4.2) failed to locate a thin, black Curvirimula-bearing carbonaceous shale documented by Logan (in Poole 1908, p., 488) and Rogers (in press, [1979], p. 9). According to Rogers (ibid.) the fauna occurs 141 m above the base of the Boss Point Formation as defined by Bell (1944). A measured section is given in Rogers (in press, [1979]).

A complete description of the fauna and its environment may be found in Rogers (ibid.) who referred the shells to Curvirimula sp. cf. C. belgica (Hind) and C. sp. cf C. tessellata (Jones).

4. 1. 2. A new Carbonicola fauna from Boss Point.

Laming & Lawson (1963) recorded the occurrence of Carbonicola in thin lacustrine beds of the Boss Piont Formation and this may be the first report of Carbonicola from the Riversdale Group of Nova Scotia. Rogers (1965) gave descriptions of two of Dawson's 'species', Carbonicola bradorica and C?. angulata , and described a further variety as C. sculponeata, all from the Canso Group.

A shell-bearing horizon was located at grid reference 651875 (sheet 21H/9W) just south of Boss Point approximately 720 m above the base of the Formation. Here a thin lacustrine sequence of thin coal and overlying intercalated calcareous silt and muddy shales and medium grey (N3-4), muddy limestones occurs between two thick channel sandstones (Figure 4.4).

Shells occur as articulated open and closed valves lying parallel to bedding and are associated with abundant ostracodes identified as Carbonita altilis, C. cf. claripuncata and C. bairdiodes. Common spirorbids and fish remains occur. Shelly material is not preserved and preservation is as internal and external moulds.

On the basis of external morphology, which is undoubtedly anthracosiid (see Trueman & Weir, 1946, systematic part of this thesis), the moulds and impressions are either of Carbonicola M'Coy or Anthracosia King. However, no internal or ligament details having been seen and as Anthracosia has not been previously reported in North America, the shells were provisionally referred to Carbonicola?. The shells, which are smaller than comparable British specimens of Carbonicola (cf. Rogers 1965), are subrectangular to subovate, fairly tumid and may represent a single biospecies.

A total of nineteen measured valves were clustered (Appendix A) into two groups on the basis of external morphology. The Nova Scotian shells are most similar to Carbonicola venusta Davies & Trueman of the British lower Modiolaris Chronozone but are much smaller (Figure 4. 5) with a lower H/L ratio. Moreover, they have a shorter, lower anterior end than C. venusta and are therefore in part, referred to to a new morphospecies, Carbonicola ? eagari sp. nov.. A small group of shells (Figure 4. 6a) separated out by cluster analysis show some degree of simmilarity to C. sculponeata Rogers but have a much shorter and lower anterior end, smaller umbones and a tendency towards a convex ventral margin. The shells in this cluster are provisionally referred to C?. sp. cf. C. sculponeata in view of the small number of shells available for study.

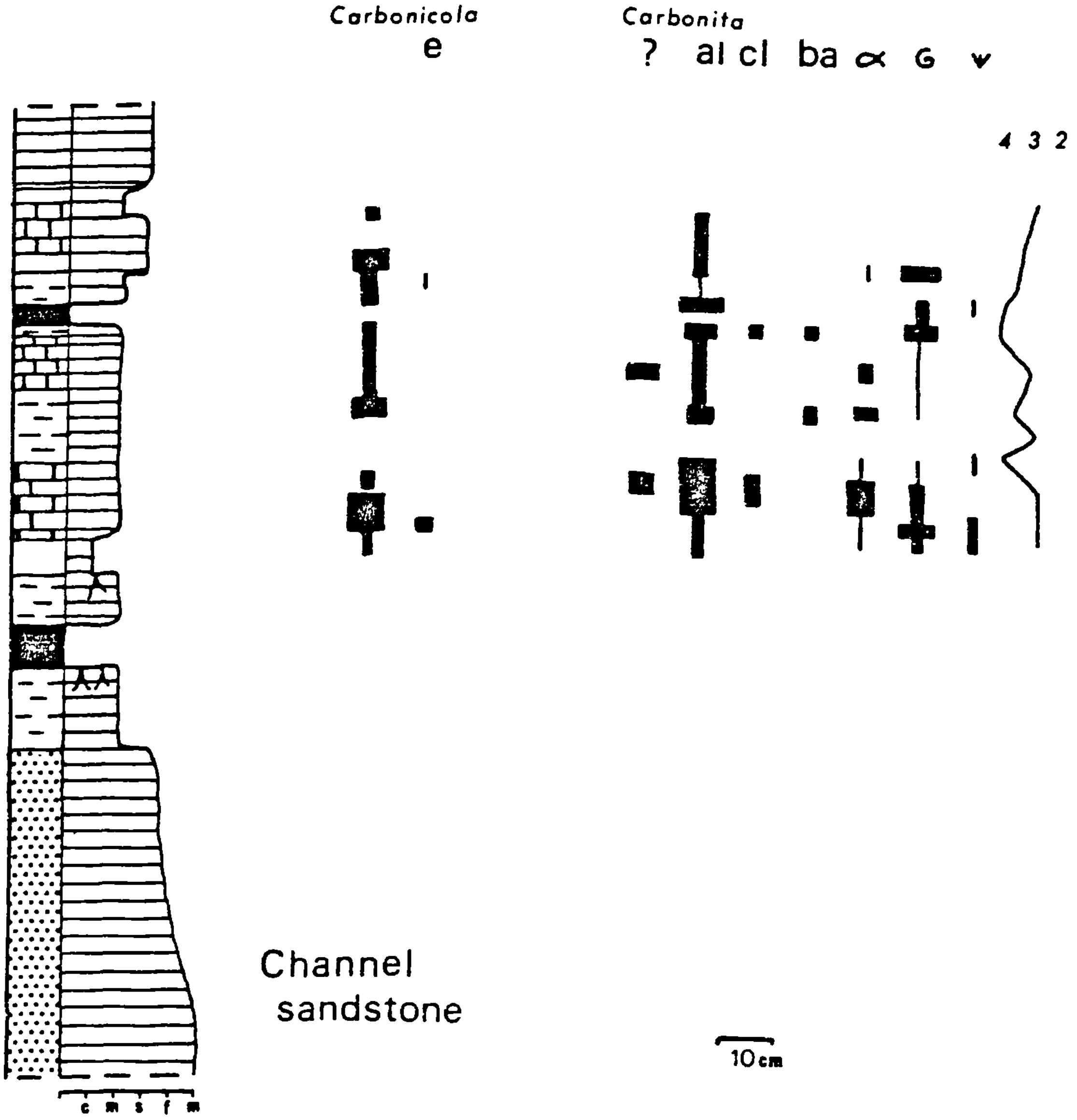
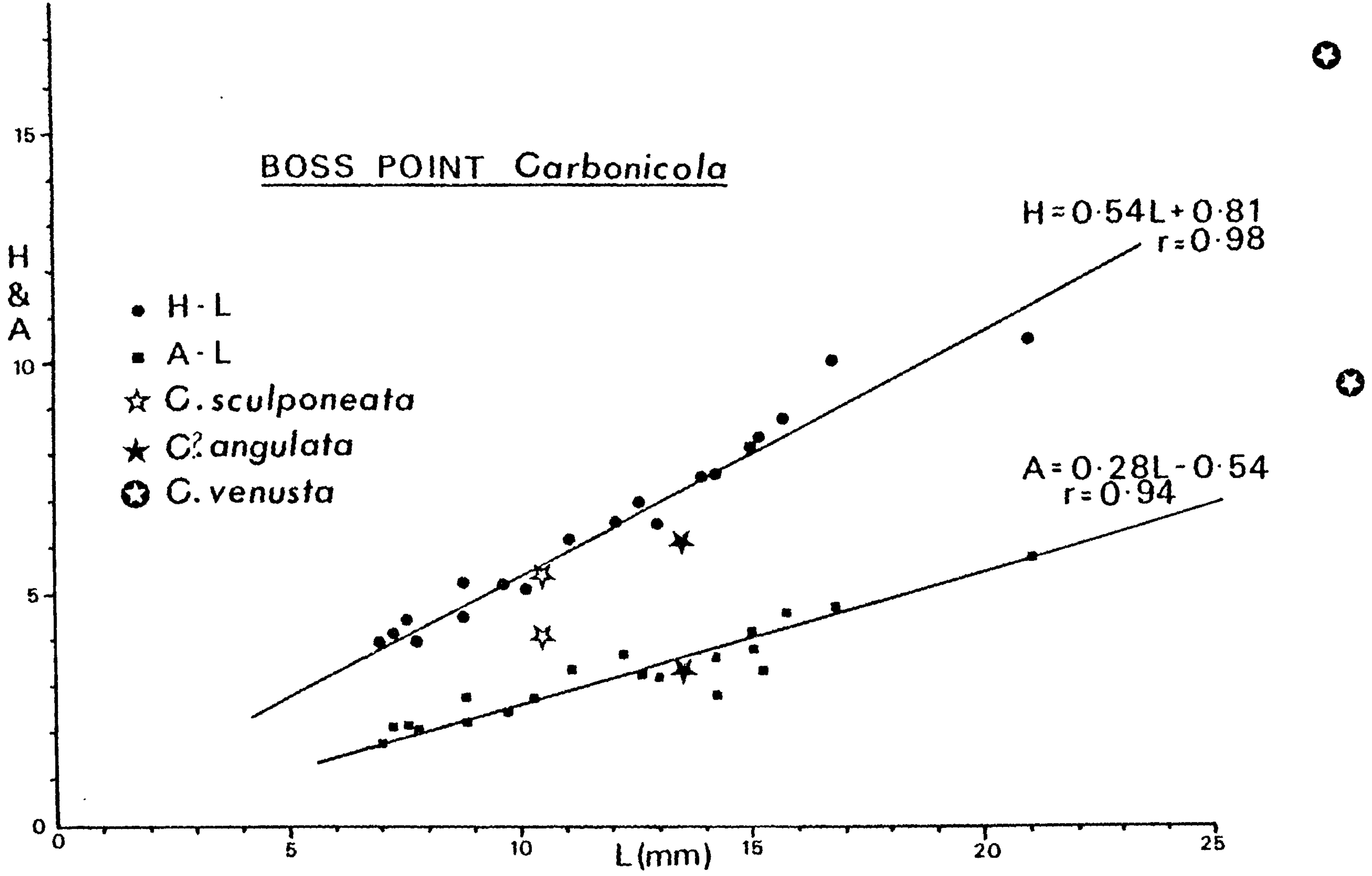


FIGURE 4.4: Section through the <u>Carbonicola</u>? <u>eagari</u> sp. nov. Bed of the Boss Point Formation (see Figure 4.3).

FIGURE 4.5: H-L and A-L scatter plots and fitted lines for the C?. eagari sp. nov. fauna of Boss Point.



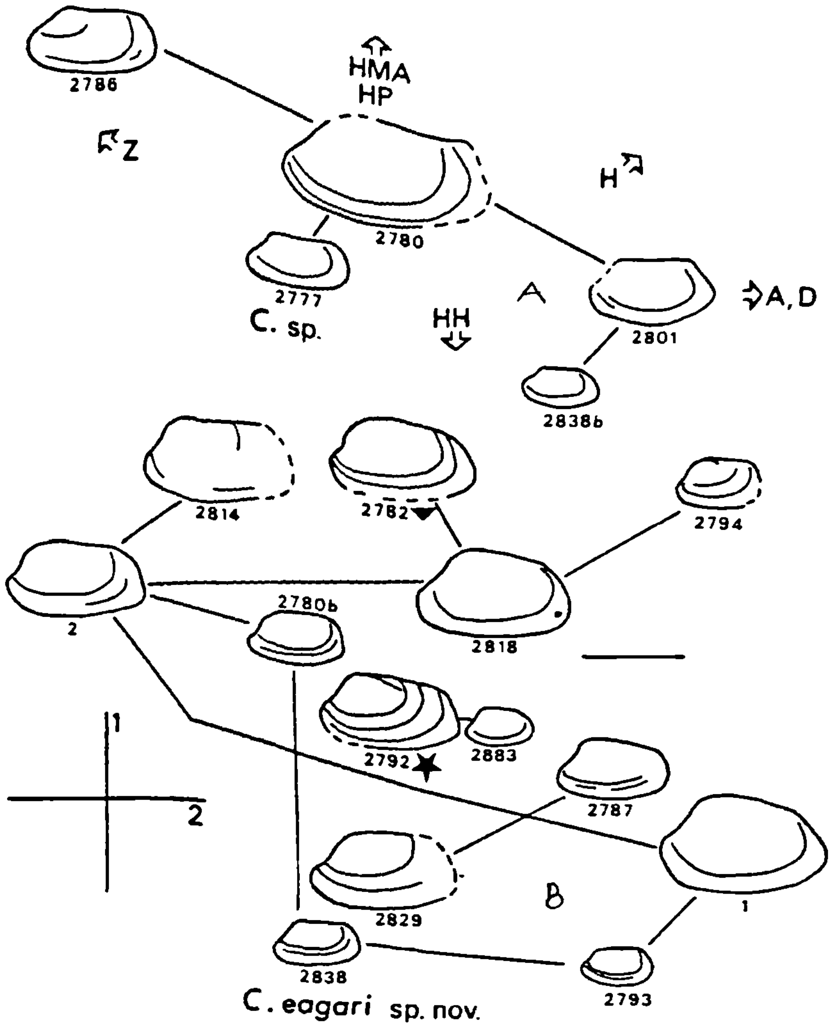


FIGURE 4.6: Pictograph of the Boss Point Carbonicola?fauna, A - C?. sp. cf. C. sculponeata Rogers, B - C?. eagari sp. nov. ✱- Holotype, ▲ - Paratype of C?. eagari sp. nov., scale bar - 1 cm. PCA1 v PCA2 plot.

Figure (4. 6b) is a pictograph of the *C*?. *eagari* sp. nov. group. Variation occurs in terms of decreased H/L ratios and decreasing anterior length (A/L) to produce shells with a slightly anthraconaioid outline. Several of the shells display forwardly tilted juvenile growth lines.

Interpretation and discussion.

Figure 4.4. shows details of the lithologies and abundances of the fauna through the shell bed. The fauna inhabitated a small, eutrophic lake in which sedimentation rates and current activity were low. The shells are subovate, having moderately high H/L ratios and long anterior ends indicative of an established fauna (Eagar 1971, 1977, p. 537). The preservation of the fauna suggests that low energy conditions prevailed allowing the deposition of carbonate material and the influx of small amounts of only fine-grained material.

The lake bottom may have been prone to oxygen deficiency and the high organic carbon-content of the sediment suggests that conditions below the sediment/water interface were anoxic. The carbonate content of the sediment ensured that the substrate was firm enough for attaching spirorbids and for resting bivalves.

4. 1. 3. Correlational aspects of the Boss Point fauna

Faunas are rare in the largely fluvial Boss Point Formation and correlation is difficult. However, three points require consideration.

(i) The reported occurrence of *Curvirimula belgica* *s.l.* and *C. tessellata* *s.l.* towards the base of the Formation, though not providing a good basis for homotaxial correlation, is important. The *C. belgica* group is wide ranging in Britain, occurring from the Lower Carboniferous through to the lower Westphalian C with a possible acme in the Communis Chronozone (Weir 1960). *C.tessellata* also characterises the Communis Chronozone (Weir 1960) but is also known from the Namurian of Belgium.

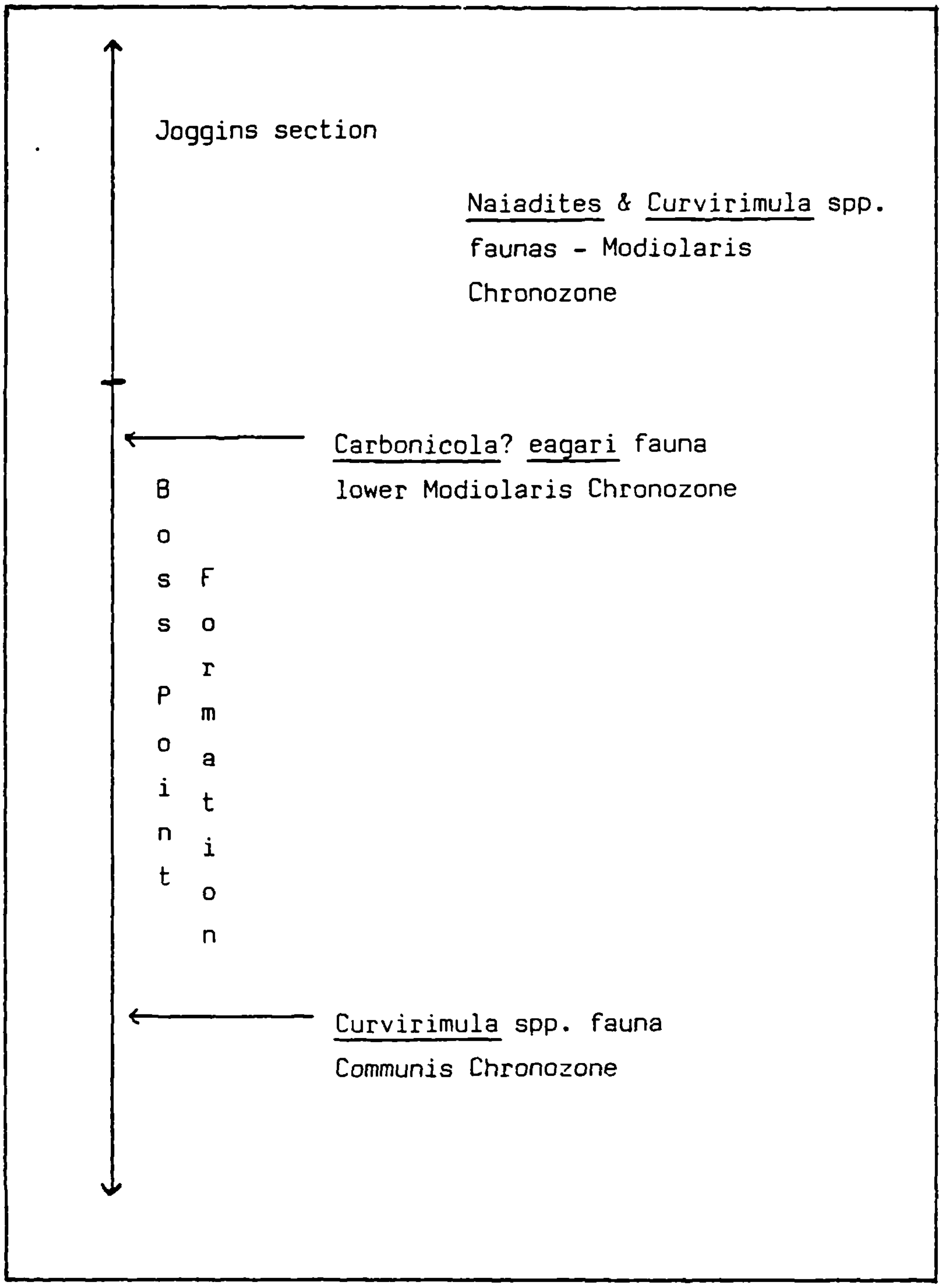
(ii) The *Carbonicola*? *eagari* sp. nov. fauna near the top of the Formation may provide a somewhat closer correlation. Shells of the *C*?. *eagari* sp. nov. group closely resemble the larger *C. venusta* of Britain and some variants are similar to *C. bipennis* (Brown). *C. venusta* occurs at a low horizon in the Modiolaris Chronozone in south Wales (Trueman & Weir, 1946, p.75). In NW Europe, *C. venusta* has been recorded from slightly higher horizons (*ibid*.). *C. bipennis* occurs in the middle-upper Communis (Eagar, pers. commun., 1984) and lower Modiolaris Chronozones of Britain (*ibid*, p.27).

Communities of *Carbonicola* spp. from above the Flockton Thin Coal of the Yorkshire coalfield figured by Eagar (1961, p.143) show great similarity to the *C. eagari* fauna and many of the smaller Yorkshire variants are of a comparable size. However, unpublished pictographs of *Carbonicola* and *Anthracosia* faunas from above the Flocton Thin Coal at the Cold Bath Opencast were kindly provided by Dr. R. M. C. Eagar for closer comparisons. Although there is a small degree of overlap in the variation displayed in these assemblages and the Boss Point fauna, they are generally quite dissimilar.

(iii) The Cumberland Group of Joggins overlies the Boss Point Formation (see next Chapter).

The Boss Point Formation of this area appears therefore, to be homotaxially correlative with strata from the lower-middle

TABLE 4.1: Correlation of the Boss Point Formation.



Communis to the top of the lower Modiolaris Chronozones of Britain, that is middle to upper Westphalian A, excluding its highest part, Table 4.1. This correlation agrees with the previously reported floral and microfloral correlations.

4. 2. Faunas of the Parrsboro area, the West Bay Formation and Parrsboro Formation.

Bell (1944, p.17) recorded the presence of several shell beds within the Parrsboro Formation containing Naiadites and "Anthracomya" (probably Curvirmula) and Rogers (1965, p.664) also recorded Carbonicola? angulata (see systematic section) from the Canso Group of the Parrsboro area, Dawson having possibly collected some of his type material here (Dawson 1860, 1868, Rogers 1965, p. 669).

4.2.1. Carbonicola? angulata faunas of the West Bay Formation

Rogers (1965, p. 671) stated that C?. angulata "is diagnostic of the Canso Group of Nova Scotia, being abundant in certain of the horizons in the shales of the Minas Basin and Cape Breton Island". On the geological map of the Parrsboro area the West Bay Formation is shown as being in the Canso Group.

An exposure bearing elongate shells which on the basis of external morphology are referable to Carbonicola? was located in a road cutting at grid reference 263937 (Sheet 21H/8) on the Parrsboro-Black Rock coastal road (Figure 4.7). This section, shown in Figure 4.8. comprises finely laminated, medium grey (N3-4) mudstones, siltstones and muddy sandstones displaying ripple lamination. The beds are steeply dipping at 85 SSW which compares well with Bell's (1944, p.18) measurement of 80 SSW for the West Bay Formation at this locality. On the basis of the fauna, lithology and structure these beds are inferred to belong

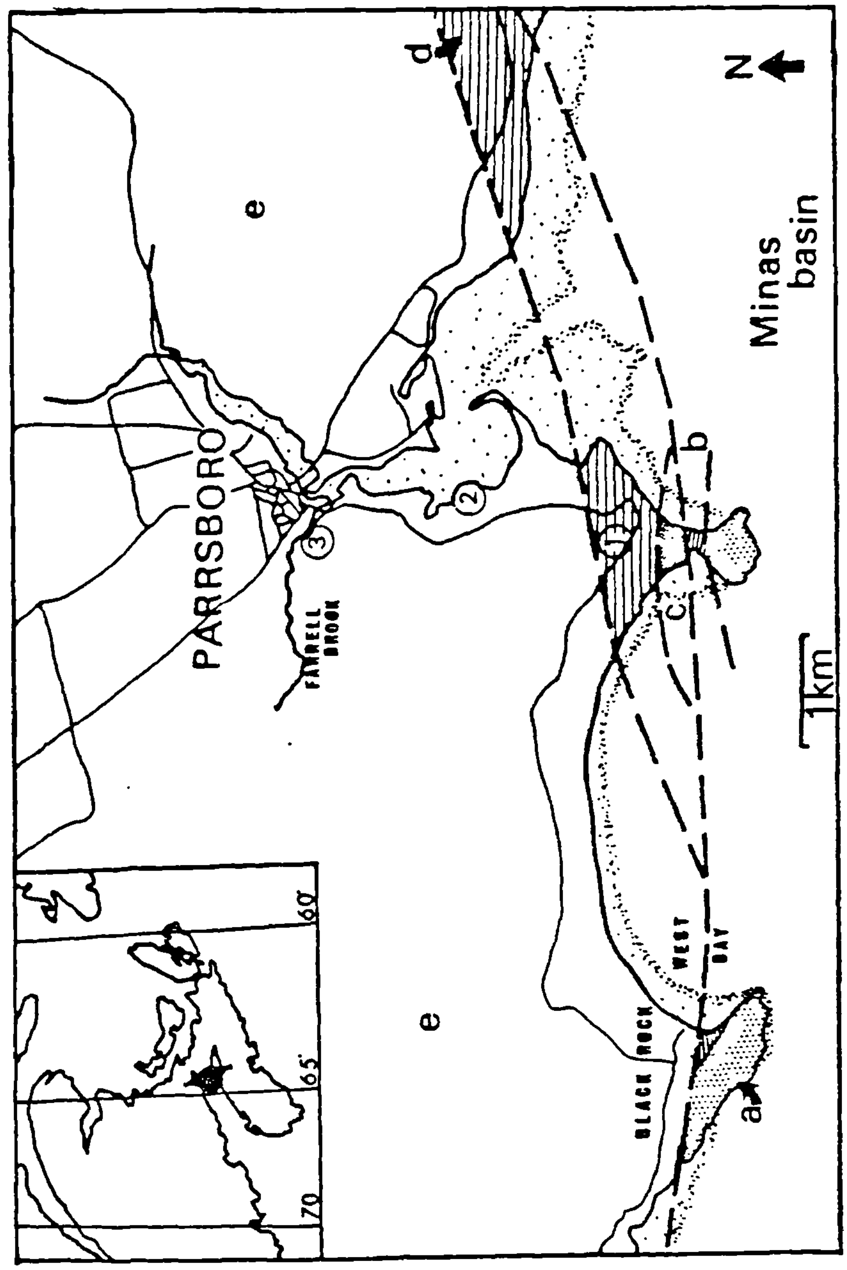


FIGURE 4.7: Sketch geological map of the Parrsboro area. Locality 1 - Parrsboro road cutting, Locality 2 - West side of Parrsboro Bay and Locality 3 - Farrell Brook. d - West Bay Formation, e - Parrsboro Fm., a-c - Triassic and younger rocks.

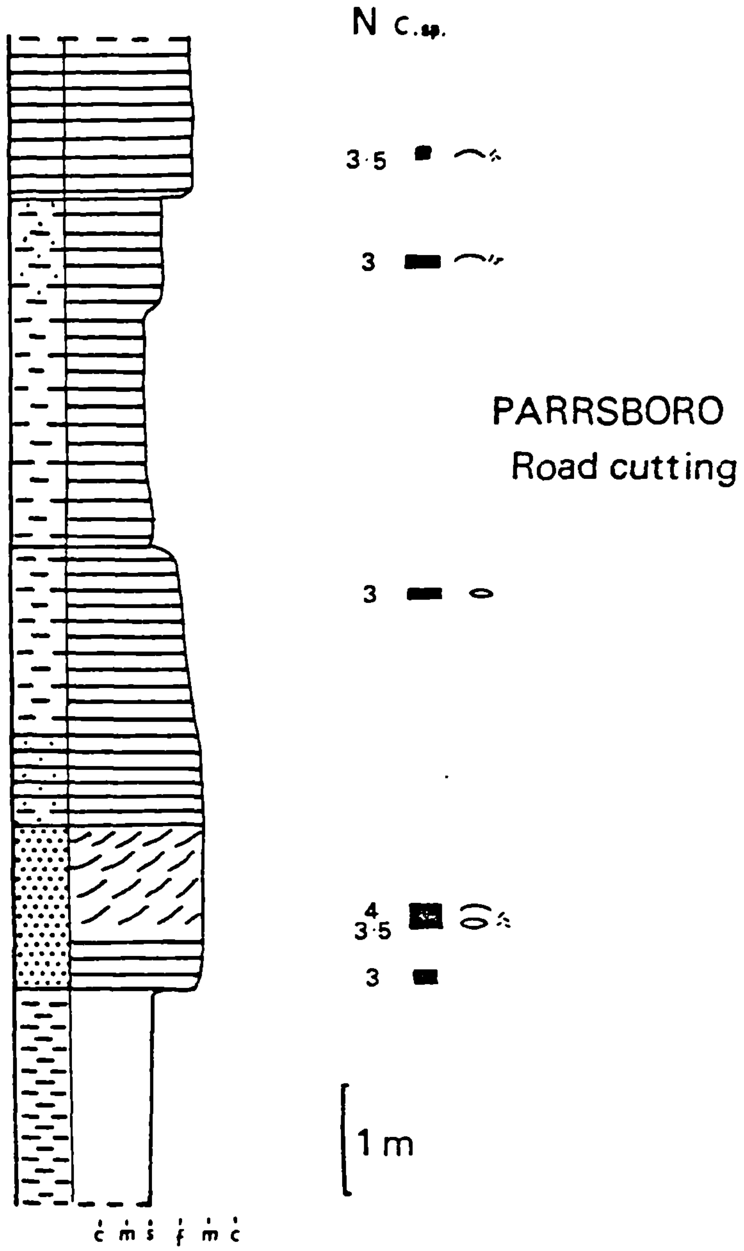


FIGURE 4.8: Parrsboro roadcutting section. Parrsboro, Nova Scotia (West Bay Formation). Distribution and mode of occurrence of C?. angulata s.l.group faunas and colour codes of lithologies shown.

to the West Bay Formation.

Fauna: preservation and distribution

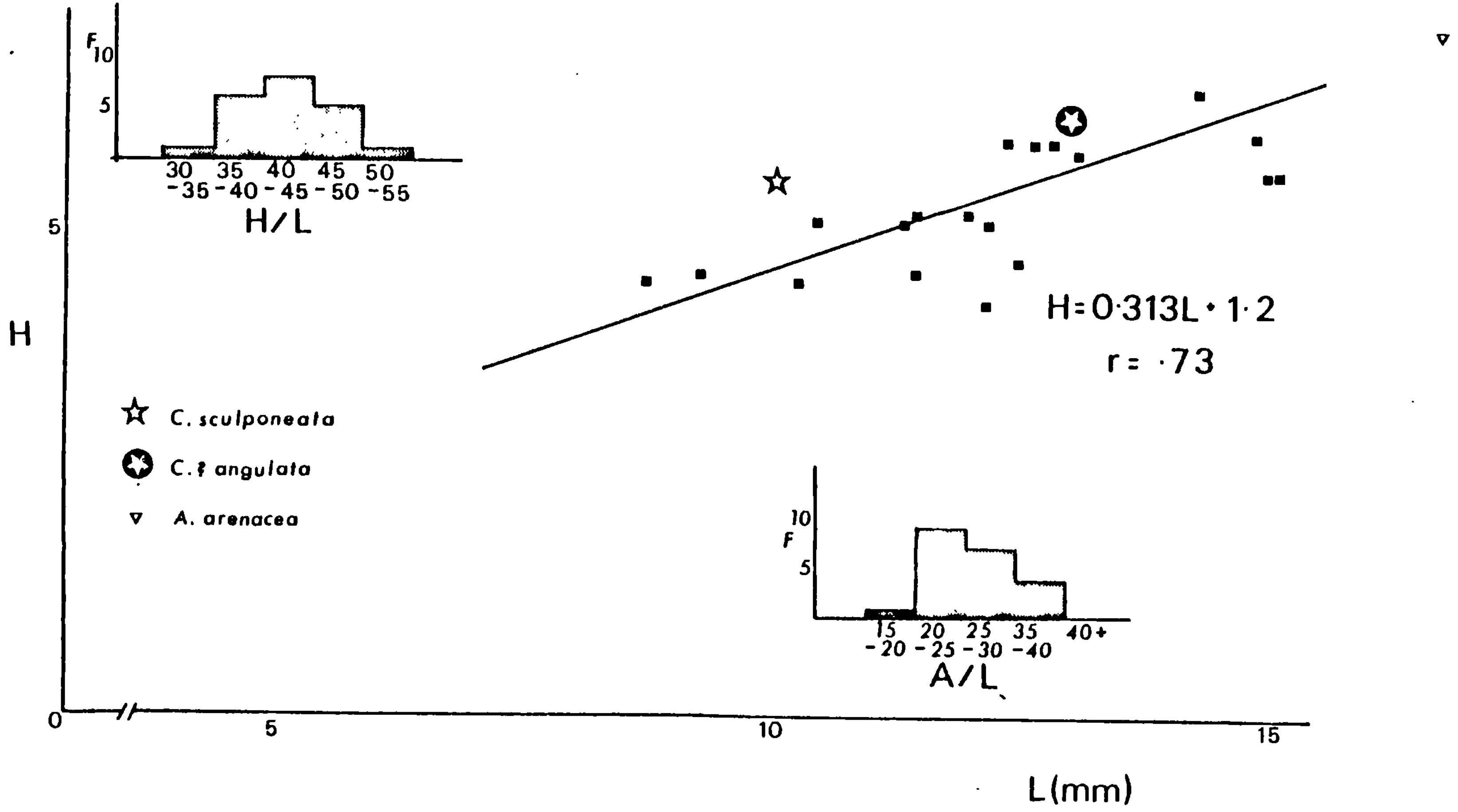
Shells referable to the Carbonicola? angulata group are present sporadically through the section as angular fragments, single valves and rare articulated shells lying subparallel to bedding. Associated fauna is restricted to rather poorly preserved and rare estheriids.

Statistical and biometrical analysis of measurable valves (Figure 4.9) shows the sampled population to be normally distributed in terms of the H/L and A/L ratios though, the A/L ratios are skewed towards smaller values. An H-L scatter and fitted regression line (Figure 4.9) shows some variation in terms of H/L ratios resulting in a low r value of 0.73.

Two clusters were obtained by cluster analysis primarily on the basis of H/L ratios and the point of maximum depth on the ventral margin. A group of very elongate shells is referred to C?. angulata whilst a second group of moderately elongate shells is referred to C?. sp. cf. C. fallax ? Wright (Figure 4.10). Variation within the C?. angulata cluster produces very elongate variants with short anterior ends and a nearly straight ventral margin which, in isolation, would prove difficult to separate from the late Westphalian Anthraconaia arenacea. A similar trend towards anthraconaiaioid forms is also seen in less elongate forms displaying posterior expansion reminiscent of shells figured by Eagar (1947, 1951).

The section described above lies very close to the top of the Formation and no evidence for hypersalinity was found. The section was interpreted as a fluvial deposit (Figure 4.8) deposited in moderately high energy conditions. Current activity, indicated by ripple laminations, and periods of high sedimentation interspersed with periods of low energy conditions depositing dark

FIGURE 4.9: H-L scatter plot and fitted regression line (reduced major axis) of C?. angulata s.l. faunas. A/L and H/L frequency distributions also shown.



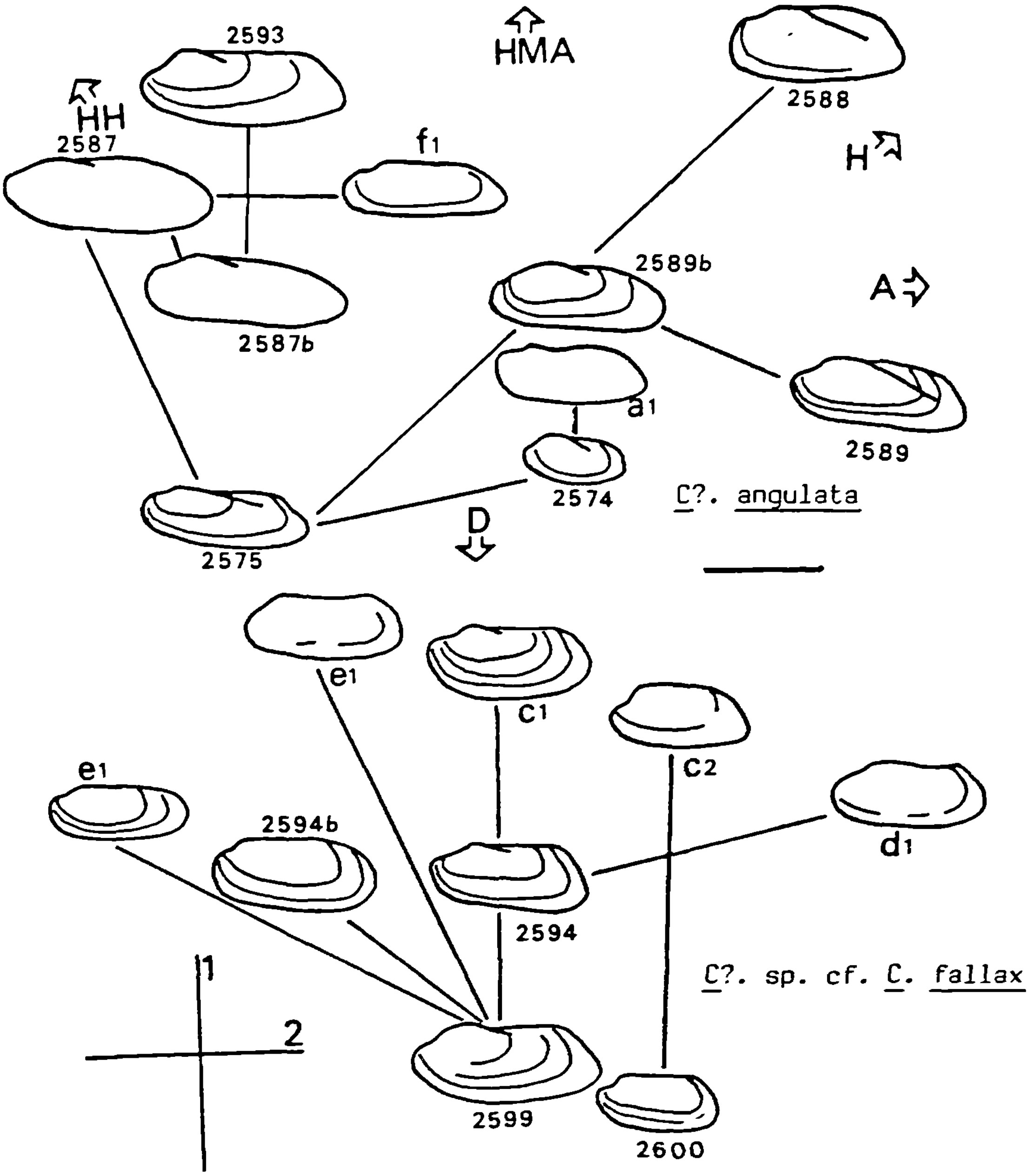


FIGURE 4.10: Pictographs of C?. angulata and C?. sp. cf. C. fallax groups from the West Bay Formation of Parrsboro. PCA1 v PCA2 representation. Variational trends shown.

grey mudstones. Scattered bivalve remains occur throughout the section, though there is a higher degree of articulation in the mudstones. Estheriids appear to be limited to the darker, finer-grained lithologies.

The preservation of the fauna as mainly fragments and single valves in coarser lithologies and articulated shells in finer horizons tends to suggest that the *Carbonicola?* fauna represents a near life assemblage (Boucott 1953, Eagar 1961, p. 139). Periods of higher current activity led to fragmentation and disarticulation. Overall shell shape is consistent with such conditions representing an invading fauna (Eagar 1977).

Correlational aspects of the fauna

Rogers (1965, p.685) tentatively correlated the Canso Group with the Lenisulcata Chronozone and possibly , the upper Namurian of Britain. *C. fallax*, the most closely similar British form to the West Bay Formation shells, occurs in the Lenisulcata Chronozone (Trueman & Weir 1948, p. 80, Eagar 1947 Calver 1956). On this basis the top of the West Bay Formation is homotaxially correlative with the Lenisulcata Chronozone of Britain (lower Westphalian A) or upper Namurian age as Rogers (1965, Table 8) suggested. Though, the Nova Scotian *Carbonicola?* faunas are much smaller than their supposed homotaxial equivalents.

4.2.2 Faunas of the Parrsboro Formation

Bell (1944, pp.16-17) briefly described strata ascribed to the Riversdale Group which crop out in the Parrsboro area (Figure 4.7) both along the shore and in stream and railway cuttings. Hyde (in Bell 1944, p. 16) made detailed measurements of the Parrsboro Formation. Several shell beds were recorded as yielding '*Anthracomya*' and *Naiadites*.

Pluim (1980) investigated the 1500 m thick Parrsboro Formation in the Parrsboro area, recording six facies associations (Table 4.2). Thick channel sandstone sequences are rare (McCabe et. al. 1980) and it is possible that differential subsidence in the Minas Basin kept the major channels away from the Parrsboro region. Deposition took place on a fault-bounded, alluvial plain (*ibid*.).

Two small sections were examined in the Farrell Brook (Figure 4.7.) and on the west side of Parrsboro inlet. Collections were made at both localities.

4.2.2.1. Farrell Brook.

Several hundred metres of the Parrsboro Formation are exposed along the banks of the lower part of Farrell Brook where the succession comprises thick cross-bedded, fining-upward sandstones, thin crevasse splay sandstones, floodplain and lacustrine shales (Figure 4.11). The strata dip 75°to the north.

Faunas were recorded at three horizons consisting of medium to dark grey (N2.5-3.5) muddy and silty shales and muddy sandstones. Fragments, single valves and articulated shells of *Naiadites* spp., mostly poorly preserved and crushed, occur. *Curvirimula* was not recorded. Associated fauna is limited to rare fish fragments and encrusting spirorbids in the darker, finer-grained lithologies.

Adult shells proved to be rare and occurred mainly as single valves or angular fragments whilst juvenile shells are abundant and are preserved as single valves or as articulated shells. Measurable valves were rare and generally of small size, and for this reason, little useful statistical work could be done.

TABLE 4.2: FACIES ASSOCIATIONS AT PARRSBORO (PLUIM 1980).

1.	BASAL CONGLOMERATE - Deposit of a braided river.
2.	FINING-UPWARD SANDSTONES - Deposit of meandering rivers approximately 2 m deep.
3.	NON-FINING THICK SANDSTONES - Proximal crevasse splays.
4.	PARALLEL - SIDED SANDSTONES - Cre vasse splays.
5.	CALCAREOUS SILTSTONE - SEATEARTH SEQUENCES - Lacustrine and vegatated floodplain.
6.	FINE - GRAINED SEQUENCES - Overbank and lacustrine deposits.

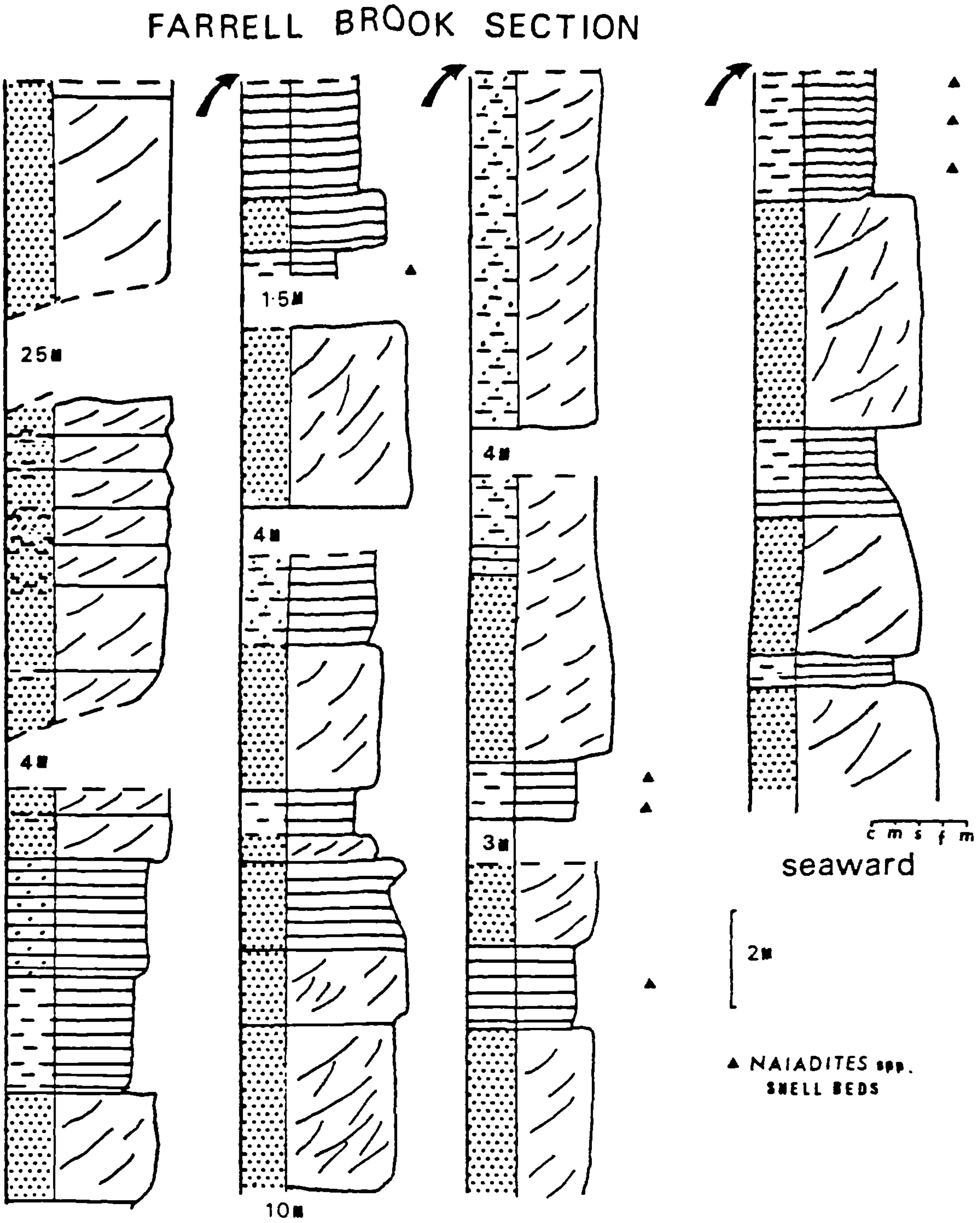


FIGURE 4.11: Measured section of the Parrsboro Formation in Farrell Brook (See Figure 4.7). Shellbeds indicated.

4.2.2.2 West side of Parrsboro inlet.

A 50 m thick section (Figure 4.12) was measured and examined along the west side of Parrsboro inlet shore (grid reference 267962). Thick medium-grained sandstones, crevasse splay sandstones, floodplain and lacustrine shales and muddy sandstones comprise the section. Thick sandstone beds are less abundant than at Farrell Brook.

Faunas occur in the finer-grained, darker horizons and muddy sandstones of lacustrine origin. Naiadites spp., often with encrusted spirorbids, occur as angular fragments, convex-upward single valves and as rare articulated shells. As at Farrell Brook, juveniles are far more common and are much better preserved than adult shells.

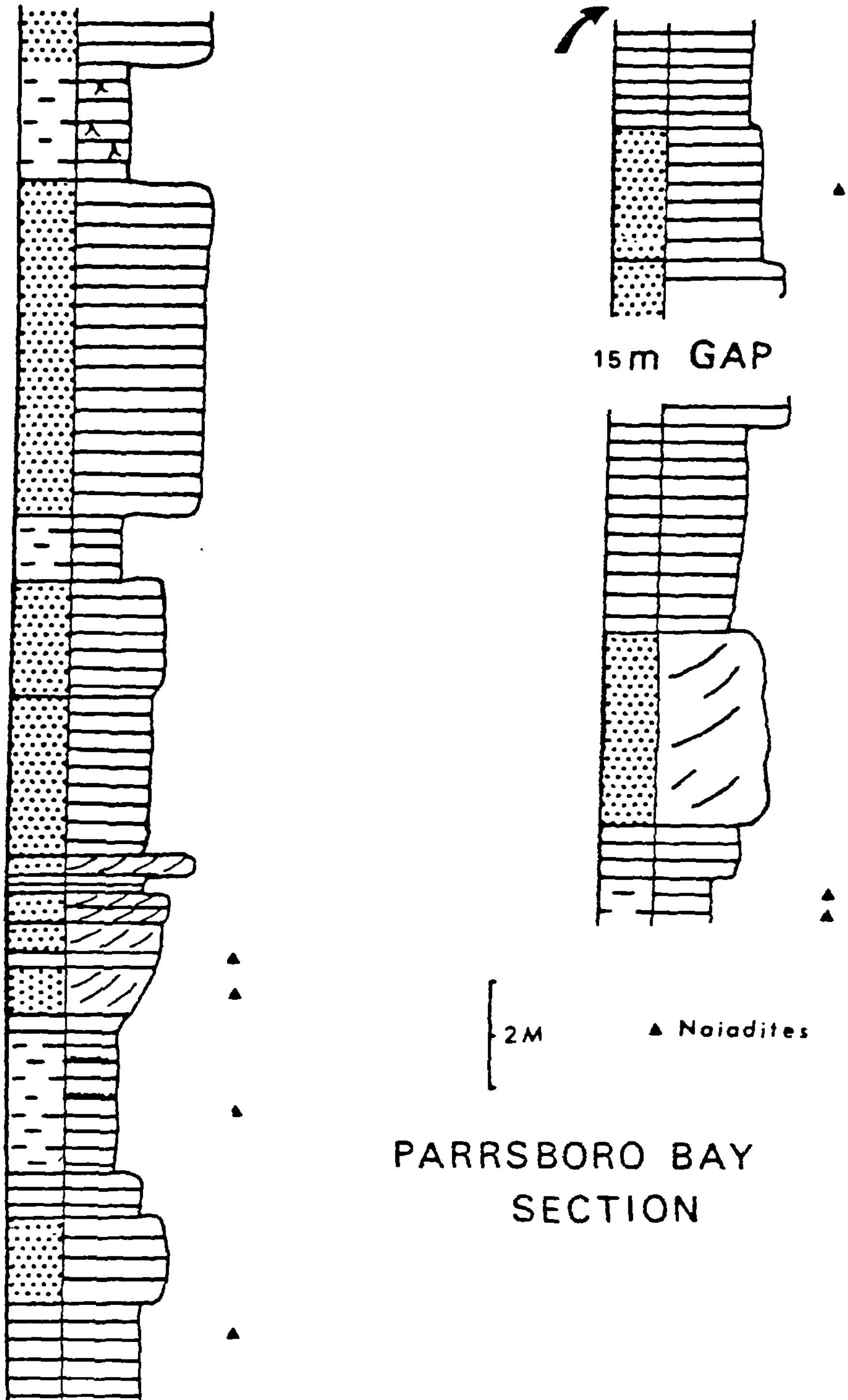
Discussion of the Parrsboro Naiadites faunas.

Due to the paucity of measurable specimens, the general small size and preservation of such, the Naiadites faunas of both localities have been treated together. In addition, Rogers (in press, [1979]) examined several shells from the west side of the Parrsboro inlet which were subjected to multivariate analysis (Figure 4.13).

The exact location of the three sections within the Parrsboro Formation is unknown. Moreover, the available literature dealing with this Formation does not allow detailed stratigraphic analysis (e.g. Bell 1944, McCabe et. al. 1980, Pluim 1980) being mainly of a sedimentological nature. For these reasons, it is felt that only a general correlation is possible until detailed stratigraphic work and further collecting of this Formation takes place.

Cluster analysis was performed on the combined fauna (23 measurable valves). Two major clusters were obtained (Figure 4.

FIGURE 4.12: Section through strata of the Parrsboro Formation on the west side of Parrsboro Bay.



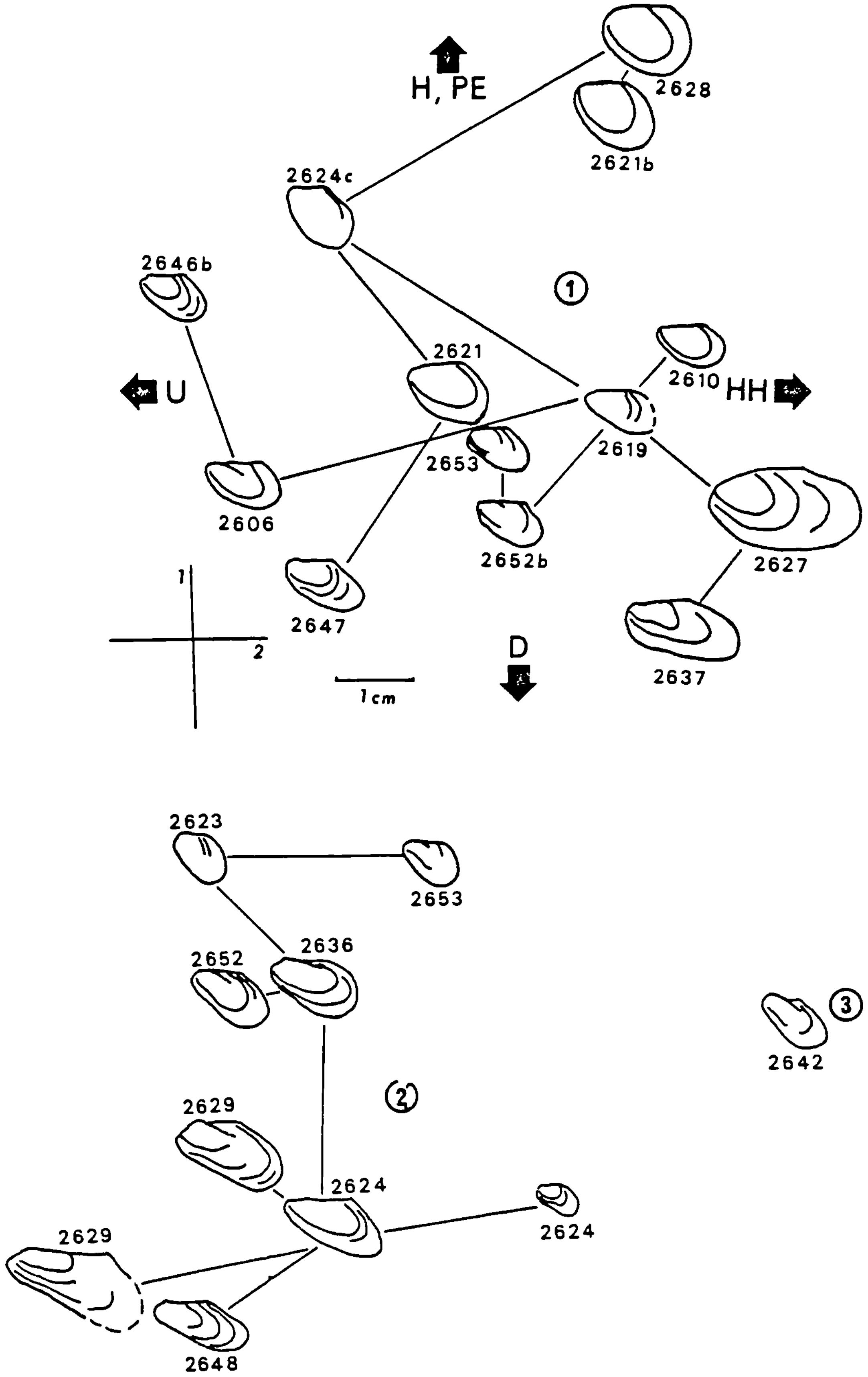


FIGURE 4.13: Pictograph of *Naiadites* spp. from the Parrsboro Formation in Parrsboro Bay and in Farrell Brook. 1 - *Naiadites daviesi* group, 2 - *N. productus* group, 3 - *N.* sp. PCA1 v PCA2 plot, variational trends as in group 1.

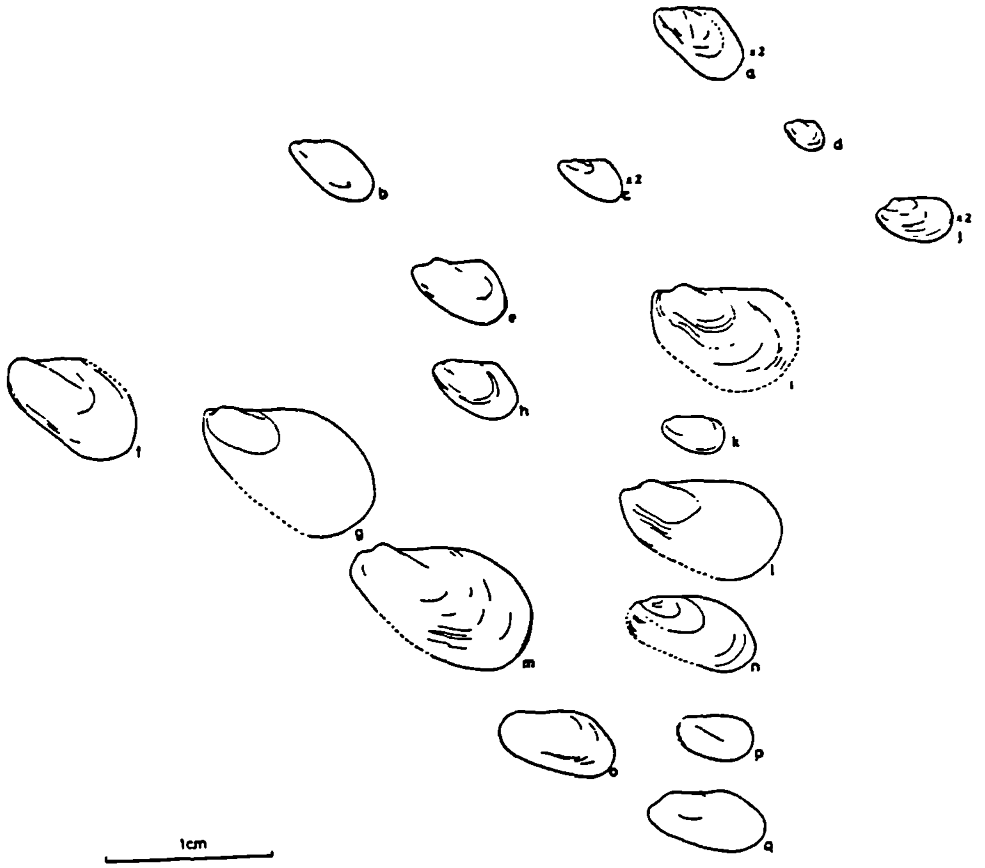


FIGURE 4.14: Rogers pictograph of Naiadites from the West side of Parrsboro Bay. (From Rogers in press [1979]).

13 1, 2), both of which show similar variational trends. The two clusters are referred to the *Naiadites daviesi* group and to the *N. productus* group.

The modal form in the *N. daviesi* group cluster Figure 4.13,2) is close to *N. daviesi* *s.s.* (GMV 2619) and a trend of decreasing H/L ratio, posterior expansion and D/L ratio tends to occur producing anthraconautiform variants referable to *N.* sp. cf. *N. daviesi* (but unlike any of the shells figured by Trueman & Weir (1955, Plate 27). An opposite trend towards more obliquely subovate, carinate variants produces shells possibly comparable to *N. carbonarius* *s.l.*, though shells closely similar to *N. carbonarius* *s.s.* do not occur. In the second cluster (Figure 4.13,1), *N. productus* *s.s.* proves to be a near-modal form. Trends towards a longer dorsal margin, higher D/L ratios and lower obliquity produces several variants which approach *N. subtruncatus* (Brown) (Figure 4.13,1., GMV 2629, 2648). An opposite variational trend results in forms of high obliquity with a convex upper posterior margin and narrowly rounded anterior end referred to *N.* sp. cf. *N. productus* (e.g. Figure 4.13,1., GMV 2623, 2653b. cf. with Trueman & Weir 1955, Plate 28, figure 36).

Shells of Rogers (in press [1979]) display trends towards *N. productus*, *N. subtruncatus* and *N. modiolaris*, the types of *N. carbonarius* and *N. daviesi* tending to fall on the outer limits of the variation displayed by the sampled population. Unfortunately, Rogers'(*ibid*.) method does not discriminate shell shape groupings but rather accurately displays shell shape variation (except at the postero-dorsal angle).

Interpretation.

Naiadites spp. faunas tend to occur in the finer-grained parts of the Parrsboro Formation and are probably lacustrine in origin. The shell beds are generally coarser-grained than at Port Hood or Chimney Corner (see later) and were probably deposited in moderate energy conditions. The preservation is generally poor and juveniles are generally more abundant and better preserved than adult shells. Such a preservation is suggestive of current winnowing in shallow water. The abundance of root marks, rain pits and other surface traces and the unusually coarse-grained lithology tends to support this hypothesis.

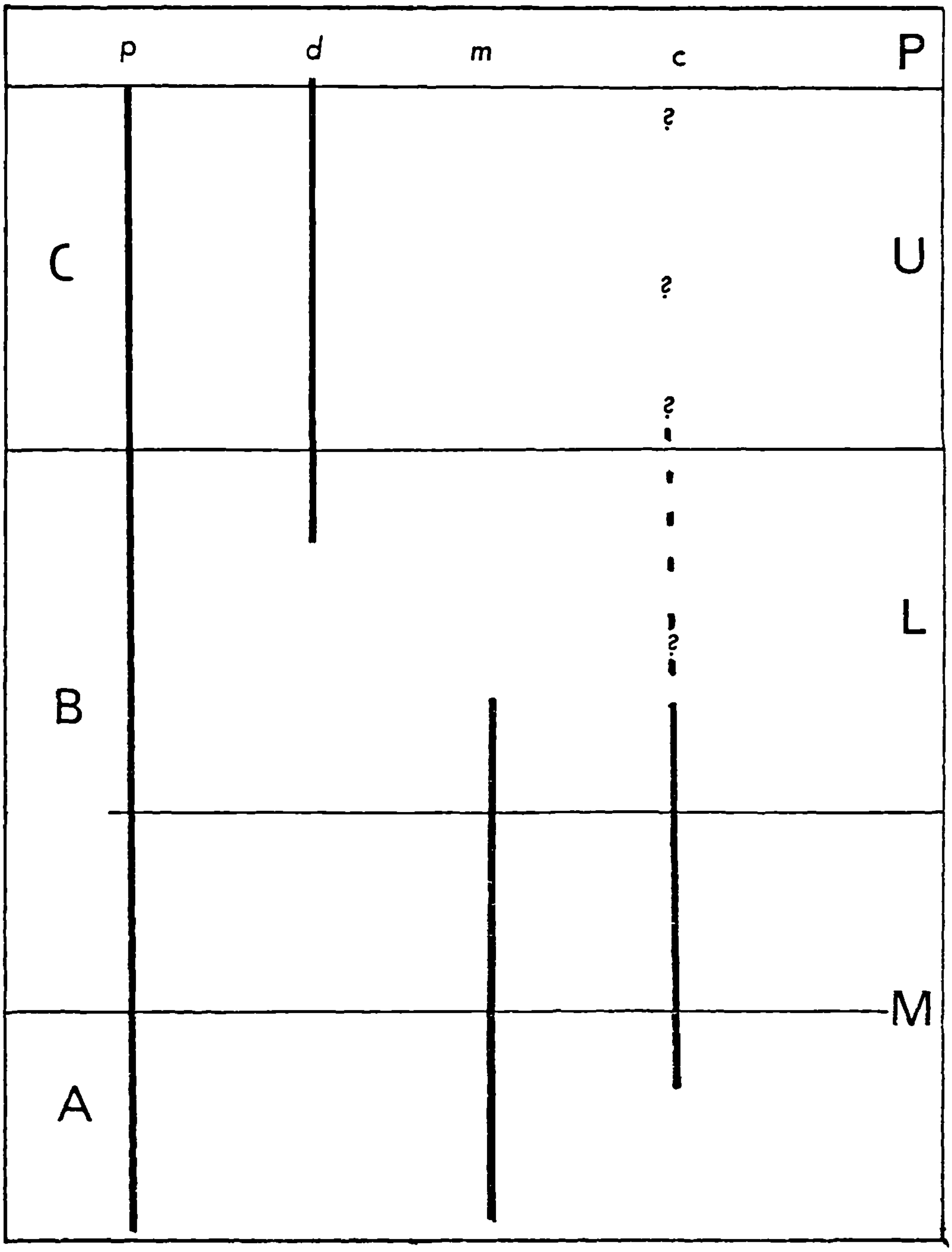
Correlational aspects of the fauna.

Figure 4.15 shows the ranges of *Naiadites productus*, *N. daviesi*, *N. subtruncatus* and *N. modiolaris* in Britain (Trueman & Weir 1955) and also, fitted for comparison is the estimated range of *N. carbonarius* *s.s.* (Rogers 1965, this study). *Curvirimula* was not recorded, either by Rogers (1965, in press [1979]) or in this work. On a purely homotaxial basis, the most reasonable correlation with Britain would be with the mid-upper Westphalian B (lower Similis-Pulchra Chronozone) however, this assignment does not agree with the floral and microfloral ages obtained by Bell (1944) and by Barss (in Hacquebard 1972) respectively. In view of this marked disagreement some discussion of the faunas is required (see Chapter seven).

4.3. Faunas of the Port Hood Formation.

The Port Hood Formation, considered by Gersib & McCabe (1981) to have been deposited by the same river system as the Boss Point Formation (Figure 4.16), crops out in an area 5 km wide that extends 6 km eastward from the coast at Port Hood (Figure 4.17). Strata of Riversdale age along the coast from Chimney Corner to Cheticamp are also assigned to the Port Hood Formation on the Nova Scotia Department of Mines and Energy geological map (1979). For the purposes of this study, the Chimney Corner area faunas are dealt with separatpe. In the Port Hood area the Formation is conformably underlain by non-marine sediments of the Canso Group and overlain by the Pictou Group, though the nature of this upper contact is unclear (Bell 1944, Belt 1965).

FIGURE 4.15: Ranges of Naiadites productus (p), N. daviesi (d), N. modiolaris (m) and N. carbonarius (c). Left hand column shows Westphalian stages and boundaries, right hand column shows Chronozones thus: M - Modiolaris, L - lower Similis-Pulchra, U - upper Similis-Pulchra, P - Phillipsii.



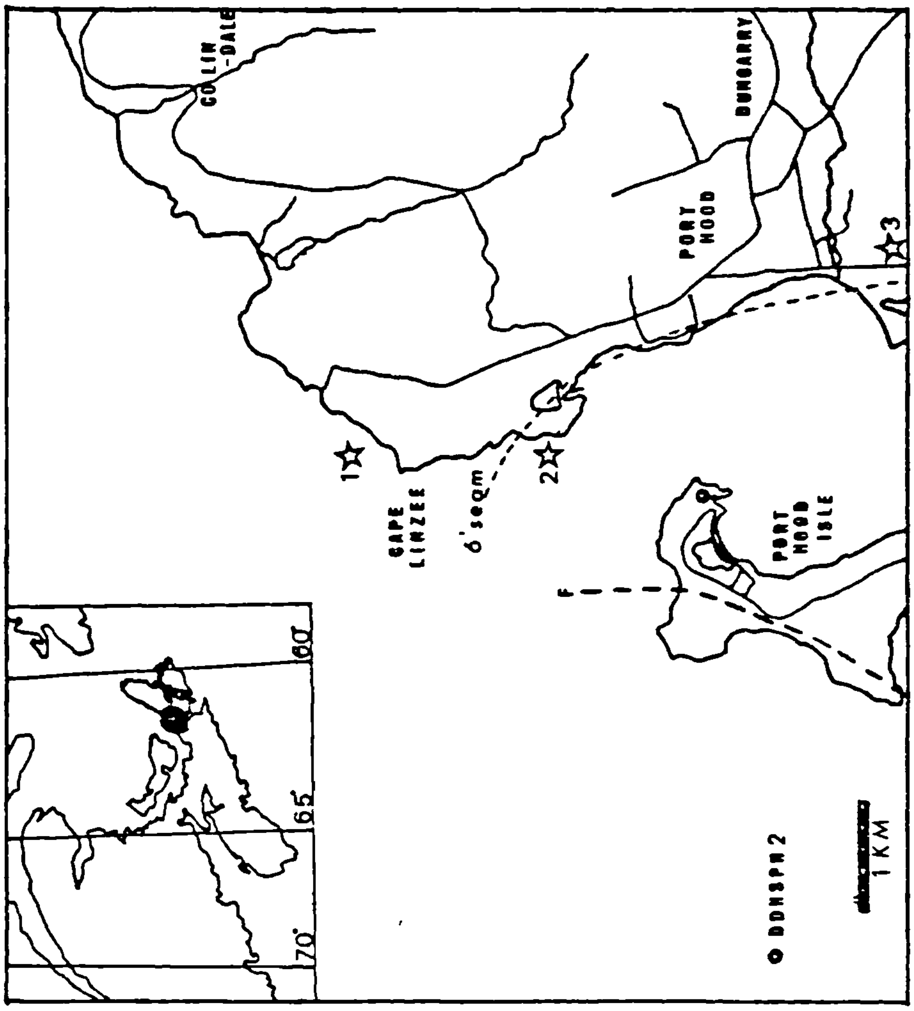


FIGURE 4. 16: Sketch map of the Port Hood area showing major faults and the 'Six-foot' seam incrop. Localities marked by a star. Locality 1 - The Cape Linzee section, Locality 2 - Port Hood Wharf, Locality 3 - Port Hood Mine. Borehole D.D.N.S.P.H.-2 indicated thus,

Bell (1944) assigned the Formation to the Riversdale Group on the basis of floral and faunal evidence. Microfloral work (Barss 1967) supported Bell's findings though Belt (1965) suggested that the lower part may be Namurian in age. The most recent sedimentological interpretation was that of Gersib & McCabe (1981) who suggested deposition by meandering rivers in a continental setting.

The Formation was divided into two parts by Norman (1935), the lower 885 m consisting of grey, fluvial channels with interbedded red mudrocks. The upper part also contains grey, fluvial channels but the mudrocks are predominantly grey and contain coals. Coals are generally thin and laterally impersistent however, mining of the 'Six foot' seam took place early in this century (Douglas 1945). A general section of the Port Hood Formation in this are is shown in Figure 4.17.

Bell (1944) recorded faunas comprising '_Estheria_', '_Anthracomya_', _Naiadites_, _Spirorbis_ sp. and ostracodes in some of the finer-grained lithologies of lacustrine origin. Gersib & McCabe (1981) reported the occurrence of "bivalves resembling _Carbonicola_ and _Naiadites_" in three distinct facies (Table 4.3). Copeland (1957) documented several species referable to the ostracode genus _Carbonita_ as well as describing a new species, _Sansabella reversa_, which should probably now be referred to _Geisina_ sp. (Dr. J.E. Pollard, pers. commun. 1981). If this ostracode is indeed _Geisina_ sp. then it would be the only reported occurrence of this brackish water form from Nova Scotia. The Formation also yielded _Romeriscus periallus_, the oldest known reptile recorded in the region from strata near Cape Linzee (Baird & Carroll 1967).

The Formation was examined at Cape Linzee, Port Hood Wharf, Port Hood mine workings; the Nova Scotia Department of Mines and Energy kindly provided a core (DDNSPH-2) for study (Figure 4.21).

Both the sections and the core represent the upper part of the Formation as defined by Norman (1935). Most of the Port Hood area coast was examined however, and it appears that faunas are restricted to a coal-bearing member towards the top of the Formation.

4.3.1. The Cape Linzee section.

The Formation is well exposed along the coast north of Cape Linzee (Sheet 11K/4, ref. 995124). This section was examined in detail by Gersib (1979) and the results published by Gersib & McCabe (1981). Nine facies were described (Table 4.3.) by these authors. The section comprises a sequence of fining-upward, grey, channel sandstones (7-17 m thick) often with erosive, cross-cutting bases, crevasse splay sandstones, floodplain and lacustrine deposits. Several thin coal seams (Figure 4.17) occur in the section but prove difficult to correlate with seams in the core. Coals occur mainly within floodplain and lacustrine sequences although several occur at the top of crevasse splay and channel sandstones (Figure 4.17). Several fossiliferous horizons were located and Figure 4.18 shows the relative distribution of the faunal constituents in them.

Horizon PHa.

A 900 mm thick sequence of interlaminated medium to dark grey muddy and silty shales contains the following fauna:

Naiadites spp. including N. carbonarius s.l.

Curvirimula sp. fragments.

Carbonita spp. including C. altilis, C. bairdiodes, C. pungens, C. secans, C. scalpellus, C. humilis? and cf. C. corrugata.

TABLE 4.3: PORT HOOD FORMATION FACIES TYPES (GERSIB & MCCABE 1981).

FACIES	DESCRIPTION	ENVIRONMENT
A	UNLAMINATED MUDROCK: Includes all unlaminated sediments of clay to coarse silt size. Relatively small amounts of carbonaceous material. Rootlets common. Desiccation cracks, infilled with fine sand, found in some beds.	Deposited direct from suspension with no evidence of current reworking. FLOODPLAIN.
B	FOSSILIFEROUS SHALE: Carbonaceous shale of clay to fine silt grade. Fossils abundant including *Naiadites*, *Curvirimula* and ostracodes.	FRESHWATER LAKE ON FLOODPLAIN.
C	PARALLEL LAMINATED SILTSTONES: Fine-coarse siltstones which are medium to light grey (N4-6). Lamination produced by grainsize variation. Articulated bivalves and plant remains common.	standing body of water. FLOODPLAIN LAKES, SHALLOW.
D	COAL & CARBONACEOUS MUDROCK: Coal varies from vitrain to durain. mudrock dark-grey (N3) of clay-silt size. common ostracodes and rare bivalves.	SWAMPY FLOODPLAIN
E	RIPPLE-LAMINATED SANDSTONE: Beds of cross-laminated coarse silty sandstone produced by migration of assymetrical ripples. Bases of beds erosional or gradational.	CREVASSE SPLAY.
F	CROSS-BEDDED SANDSTONE: V.f.g-medium sandstones trough cross beds.	CREVASSE SPLAY.
G	PARALLE LAMINATED SANDSTONES: Fine-coarse sstn. laminae defined by grainsize. Rootlets in coarser horizons.	CREVASSE SPLAY
H	MASSIVE SANDSTONE:	FLUVIAL CHANNEL SSTN.
I	PEBBLY SANDSTONE:	CHANNEL LAG.

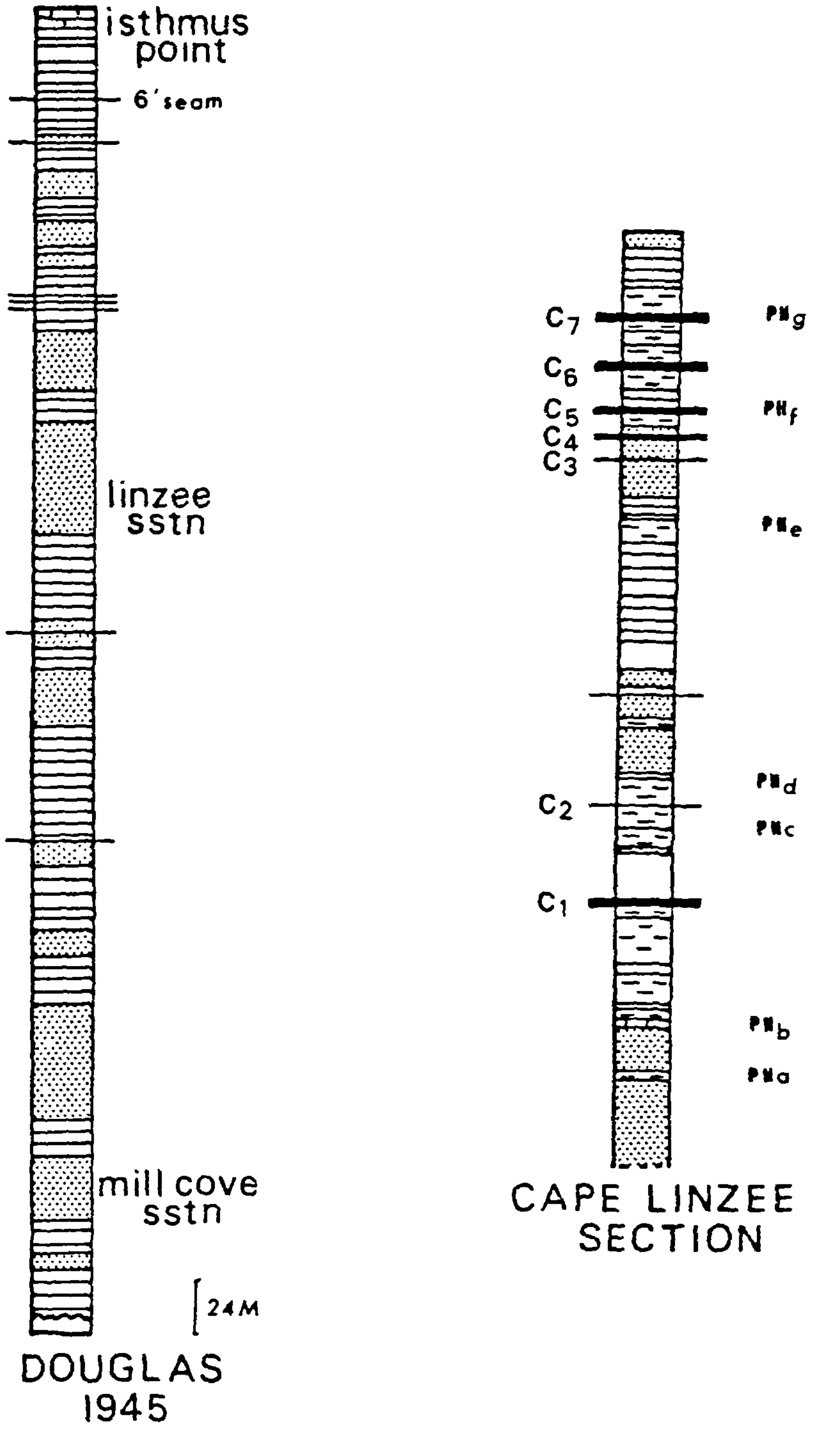


FIGURE 4.17: Section through the Port Hood Fm. in the Port Hood area by Douglas (1945) and the Cape Linzee section. Coals and faunal horizons labelled.

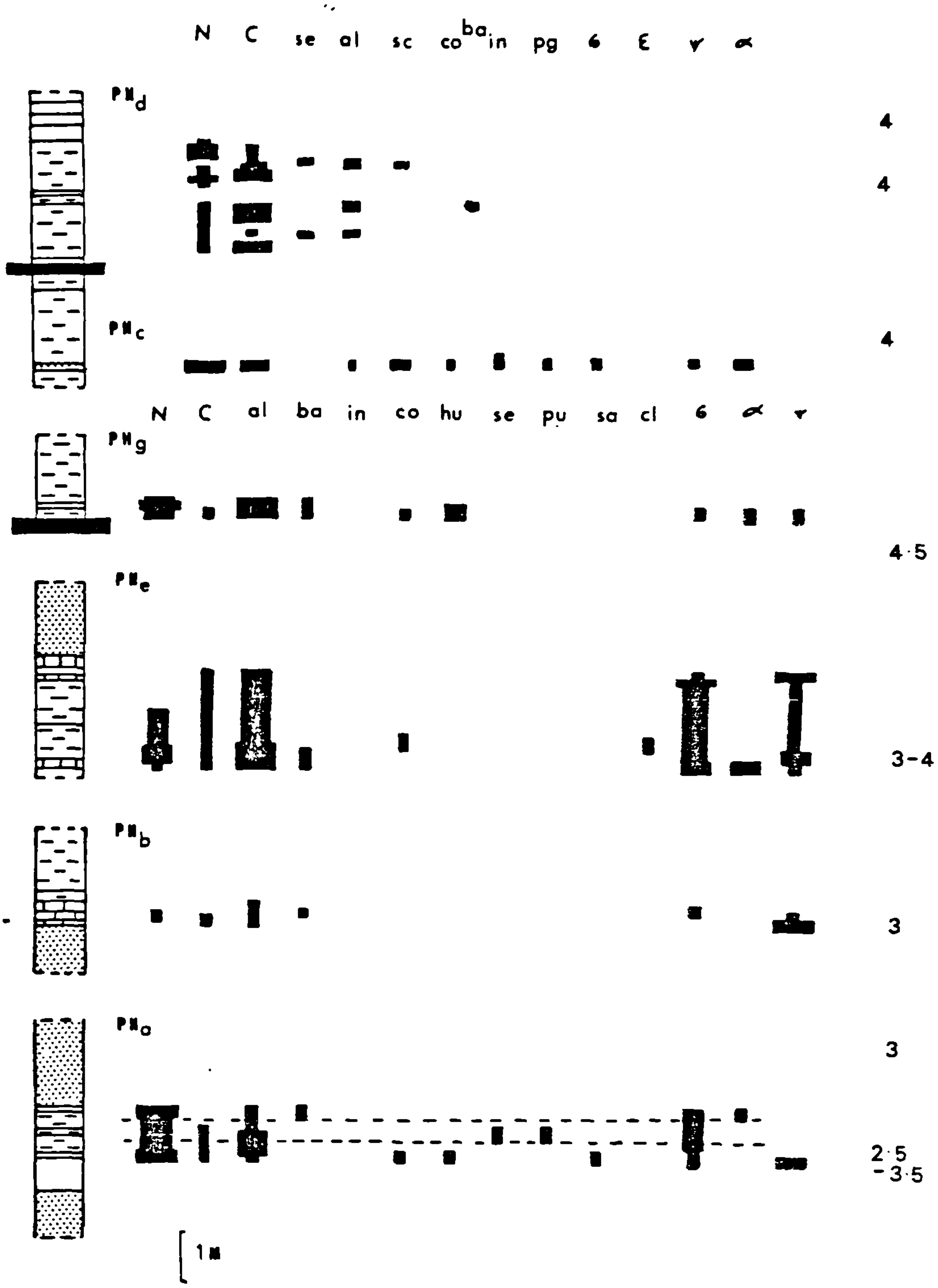


FIGURE 4.18: Faunal horizons and abundances of faunal elements in the Cape Linzee section of Port Hood.

Spirorbis sp.

Fish fragments including *Rhabdoderma* sp.

Bivalves are preserved mostly as fragments, though *Naiadites* occasionally occurs as convex-upward, single valves lying subparallel to bedding. *Carbonita altilis*, a thick shelled, punctate ostracode, is the dominant form, the distribution of the other subordinate forms tending to be controlled by the nature of the lithology.

Horizon PHb.

A 500 mm thick, hard calcareous medium grey mudstone containing the following fauna;

Naiadites spp. fragments.

Spirorbis sp.

Carbonita altilis and *C. bairdiodes*.

Horizon PHc.

A distinctive and well preserved fauna was recorded from a 110 mm thick pale grey, calcareous siltstone below coal C2 (Figure 4.18). Bivalves occur mainly as single valves lying convex upward; are normally uncrushed or slightly crushed, indicating some degree of cementation before compaction. Rarely, shells are found articulated and open, lying subparallel to bedding.

Naiadites of the *N. subtruncatus* and *N. carbonarius* groups commonly occur along with *Curvirimula belgica* and *C. trapeziforma s.l.*. Ostracodes are dominated by *Carbonita altilis*, but other forms such as *C. inflata*, *C. scalpellus* and *C.* sp. cf. *C. corrugata* also occur. Ostracodes and spirorbids tend to be locally abundant in 'pockets' where the spirorbids usually appear to have been attached to the substrate. Some however, are attached to the posterior lobes of *Naiadites* (cf. Trueman 1942).

Head shields and segments of the thorax of a small, crawling arthropod such as perhaps, *Pygocephalus* sp. (cf. Copeland 1957) were found associated with the pockets of ostracodes and may have fed on them (Bless & Pollard 1973). Fish fragments occur, including scales of *Rhizodopsis* sp. and *Rhabdoderma* sp..

Horizon PHd

Some 2 m above horizon PHc in the roof shales of coal C2 a fauna fairly similar to that above occurs. The roof shales comprise a 2.5 m thick sequence of muddy and calcareous muddy shales. Several of the calcareous horizons may be termed muddy limestones.

Bivalves occur as single valves and angular fragments which are often convex-upward, particularly on siltier horizons. Juveniles are common and are generally better preserved than adult shells. Colour values of the sediment range from N5 to N4 reflecting the low organic carbon-content of the shales.

The fauna includes *Naiadites carbonarius*, *N. subtruncatus s.l.* and *N. productus s.l.* and variants close to *N. daviesi s.l.* (Figure 4.19). *Curvirimula* including *C. belgica* and *C. trapeziforma s.l.* were recorded as well as the ostracodes *Carbonita altilis*, *C. secans*, *C. scalpellus* and *C. bairdiodes*.

Horizon PHe.

Two metres of muddy shales contain shell fragments of *Curvirimula* and *Naiadites*. Spirorbids occur often attached to the posterior lobes of shells (mostly *Naiadites*). Ostracodes include *Carbonita altilis* with subordinate *C. secans* and *C. bairdiodes*.

This fossiliferous horizon occurs at the top of a 7 m thick fining-upward channel sandstone and is overlain by muddy sandstones.

Horizon PHf.

The roof shales of coal C5 contain only abundant plant material and rare fish fragments referable in part to *Rhabdoderma* sp..

Horizon PHg.

A sequence of lacustrine muddy and silty shales form the roof shales of coal C7 and contain the following fauna;

Naiadites carbonarius s.l.,

Curvirimula belgica,

Carbonita altilis with or without *C. corrugata*, *C. bairdiodes* and *C. humilis*.

Cluster analysis of some Cape Linzee faunas.

Bivalves which are sufficiently well preserved to measure accurately are rare in the Cape Linzee section and for this reason, cluster analyses were performed for both the *Naiadites* and *Curvirimula* faunas from horizons PHc-d combined. Obviously, the use of faunas from more than one horizon only provides a broad picture of variation in bivalve faunas in a particular short stratigraphic interval.

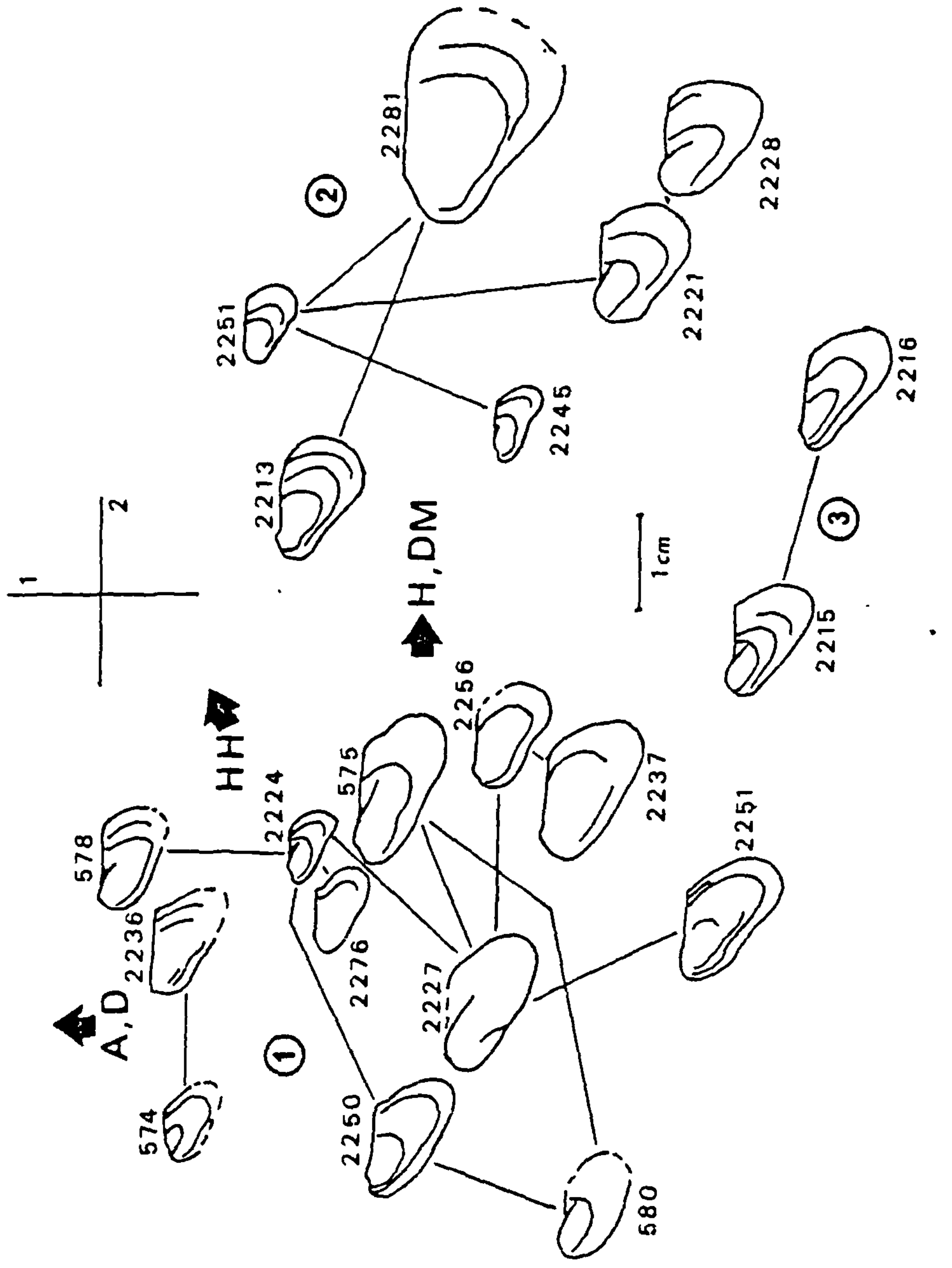
Naiadites faunas.

Figure 4.19 is a pictograph of *Naiadites* shells from horizons PHc-d (above and below coal C2). Three clusters were obtained and referred to the *N. subtruncatus*, *N. carbonarius* and *N.* sp. aff. *N. productus* groups. *N. productus s.l.* is represented by two 'unproduced' variants (cf. Trueman & Weir 1955, p. 224) with strongly sigmoidal carinas of the type discussed by Trueman & Weir (ibid.) as probably being the morphic norm of British *N. productus* assemblages. Shells assigned to the *N. carbonarius s.l.* group are similar to these unproduced shells except that their posterior lobes are broader and more evenly rounded. This feature is combined with a short, broad anterior end and a shallow byssal sinus high on the ventral margin to produce forms very close indeed to *N. carbonarius s.s.* (e.g. GMV 2221, see Rogers 1965, p. 671, Pl.83, fig.19). However, variation within the cluster tends towards shells with a longer anterior end and reduced posterior expansion which approach close to *N. daviesi*. The largest cluster is that referred to *N. subtruncatus* in which variation tends towards shells with broader, more evenly rounded posterior lobes and a shorter dorsal margin than in *N. subtruncatus s.s.* (e.g. GMV 580) and resembling some of the *N. productus* variants figured by Trueman & Weir (1955, Pl. 28, figs 23-24). The modal form of the cluster is within the range of variation allowable for *N. subtruncatus s.s.* being a shell of low obliquity and with a long dorsal margin (GMV 575).

Curvirimula faunas.

Cluster analysis of eighteen shells referred to *Curvirimula* spp. resulted in the identification of a single cluster. Variation occurs around several shells identified as *C. belgica s.s.* tending towards *C. trapeziforma* through increasing H/L ratios and decreasing W/L ratios, resulting in attenuation.

FIGURE 4.19: Pictograph of Port Hood Naiadites spp. faunas. 1 - N. subtruncatus group, 2 - N. carbonarius group, 3 - N. sp. aff. N. productus group. PCA1 v PCA2 plot. Variational trends as indicated.



4.3.2. The Port Hood Wharf section.

A section was examined north of Port Hood wharf (grid ref. 968132, Sheet 11k/4) that comprises several thick fining-upward channel sandstone sequences. A thin sequence of overbank deposits bearing several very thin coal seams (<100 mm thick) occur and is cut by a 7+ m thick channel sandstone (Figure 4.20). The roof shales of one of these thin coals comprises dark-grey, rootletted referabledy shale with crushed valves of Curvirimula belgica s.l., fish fragments, spirorbids and Carbonita spp. indet. The stratigraphic position of this section which was noted by Douglas (1945), is deduced to lie between the 'Five-foot' and 'Six-foot' seams (Figure 4.17).

4.3.3. Port Hood mine.

The Port Hood mine situated on the 'Six-foot' seam is now abandoned. The mine tips are largely overgrown but through careful work, loose slabs can be collected. Curvirimula reaches rock-forming proportions in a very dark grey muddy shale that appears to have lain not very far above the top of the coal seam, but specific identification is impossible due to crushing. Naiadites was not observed in any of this material. Ostracodes are mainly referable to Carbonita altilis though other forms do occur such as Gutschickia and also, Geisina.

4.3.4. Nova Scotia Department of Mines & Energy core DDNSPH2.

Of several borehole cores from the Port Hood area available for examination at the N.S. Department of Mines & Energy, one (DDNSPH2) was made available for detailed examination. The location of the hole is shown in Figure 4.16. Figure 4.21 is a log of the core showing the position and content of shell beds.

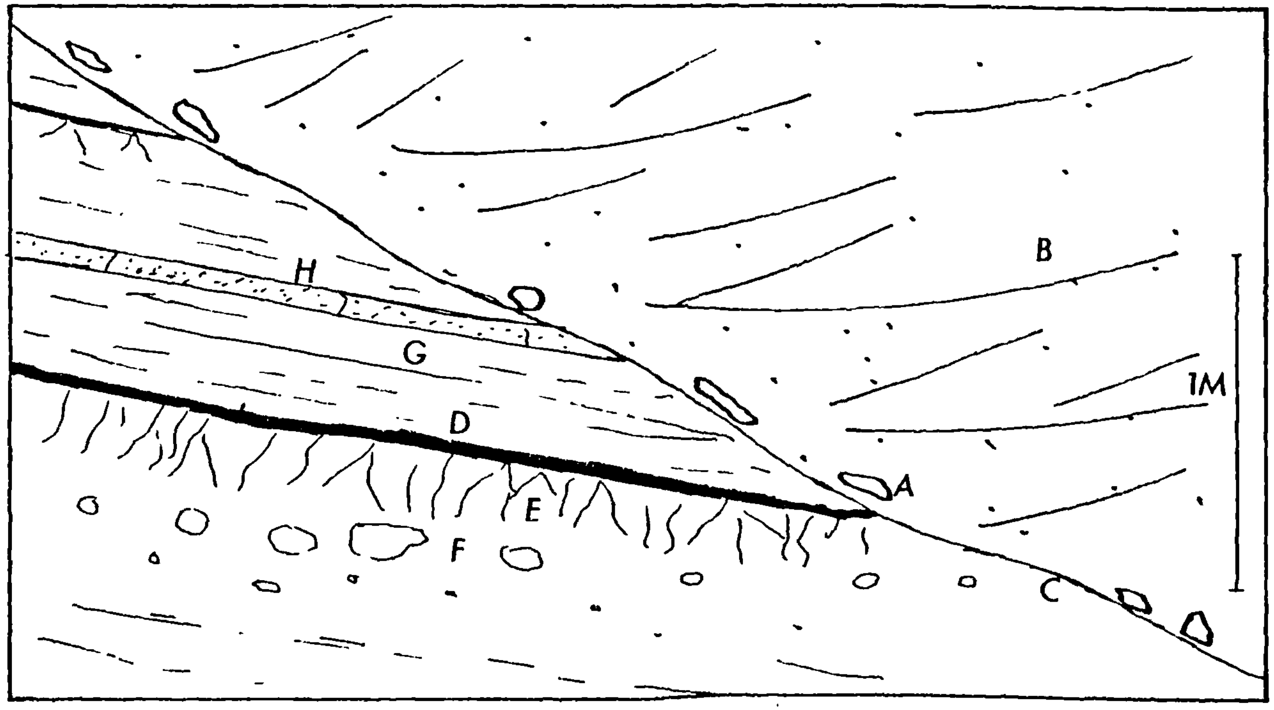


FIGURE 4.20: Field sketch of part of Port Hood Warfe section, Port Hood. A - Channel lag (plant material), B - Channel deposit comprising cross-bedded coarse-grained sandstone, C - Erosive base of channel, D - thin coal, E - rootletted seatearth, F - Calcrete comprising calcite/ironstone nodules in a pale grey silty shale, G - Muddy shales with ostracodes and plant debris, H - Thin parallel-sided sandstone (crevasse splay).

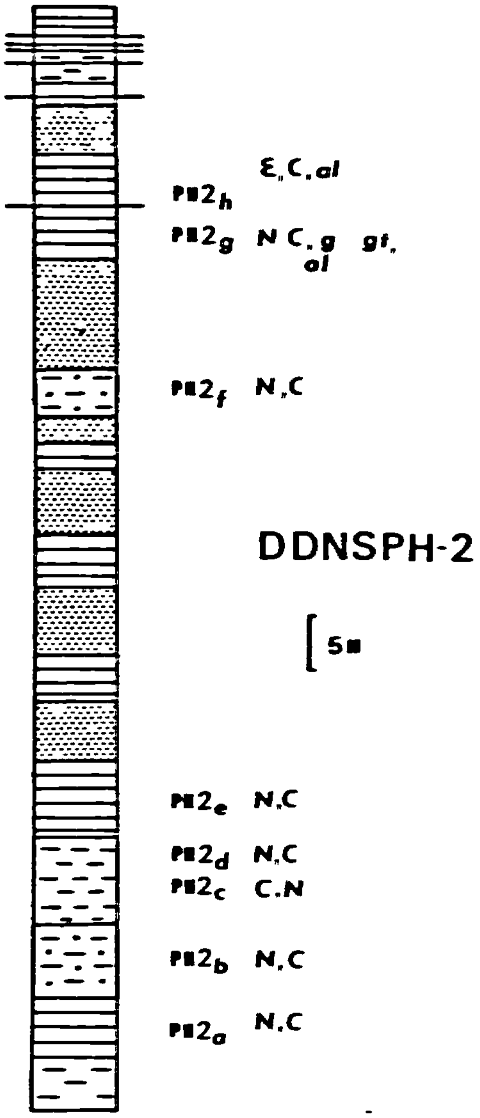


FIGURE 4.21: Log of N.S. Dept. of Mines & Energy Hole D.D.N.S.P.H.-2, faunal horizons and elements indicated.

The upper part of the core comprises thick channel sandstones which are predominantly reddened towards the top of the core, with thin, red overbank shales. Channels are locally 'stacked' and can reach over 25 m thickness. The lower half of the core section however, comprises thinner, grey channel sandstones with fine-grained, grey overbank deposits. Thin coals occur which occasionally have roof shales of lacustrine origin containing typical Riversdale faunas. The shell beds have been labelled in ascending stratigraphic order (Figure 4.21).

The lower fossiliferous horizons (PH2a-e) contain generally poorly preserved faunas including;

Naiadites spp. dominated by *N. carbonarius s.l.* and *N. subtruncatus*.

Curvirimula spp. including *C. belgica* and *C. trapeziforma s.l.*,

Fish fragments and spirorbids.

N. subtruncatus s.s. is confined to horizon PH2d, only a few examples of *N. subtruncatus s.l.* occuring elsewhere.

Three higher horizons (PH2f-h) contain a slightly different fauna. *Naiadites* is again represented by forms referable to the *N. carbonarius* group whilst *Curvirimula* is represented by the *C. belgica* group and elongate, attenuated variants of the *C. trapeziforma* group. Ostracode assemblages are dominated by *Carbonita altilis* though horizon PH2g contains rare forms referreable to *Gutschickia ninehvensis* and *Geisina* sp..

4.3.5. Discussion.

The Port Hood faunas recorded are typical of the Riversdale Group as reported by Bell (1944) and Rogers (1965), comprising Naiadites and Curvirimula with ostracodes, fish fragments and spirorbids. Gersib & McCabe's (1981) report of "bivalves resembling Carbonicola" remains unsubstantiated.

Fossiliferous horizons tend to occur consistently in several stratigraphic positions;

(a) within floodplain sequences,

(b) overlying coal seams and

(c)overlying the rootleted tops of crevasse splay sandstones.

The general depositional environment as envisaged by Gersib & McCabe (1981) is shown in Figure 4.22 and comprises a large meandering river cutting across a vegetated floodplain on which lakes were formed by chute cut-off, meander loop cut-off and through subsidence. Lakes were slowly infilled with fine-grained sediment during floods, or more rapidly, by crevasse splay deposition. Given such an environment, the position of faunal horizons is governed by lake formation; thus lakes formed on the floodplain through differential subsidence or the mechanisms outlined above. Occasionally, peat formation was curtailed through increased subsidence and/or flooding and the peat-forming plants were subsequently drowned as the lake formed. Crevasse splay deposition into lake areas led to the building out of deltas and resulted in shallowing or even emergence, allowing plant growth. In these three types of lake formation the faunas entered the environment as soon as there was sufficient water cover to allow it. Environmental factors such as turbulence and substrate

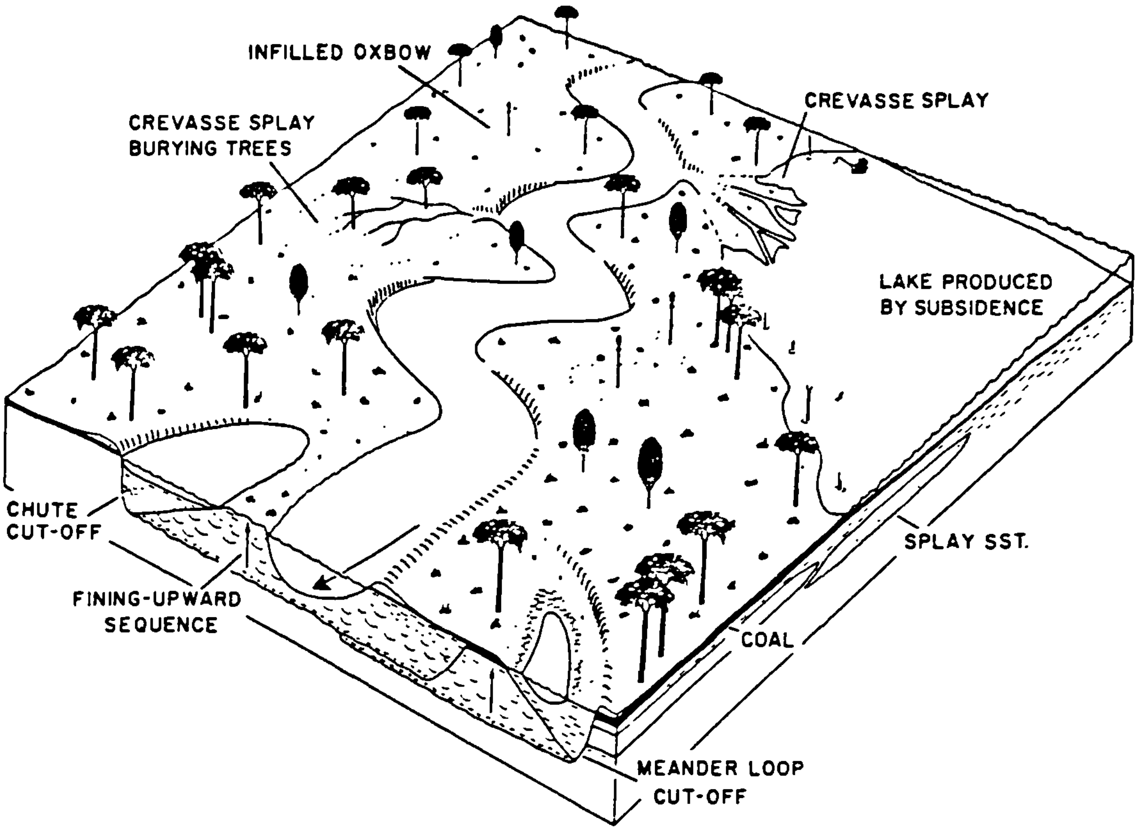


FIGURE 4.22: Gersib & McCabe's (1981) model for the depositional environment of the Port Hood Fm. at Port Hood. See text for discussion, no scale implied.

condition were reflected in the overall external morphology of the bivalves and influenced the ostracode faunas (Eagar 1978, Chapter 7).

The lakes were predominantly freshwater, Naiadites, a bivalve favouring fresh to slightly brackish water (Eagar 1961, Calver 1968a) being the predominant form. Curvirimula is considered to be tolerant if not typical, of brackish to near-marine conditions (Weir 1960, p.299, Eagar 1947, 1961, Calver 1968a) however, in Nova Scotia it commonly occurs with Naiadites and Carbonita spp., an ostracode considered to favour fresh to slightly brackish water (Pollard 1966, Calver 1968a). A fuller discussion of the environmental tolerences of Curvirimula is deferred until Chapter 7.

The roof shales of the 'Six-foot' seam contain an unusual fauna: Curvirimula without Naiadites, is associated with Geisina sp., Gutschickia sp., Carbonita altilis and 'Estheria'. This assemblage would suggest brackish water (Chapter 7).

Preservation of the faunas, generally as single valves and fragments, indicates that current activity within the lakes was strong enough to disarticulate shells and also, to sustain oxygenation of the lake bottom waters.

4.3.6. Correlation.

The lack of thick, laterally continuous coal seams and marine horizons make correlation of the Port Hood Formation difficult. The 'Six-foot' seam is perhaps the only coal having a sufficiently distinctive roof shale fauna and being thick and laterally persistant enough to trace. On the basis of the distinctive Curvirimula, Geisina and 'Estheria' roof shale fauna, the 'Six-foot' seam can be correlated with a 1.15 m thick coal in core DDNSPH2 (see Figure 4.21). In addition, the apparent limited distribution of forms referable to Naiadites subtruncatus in both the core and in the Cape Linzee section may be a basis for a further correlation. However, numerous thin coal seams in the Cape Linzee section at this stratigraphic level are absent in the core (Figure 4.21). The almost ubiquitous occurrence of Curvirimula in the Port Hood Formation would, by comparison with Britain, indicate a Westphalian A age (Communis Chronozone). However, Naiadites subtruncatus and N. productus range from the base of the modiolaris Chronozone in Britain. Also, N. carbonarius is a form deemed to be typical of the Cumberland Group by Rogers (1965) though this author did not know the full stratigraphic range of this bivalve.

Curvirimula belgica ranges from the Lower Carboniferous through to the upper Similis-Pulchra Chronozone (Weir 1966, p.308) with an apparent acme in the upper part of the Communis Chronozone. C. trapeziforma is also characteristic of the British Communis Chronozone (ibid.) whilst C.corvosa is known only from Nova Scotia.

The ostracode assemblages show obvious environmentally influenced distribution patterns but Geisina is a Lower Coal Measures form in Britain being associated with marine bands at higher stratigraphic levels (Calver 1968a). Carbonita corrugata, if the identification is correct, is apparently confined to beds of the Modiolaris Chronozone of Britain (Gregory 1974).

A correlation on this basis proves difficult. However the Port Hood Formation is considered to be upper Westphalian A - lower Westphalian B here for the reasons outlined in Chapter 7.

4.4. Faunas of the Chimney Corner area.

Coal-bearing strata assigned to the Riversdale Group (Bell

1943) crop out along the western shore of Cape Breton Island from Broad Cove to Margaree Harbour (Figure 4.23). The Carboniferous sediments in this area are folded into a broad syncline and Bell (ibid.) calculated the thickness of the Riversdale Group in the eastern limb as about 2590 m. The area as a whole is known as the Chimney Corner - St. Rose coalfield.

The Chimney Corner coal area extends from the Gulf of St. Lawrence at Chimney Corner, SSW for about 1.5 km and has a mean width on land of about 340 m (an area of about 0.65 km). Here, the Riversdale Group is underlain by non-marine strata of the Canso Group.

Figure 4.24 shows two measured sections through the Riversdale Group at Chimney Corner. The first is taken from Bell (1943) who attempted a correlation of the seams of the St. Rose coal area with those of Chimney Corner. The second is a section measured from Chimney Corner (390406, Sheet 11k/4) to grid reference 404417. The Group consists of thick channel sandstones, crevasse splay sandstones and floodplain and lacustrine mudrocks. The strata dip at around 30-40° to the WNW though, dip is locally highly variable.

All of the economically important coal seams occur in a thin coal-bearing interval 150 m thick (Bell 1943) towards the top of the Riversdale Group which, according to Bell (ibid.) is overlain by at least 100 m and possibly as much as 280 m more sediment. The coal seams are generally poorly exposed, probably due to early mining.

No recent work has been done on the Chimney Corner area but the N.S. Department of Mines & Energy geological map (1979) shows the Riversdale Group at Chimney Corner as belonging to the Port Hood Formation. There are certainly notable similarities as the lower half of the Group in both areas is predominantly reddened and coals are restricted to a thin coal-bearing interval towards

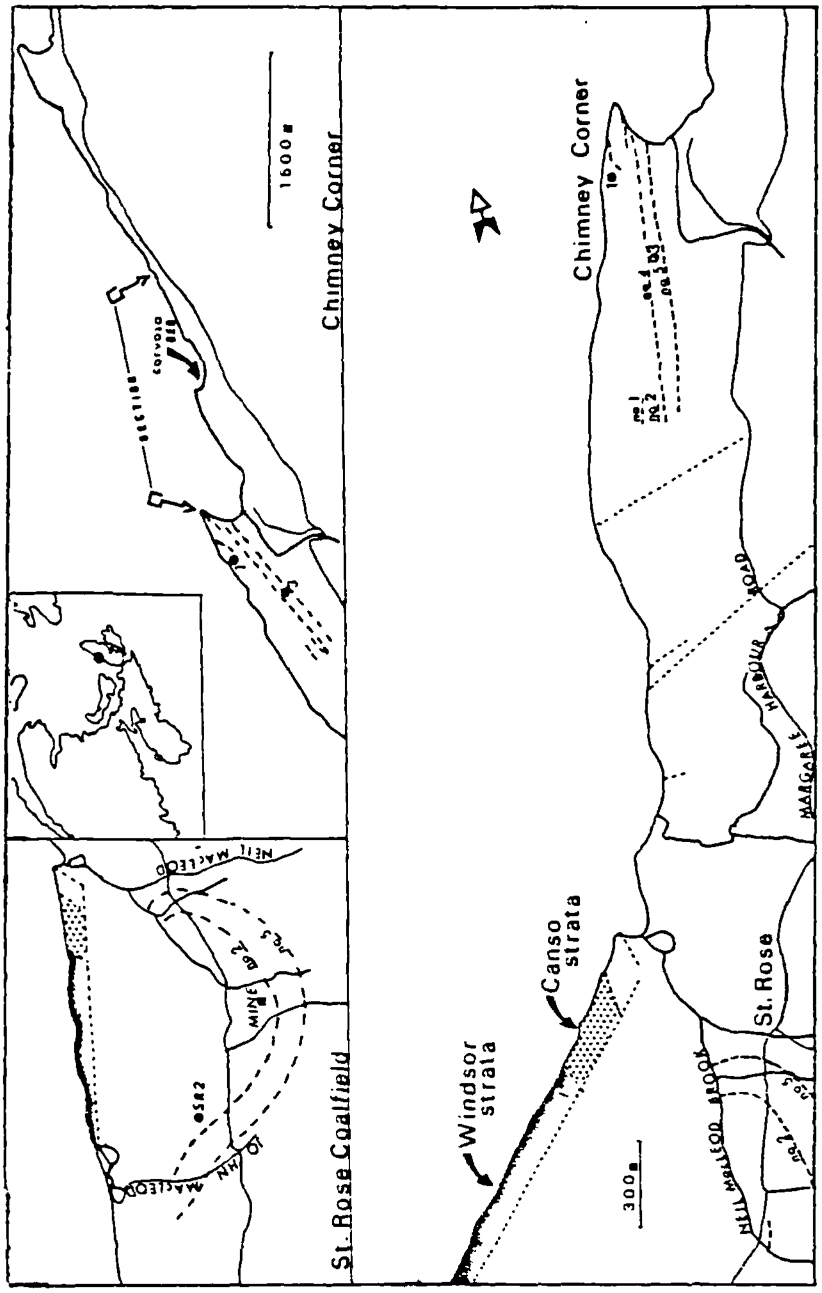


FIGURE 4. 23: Sketch maps of the Chimney Corner-St. Rose coalfield. Coal seam incrops shown after Bell (1943). Boreholes indicated thus: ●.

the top. Overall lithology is very similar and deposition probably took place in a similar environment to that described by Gersib & McCabe (1981).

Bell (1943) recorded typical Riversdale faunas of small 'naiaditiform Anthracomya', Naiadites, spirorbids, ostracodes and fish. Rogers (1965) re-examined material collected by Dawson (1894) redescribing Naiadites mytiloides (as N.? mytiloides) and describing a new 'species', Curvirimula? corvosa. Both of these morphological varieties have been re-examined in this study and both are referred to Curvirimula (see also Vasey 1984).

The Chimney Corner area Riversdale Group was examined along the shore section described above and also in two N.S. Department of Mines & Energy cores (DDNSCC1 & DDNSCC3).

5.4.1. Chimney Corner section.

The Riversdale Group in this area is exposed only in cliff sections and thick sandstone units which form long, low hills and sandstone points, makes examination of the whole section hazardous and difficult. Figure 4.24 represents the coastal section which it was possible to measure and gaps in the section can nearly always be taken as representing thick sandstones.

Several fossiliferous horizons (CCj-a) occur in the section but coals are restricted to strata in the Menzies point - Chimney Corner area (Figure 4.24) near the top of the section. The only coal that could be identified with some confidence, was a thin seam with a distinctive roof shale fauna that is probably the #5 seam of Bell's (1943) terminology.

Horizon CCj.

This comprises a thin calcareous siltstone overlain by a thin

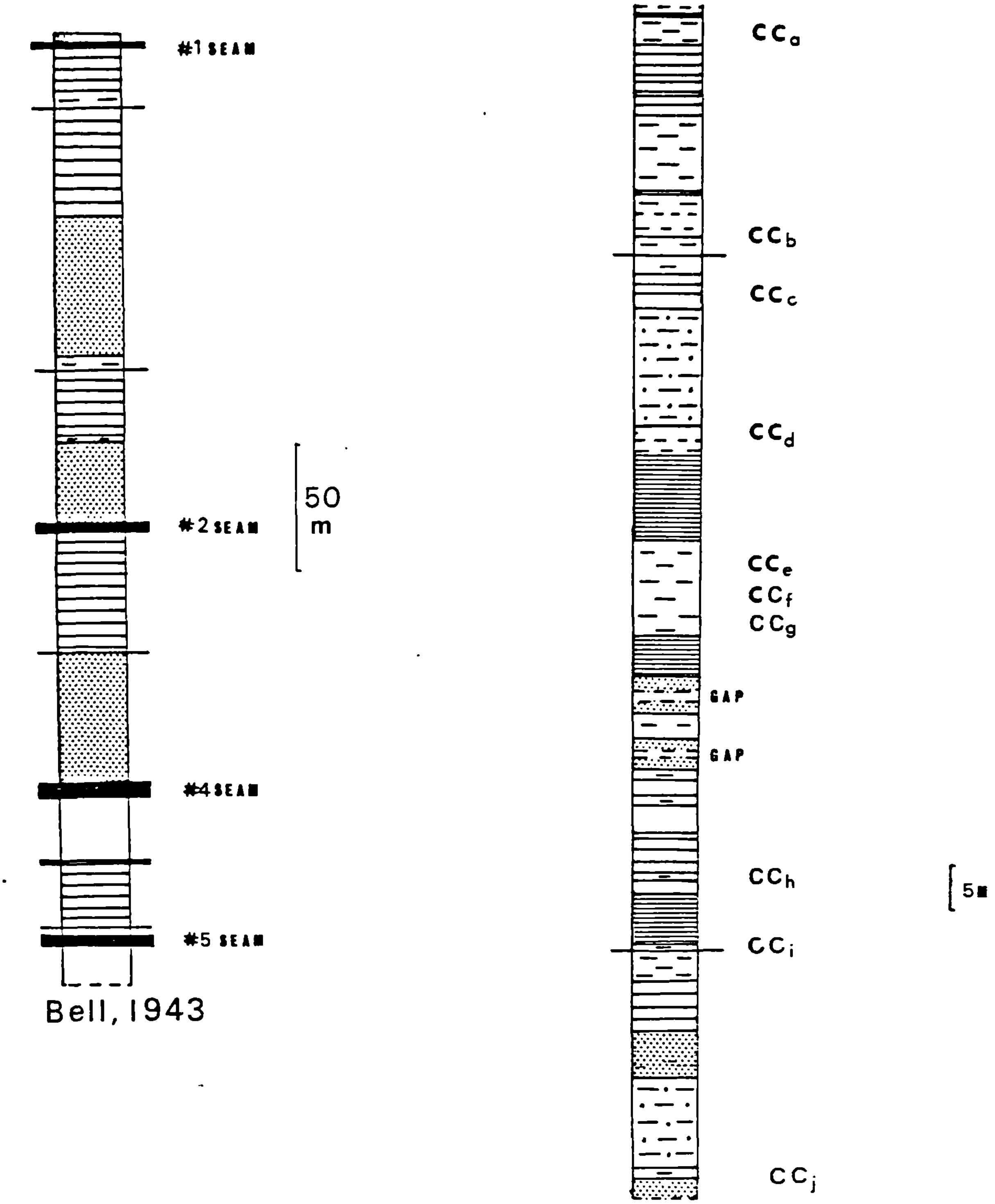


FIGURE 4.24: Sections through the Port Hood Fm. of Chimney Corner by Bell (1943) showing seam names and thicknesses, and the Chimney Corner coastal section with shell beds indicated.

dark grey (N2) muddy shale at the base of the section. Faunas in the shale include A life assemblage of articulated and closed shells referable to *Curvirimula* including *C. ovalis s.l.*, *C. corvosa s.l.* and *C. trapeziforma s.l.*. Ostracodes occur rarely with *Carbonita altilis* dominant. Both bivalves and ostracodes are often pyritised and much of the dark colour of the sediment is due to the presence of finely disseminated pyrite.

Horizon CCg-e.

Three separate fossiliferous horizons were recorded within an 11 m thick sequence of laminated silt and muddy shales (Figure 4.24). Fauna is restricted to *Naiadites* spp. preserved mainly as single valves and shell fragments, although a few shells were articulated and in close to a life position. The shells are predominantly small in size with many juveniles present so that they are difficult to identify with certainty. However, several larger shells could be referred to the *N. carbonarius* group. Variation within this group comprise trends towards a smaller, sharper anterior end and a more triangular posterior lobe. A second trend towards shells with a more widely developed posterior than is typical in *N. carbonarius*. The two extreme variants produced by these trends were referred to *N.* sp. cf. *N. triangularis* and *N.* sp. cf. *N. productus* respectively.

Horizon CCd.

Abundant well-preserved, convex-upward single valves of the *Naiadites carbonarius* group occur in this 1.4 m thick sequence of pale grey (N4) silt and muddy shales. Some of the shells display a trend towards *N. productus*.

Horizon CCc.

The roof shales of a thin coal seam identified as the #5 seam (of Bell, 1943) contains a distinctive and well-preserved fauna. The lithology is rather unusual, comprising a 4+ m thick sequence of dark-grey (N2-3) to almost black (N1.5), muddy shales. Plant material and carbonaceous debris is everywhere abundant however, much of the dark colour of the sediment seems to be due to the presence of finely disseminated pyrite. Pyrite also occurs replacing shell and plant material.

Naiadites is absent and all the shells were identified as *Curvirimula* occurring both as articulated closed shells, articulated open shells and as single valves. Ostracodes are abundant, forming an assemblage of *Carbonita altilis* with occasional *C. bairdiodes*, *C. pungens* and large, punctate forms referable to *Gutschickia ninehvensis*. Spirorbids occasionally attain rock-forming proportions (Figure 4.25).

Curvirimula, including shells of the *C. corvosa*, *C. trapeziforma* and *C. attenuata* sp. nov. groups, are abundant. Variation is discussed under a separate heading. The abundance of *C. corvosa s.l.* and the distinct litholgy of the bed suggests that this is the type horizon of *C. corvosa* and of Dawsons' *C. mytiloides* (Dawson 1894, Rogers 1965).

Horizon CCb.

An unnamed coal seam above the #5 seam, is overlain by a sequence of fossiliferous, pale to medium grey (N3-5) muddy and silty shales. The fauna is restricted to angular shell fragments and external impressions and defies identification.

Horizon CCa.

A thin brown sparite with interlaminated pale grey, calcareous mudstone lies at the top of the measured section. Uncrushed, sparitised shells of the *Curvirimula corvosa* group occur abundantly with associated ostracodes and fish remains.

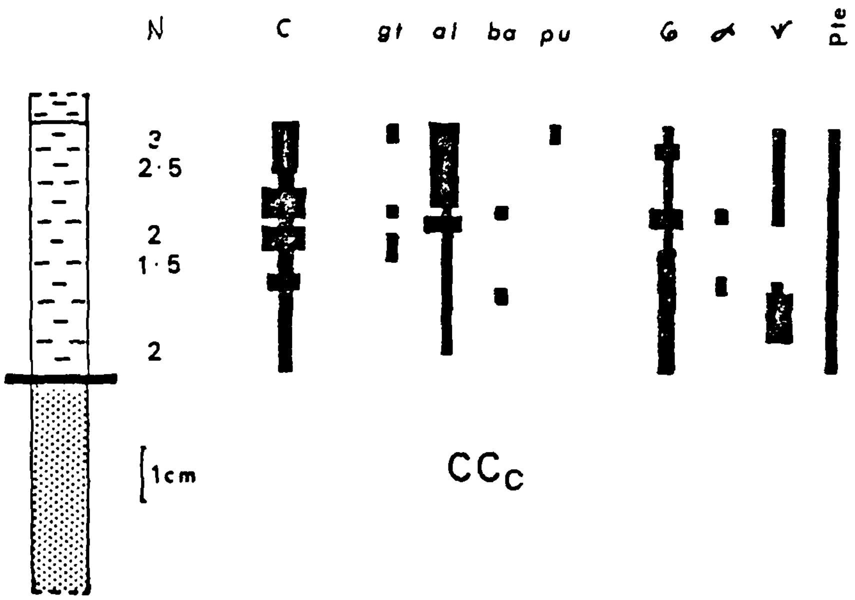


FIGURE 4.25: Distribution of fauna in horizon CCc of the Chimney Corner coastal section (roof of the #5 seam) - Curvirimula corvosa Bed.

4.4.2. N.S. Department of Mines & Energy core DDNSCC1.

Figure 4.26 shows a log of this core and its location is shown in Figure 4.24. The hole cut several coal seams which according to Bell (1943), can be named the #2, #4 and #5 seams. Several fossiliferous horizons (CC1e-a) were located and collected from.

Horizon CC1e.

A fining-upward, 6 m thick seqeunce of pale grey silty to muddy shales occur. At the base of the sequence, articulated shells of *Naiadites* occur without associated fauna and are referable to *N. carbonarius s.l.* and *N. subtruncatus s.l.*. In the finer-grained shales higher in sequence Naiadites is rare, being preserved mainly as shell fragments, though a few single valves can be named *N.* sp. cf. *N. productus*.

Curvirimula is the dominant bivalve in these finer-grained rocks comprising shell fragments, single valves and articulated and open shells, one of which was identified as *C.* sp. aff. *C. trapeziforma*. Ostracodes associated with *Curvirimula* and include *Carbonita altilis*, *C. pungens* and cf. *C. salteriana*.

Horizon CC1d.

A poorly preserved fauna which includes shell fragments and external impressions of *Naiadites* of the *N. carbonarius* group, *Carbonita altilis*, *Gutschickia ninehvensis* and *Spirorbis* sp. occurs in a pale to medium grey muddy shale.

Horizon CC1c.

A thin, medium grey muddy shale overlying a crevasse splay sandstone was found to contain to following fauna:-

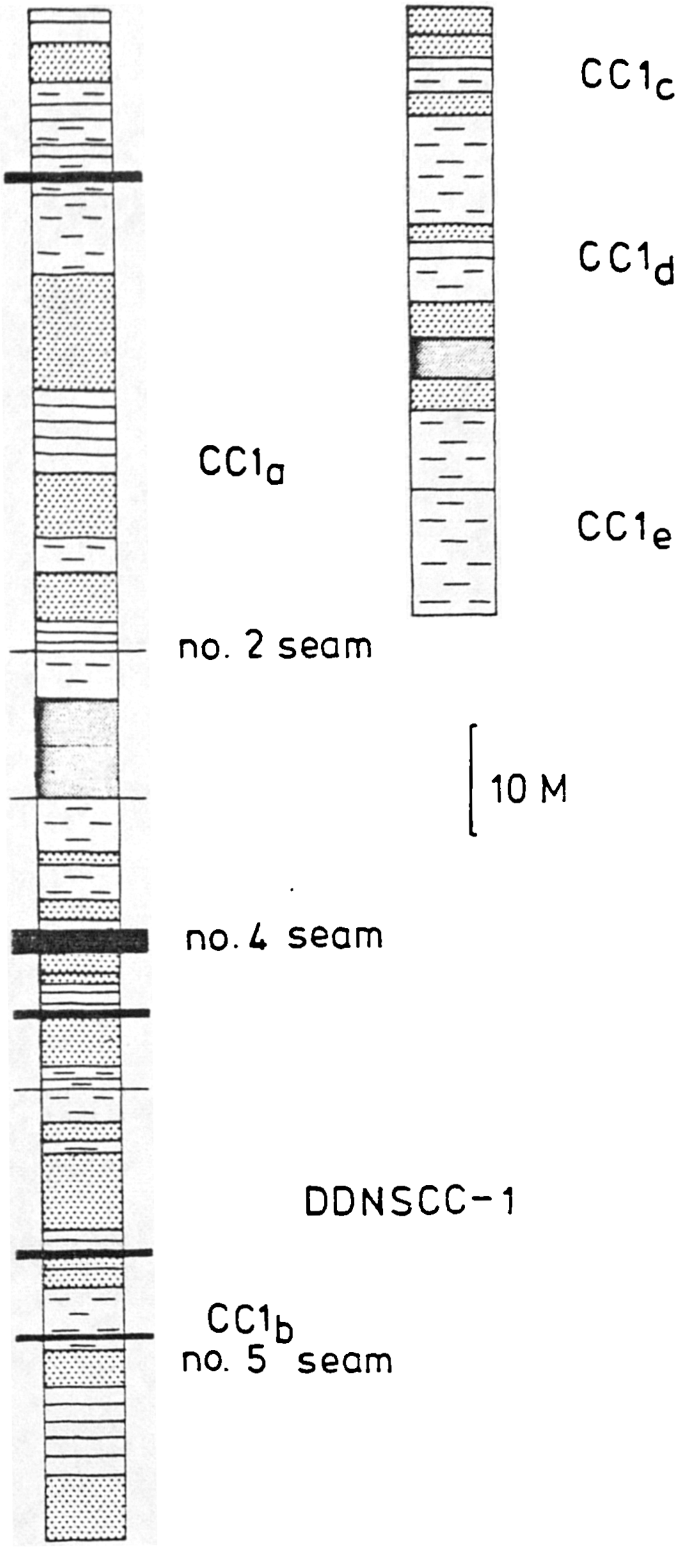


FIGURE 4. 26: Log of N.S. Dept. of Mines & Energy Hole D.D.N.S.C.C.-1. Faunal zorizons indicated.

FIGURE 4.27: Distribution of fauna in the <u>Curvirimula corvosa</u> Bed above the #5 seam in Hole D.D.N.S.C.C.-1.

Naiadites including *N.* sp. cf. *N. carbonarius* preserved as partially fragmented single valves,

Curvirimula spp. including shells referable to *C. attenuata* sp.nov. preserved as single valves and fragments,

Spirorbis sp. and unidentified ostracodes.

Horizon CC1b.

The roof shales of the #5 seam contain a closely similar fauna to that of horizon CCc of the coastal seaction. 4 m of dark-grey to almost black muddy shales, silty in places, contain the following fauna:-

Curvirimula spp. including *C. corvosa*, *C. attenuata* sp. nov., *C. belgica* *s.l.* and *C. ovalis* *s.l.*,

Carbonita altilis, *C. corrugata*, *C.* cf. *salteriana*, *C. pungens* and *Gutschickia ninehvensis*. (Figure 4.27).

4.4.3. N.S. Department of Mines & Energy core DDNSCC3.

A log of this hole is shown in Figure 4.28 and its geographical location in Figure 4.23. The only named seam identified in this hole is the #5 seam. Several fossiliferous horizons (CC3a-l) are present and were sampled.

Horizon CC3h.

A pale grey silty muddy shale contains shell fragments and single valves of *Naiadites* and *Curvirimula*.

Horizon CC3g.

FIGURE 4.28: Log of N.S. Dept. of Mines & Energy Hole D.D.N.S. C.C. - 3. Shell beds and coals labelled.

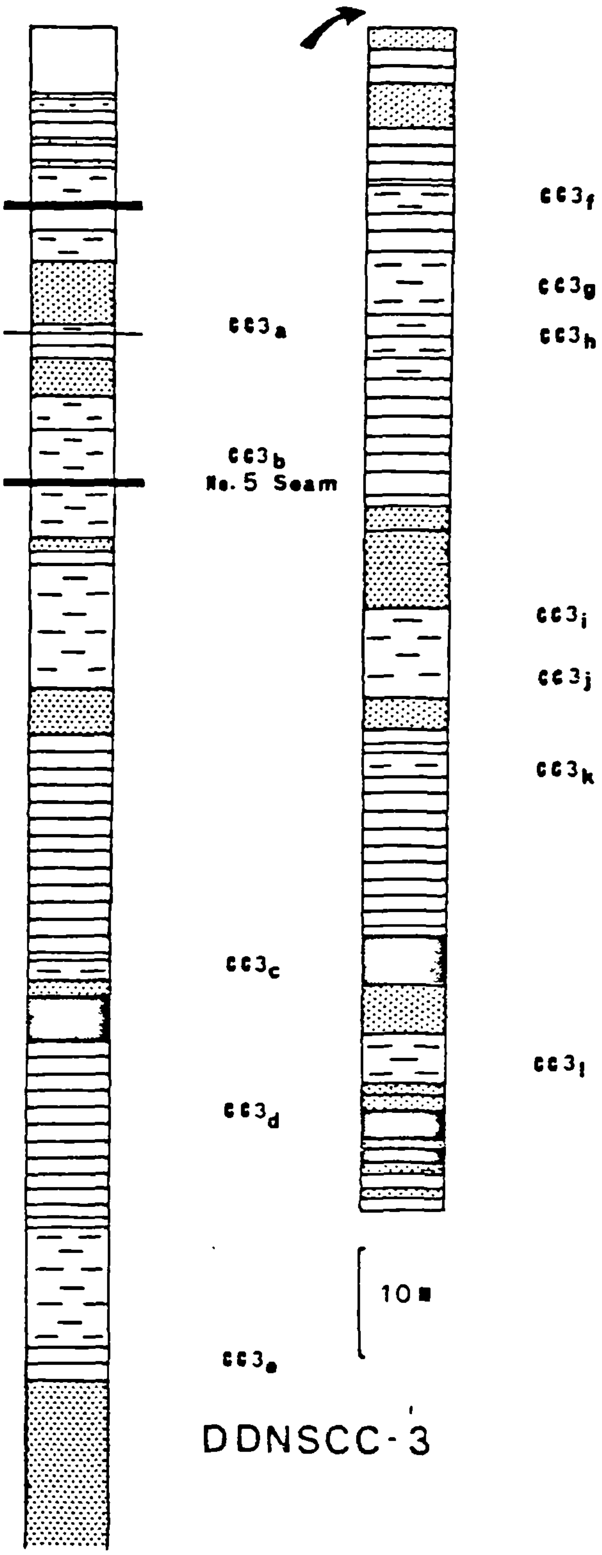


FIGURE 4.29: Distribution of fauna above the #5 seam in Hole D.D.N.S.C.C.-3. Scale bar = 1 metre

A well-preserved fauna comprising articulated shells referable to *Naiadites carbonarius s.l.*, *N. productus* and *N.* sp. cf. *N. quadratus* is present with shell fragments of *Curvirimula*.

Horizon CC3e.

A 3 m thick sequence of medium grey (N3) silty shales overlying a thick sandstone contains the following fauna:-

Naiadites carbonarius,

Curvirimula spp. including *C. trapeziforma s.l.*, *C. corvosa s.l.* and *C. belgica s.l.*,

Carbonita altilis, *C. humilis*, and *Gutschickia ninehvensis*.

Horizon CC3c.

A 1.5 m thick sequence of medium grey (N3), silty muddy shales contains the following fauna;

Naiadites spp. including *N. carbonarius*, *N.* sp. aff. *N. productus* and *N.* sp. cf. *N. carinatus*.

Curvirimula spp. including *C. corvosa* and *C. trapeziforma*.

Carbonita altilis and *Gutschickia* sp.

Horizon CC3b.

The roof shales of the #5 seam contain a closely similar fauna to that of DDNSCC1 and the coastal section at this horizon, as follows:-

Curvirimula spp. including *C. corvosa*, *C. attenuata* sp. nov., *C. trapeziforma s.l.* and *C. belgica s.l.*.

Carbonita altilis and Gutschickia ninehvensis. (Figure 4. 29).

4.4.4. Cluster analysis.

Cluster analysis was performed only on Curvirimula spp. from the roof shales of the #5 seam where shells are both abundant and well preserved. Elsewhere, the number of shells available for measurement was too low. No single locality or identifiable horizon produced a sufficient number of measurable Naiadites for valid cluster analysis to be undertaken.

4.4.4.1. Results of cluster analysis of Curvirimula spp. from the roof shales of the #5 seam.

The roof shales of the #5 seam were found to contain a very consistent fauna in all the sections examined. A total of 57 shells was measured and cluster analysis performed Figure 4.30(1), (2), (3)). The three significant clusters obtained are shown in pictographic form and can be referred to the C. corvosa, C. trapeziforma s.l. and C. attenuata sp. nov. groups.

In order to test that the populations from the sampled localities were indeed statistically similar, regression lines were fitted to an H-L scatter plot of the three assemblages (Figure 4.31). This confirms a similar distribution in terms of H and L in shells from all three localities. A frequency chart of H/L ratios suggests a bimodal distribution (Figure 4.31) however, the W/L ratio shows a unimodal distribution.

The C. corvosa group shows little variation, the holotype proving to be a near-modal form (Figure 4.30(2)) having a slighlty larger anterior end and greater width than the mean of the cluster. Two distinct shell-shape trends occur;

(a). decreasing H/L and increasing DM/L ratios tends to produce rather subovate shells lacking the postero-ventral elongation characteristic of *C. corvosa s.s.* The postero-dorsal and ventral margins form an unbroken curve resulting in a rather broad posterior end. These shells could be named *C.* sp. cf. *C. belgica*.

(b). decreased W/L and increasing H/L ratios resulting in postero-ventral attenuation combined with a short dorsal margin produces shells (Figure 4.30, 1229 and 1093) similar to *C. attenuata* sp. nov..

The *C. trapeziforma* group displays several variational trends around a near-modal form very close indeed to *C. trapeziforma s.s.*. Forms of low oblquity and short anterior ends are similar to some of those variants figured by Weir (1960, Pl.32, figs. 29-30) as *C.* sp. cf. *C. trapeziforma*. A second trend towards forms with a continuously rounded margin and subcentral umbones produces a variant similar to *C. tessellata* (Figure 4.30a, 2430). Shells of slightly lower obliquity and shorter anterior end are similar to *C. ovalis* (Figure 4.30, 1249). A third and well developed trend, produces elongated shells with short dorsal margins resembling *C. attenuata* sp. nov..) . ?

The *C. attenuata* sp. nov. group is fully described in the systematic part of this thesis. It displays a trend toward naiaditiform variants and an opposite trend towards more subovate forms.

4.4.5. Discussion.

The #5 seam roof shale can be traced across the entire Chimney Corner area by its distinctive lithology and fauna. In view of its correlational value and because it is the type horizon

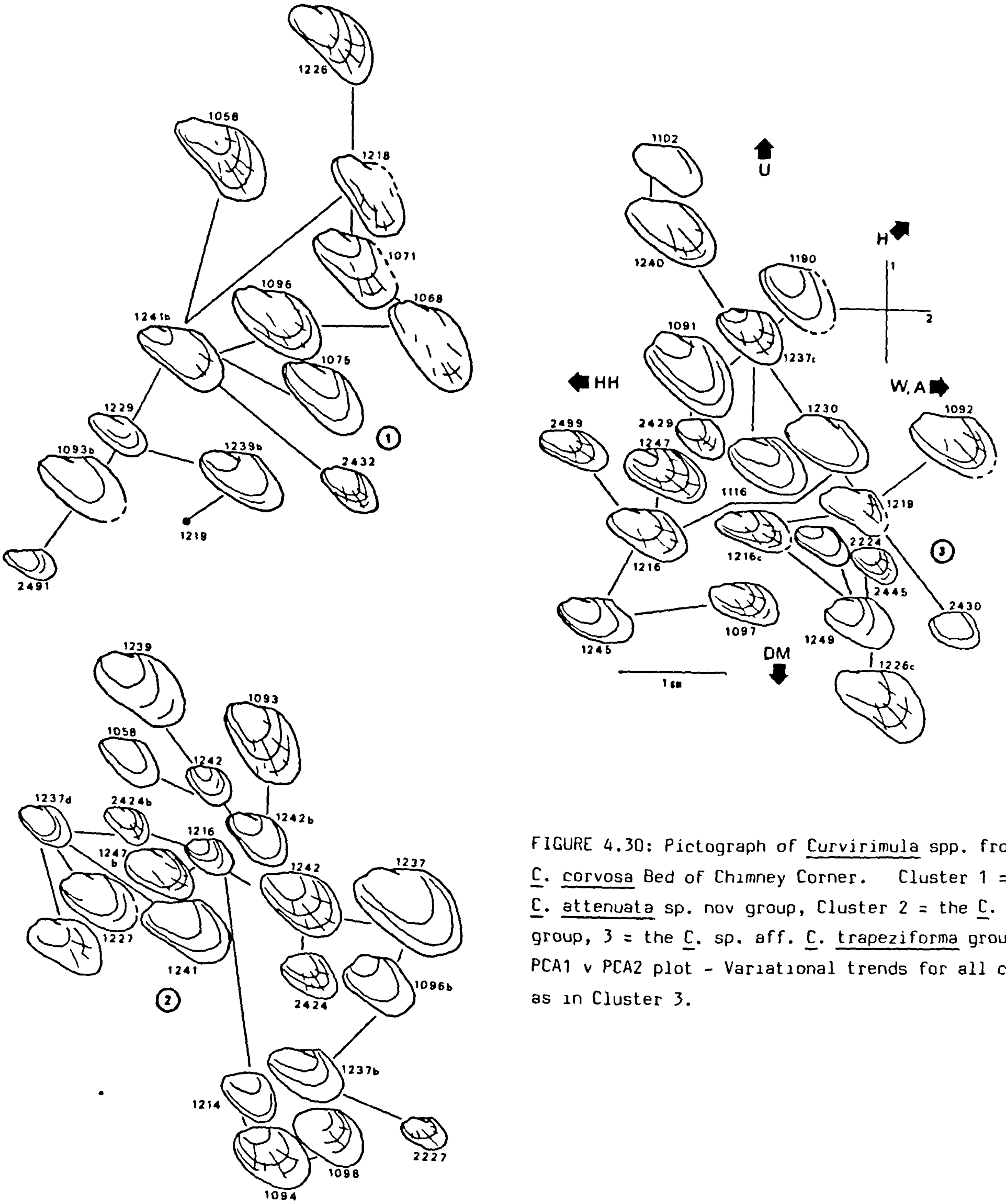
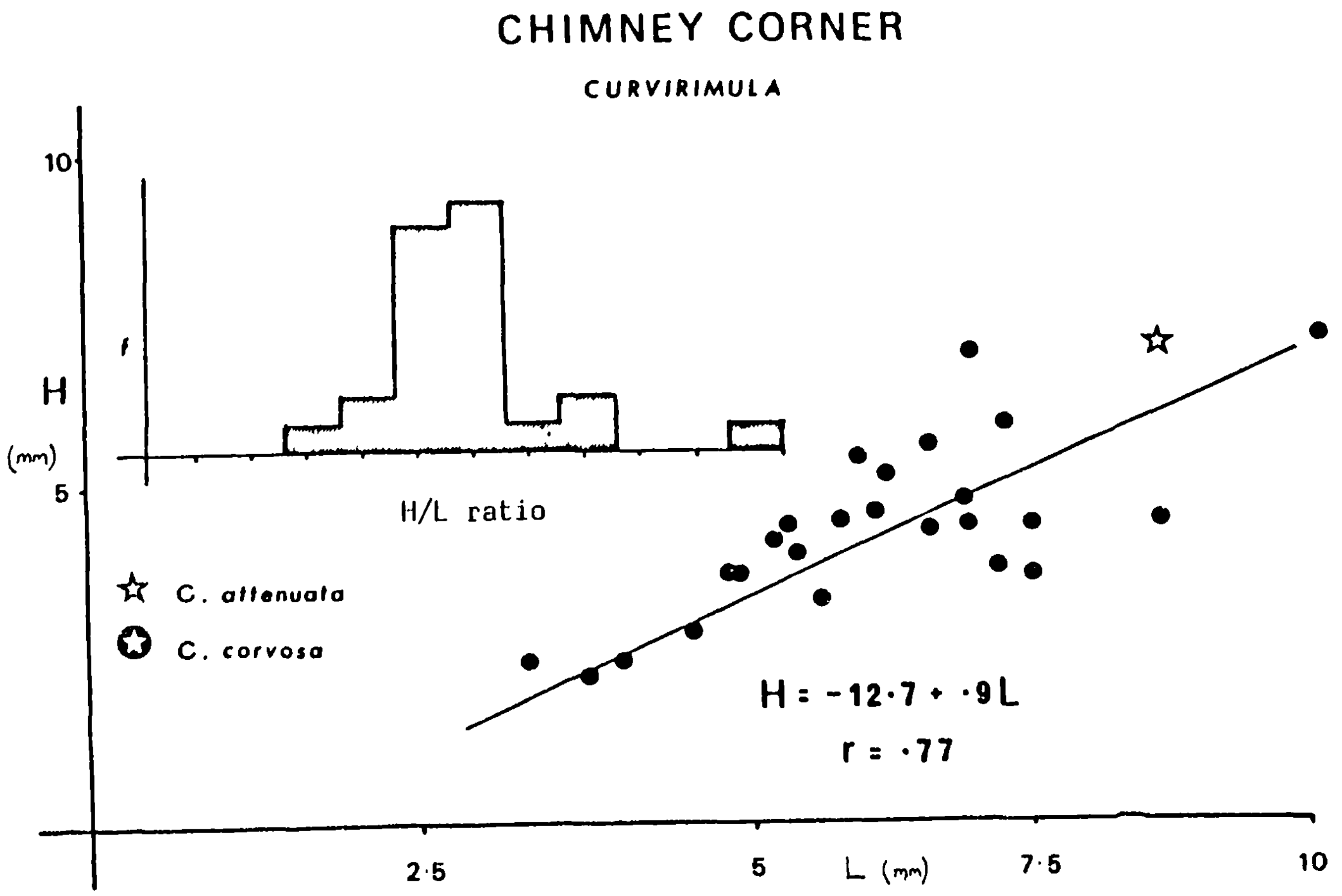


FIGURE 4.30: Pictograph of *Curvirimula* spp. from the *C. corvosa* Bed of Chimney Corner. Cluster 1 = the *C. attenuata* sp. nov group, Cluster 2 = the *C. corvosa* group, 3 = the *C.* sp. aff. *C. trapeziforma* group. PCA1 v PCA2 plot - Variational trends for all clusters as in Cluster 3.

FIGURE 4.31: H-L scatter plot and fitted regression line for Curvirimula spp. from the Curvirimula corvosa Bed (roof of the #5 seam), Chimney Corner.



of Curvirimula corvosa, it is proposed to name this horizon formally as the Curvirimula corvosa Bed.

A general correlation of the sequences of the three measured sections can be attempted on lithostratigraphic grounds using the C. corvosa Bed as a marker (Figure 4.32). This allows the assessment of the distribution of depositional environments in the Chimney Corner coal area. The general picture is one of a series of fining-upward units levee and floodplain deposits. Finer mudrocks generally follow this sequence and represent the distal floodplain - peat swamp and lacustrine phase. Most of the recorded faunas occur within the lacustrine facies. The reddened mudrocks sometimes present in the cycle are thought to represent a local subaerial phase.

The C. corvosa Bed, as the only consistent, laterally traceable faunal horizon, must have been deposited in a lake of quite considerable extent. The lithology of the Bed indicates that the lake bottom sediments were anoxic and that current activity and sedimentation rates were low.
It is believed (see Chapter 7) that the bivalve fauna was pseudoplanktonic in origin, Curvirimula perhaps being attached to floating plant debris. Similar conditions may be envisaged for horizon CCj of the coastal section.

Other lakes appear to have been local in extent as the faunas are local and cannot be traced laterally. Generally the presence of Naiadites and Curvirimula indicates essentially the same sort of conditions existed in the Chimney Corner lakes as at Port Hood.

Correlation.

Correlation between Port Hood and Chimney Corner may be possible. The coal-bearing interval of the two areas occurs in the upper part of the Riversdale Group and in both areas a coal seam

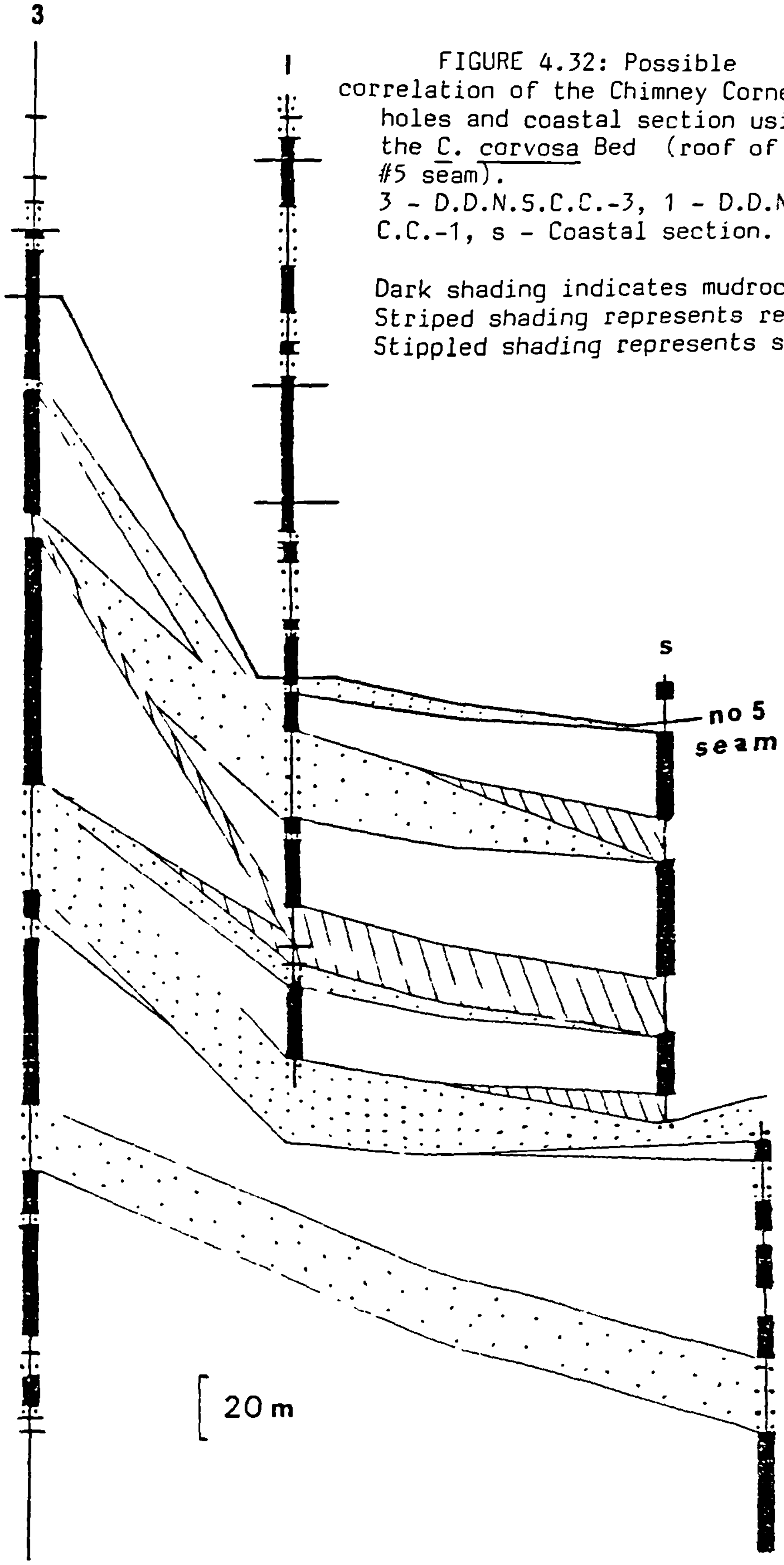


FIGURE 4.32: Possible correlation of the Chimney Corner holes and coastal section using the *C. corvosa* Bed (roof of the #5 seam).
3 - D.D.N.S.C.C.-3, 1 - D.D.N.S. C.C.-1, s - Coastal section.

Dark shading indicates mudrocks
Striped shading represents redbeds
Stippled shading represents sandstone

is overlain by a roof shale with Curvirimula not accompanied by Naiadites. Although the associated ostracode faunas in the roof shales differ somewhat, it may be possible to tentatively correlate the #5 seam of Chimney Corner with the 'six-foot' seam of Port Hood.

Correlation with Britain is somewhat difficult. Ranges of the various Naiadites spp. and those of the Curvirmula spp. do not overlap in Britain. On the basis of evidence presented in Chapter 7, the Coal-bearing Chimney Corner section is considered to be upper Westphalian A - lower Westphalian B in age.

4.5. Faunas of the St. Rose coalfield.

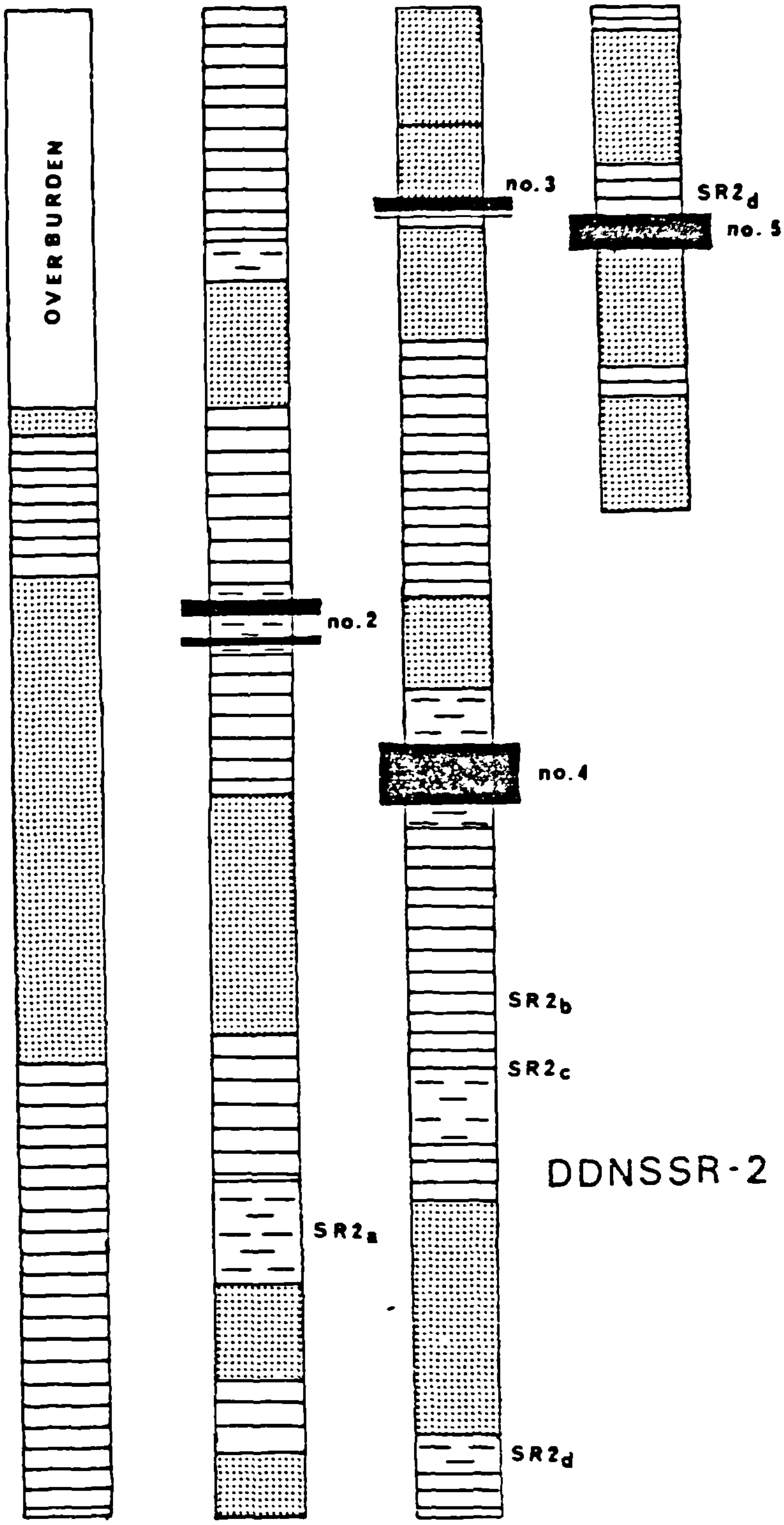
The St. Rose area of the Chimney Corner - St. Rose coalfield lies between the northern branch of the Neil Macleod Brook and the John Macleod Brook (Figure 4.23). Eastward the coal-bearing area does not reach more than 800 m from the Dunvegan - Margaree Harbour road. Westward it is limited by a fault that runs nearly parallel to and probably within 400 m of the shore of the Gulf of St. Lawrence (Bell, 1943).

The Riversdale Group of the St. Rose area contains several coal seams numbered by Bell (1943). The #2 seam has been mined intermittently from 1916 to the present and the #5 seam is known only from borehole records (Ibid). The area was not visited but information is available from examination of the core from the N.S. Department of Mines & Energy borehole and of a single slab collected by Dr. E. L. Zodrow from above the #2 seam.

4.5.1. N.S. Department of Mines & Energy core DDNSSR2.

Figure 4.33 is a core log of a borehole which cut several coal seams in the upper, coal-bearing member of the Riversdale Group. Faunas are sparse and poorly preserved. The horizons at

FIGURE 4.33: Log of N.S. Dept. of Mines & Energy Hole D.D.N.S.S.R.-2. Shellbeds and coal seams labelled.



which they occur are indicated on the figure. Faunas comprise mainly shell fragments at most horizons and include material referable to *Naiadites* spp. and *Curvirimula* spp.. *C. corvosa* *s.l.* was recorded in horizons SRa and SRc whilst, shells resembling *C. belgica* *s.l.* were collected from horizons SRc and SRd.

Notably, the roof shales of the #5 seam comprise a medium- to dark-grey (N3.5-2) mud shale containing *Curvirimula* spp. as fragments and articulated shells but preservation is too poor for specific identification. Ostracodes and fish debris also occur. This fauna and the lithology in which it occurs suggests that the *C. corvosa* Bed can perhaps be traced into the St. Rose area but, this assumption is at best tentative.

4.5.2. Fauna in a slab from the roof of the #2 ('Evans') seam.

The slab of dark-grey (N2.5) silty shale collected by Dr. E.L. Zodrow cantains abundant well preserved single valves referrable to *Curvirimula* sp.. The shells are distorted due to stress, but are tentatively referred to *Curvirimula trapeziforma* *s.l.*. Copeland (1977, and in Zodrow, 1983) reported these shells as *Anthraconaia*.

4.6. Summary.

Riversdale Group bivalve faunas comprise mainly *Naiadites* and *Curvirimula*, although *Carbonicola*? is recorded for the first time. *Naiadites* assemblages are typified by *N. carbonarius* which is considered to be the modal form among shells that show somewhat limited variation. *Curviriumla* is dominated by elongate forms best exeplified by *C. corvosa*.

Ostracode assemblages consist mainly of *Carbonita altilis*, subordinate species referrable to this genus appearing to display a distribution which is environmentally controlled. In addition, a large punctate form identified as *Gutschickia ninehvensis* occurs commonly and *Geisina* is recorded from a single horizon at Port Hood.

CHAPTER 5

FAUNAS OF THE CUMBERLAND GROUP.

5.1. Introduction.

The main coal-bearing areas of the Cumberland Group are the Joggins-Chignecto and Springhill coalfields (Figures 5.1 and 5.2) of mainland Nova Scotia, the Group being absent on Cape Breton Island. Both of these coalfields occur within the Cumberland Basin of deposition (Chapter 2) and the type section along the eastern coast of Chignecto Bay, presents in general, the lithology of the axial part of the basin. Logan (1845, pp. 92-159, and in Poole 1908, pp. 419-499) measured in detail the type section making several divisions in it (of which Divisions 1-5 represent the Cumberland Group,(Bell 1944)).

Lyell & Dawson (1853) redescribed the coal-bearing part of the Joggins sequence using Logan's section as a guide. Later, the same section was partly reproduced by Dawson (1855, pp. 128-143) and descriptions of the coal-bearing parts given in successive editions of "Acadian Geology".

Fletcher (in Poole 1908) completed the measurement of strata on the eastern shore of Chignecto Bay begun by Logan. Sections 1-12 of Fletcher represent the Cumberland Group (Bell 1944).

Bell (1914, 1944) investigated the area and defined the Cumberland Group. Bell (1944) stated that the Group lies disconformably on strata of the Boss Point Formation and concluded that the base of the Group is at least 300 m stratigraphically higher 29 km to the east of Joggins than in the coastal outcrop there. A list of 92 plant species was given by Bell (1944) of

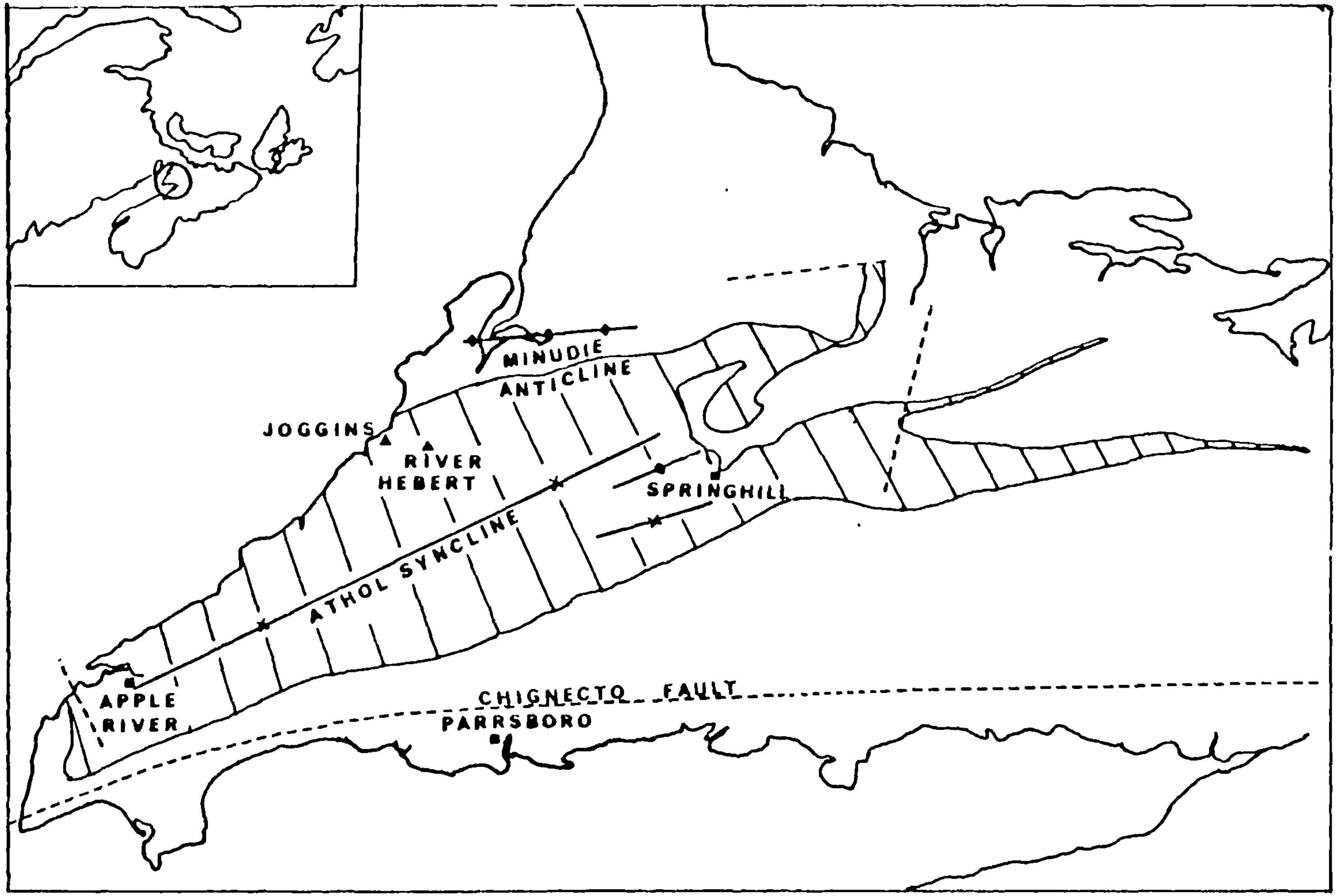


FIGURE 5. 1: Map of the Cumberland Basin. Cumberland Group outcrop shown. Dashed lines are faults, are localities collected from, are other towns and localities mentioned in the text.

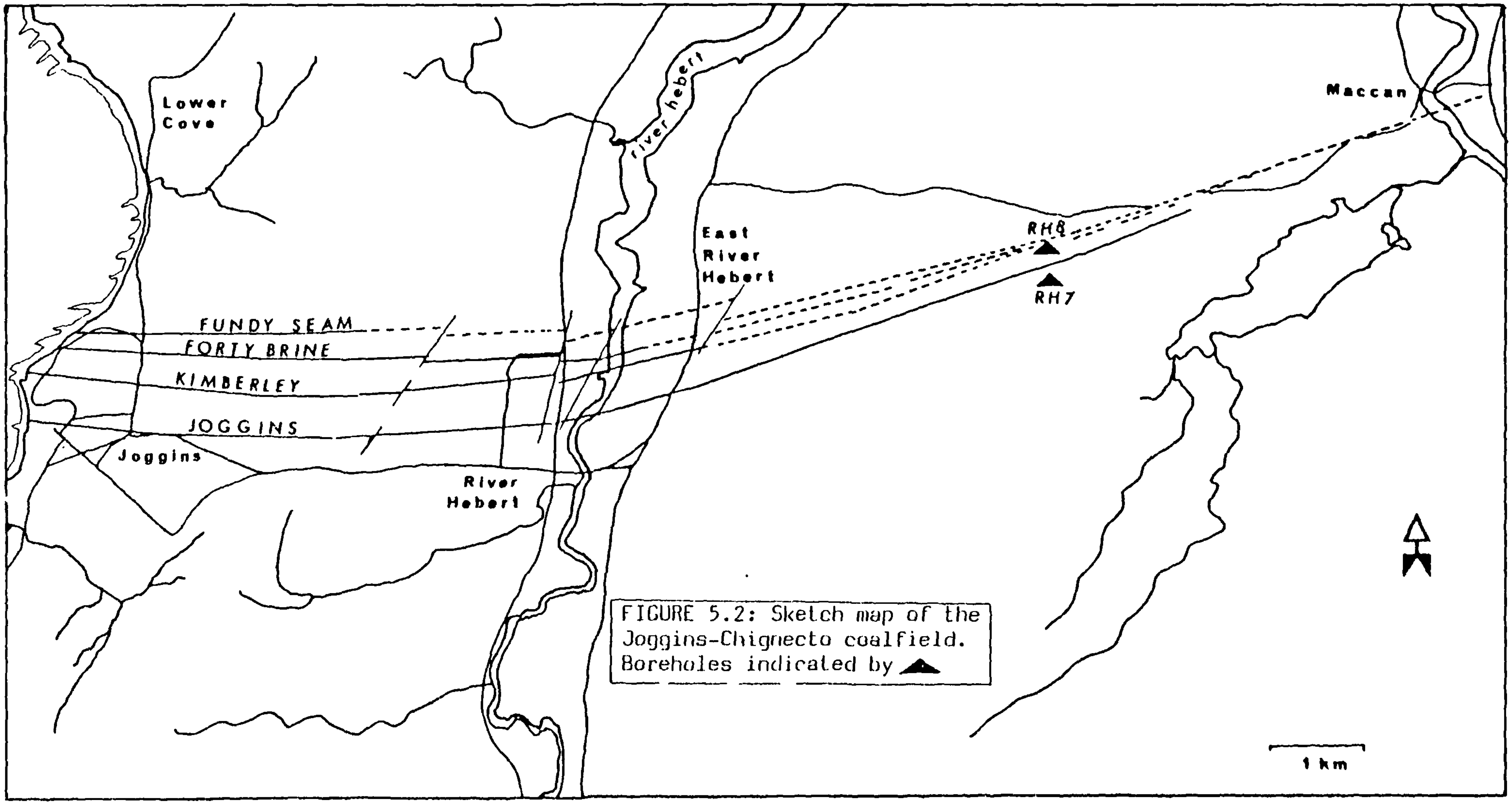


FIGURE 5.2: Sketch map of the Joggins-Chignecto coalfield. Boreholes indicated by ▲

which several were found to be characteristic of the Group.

Copeland (1958) described the coalfields of Cumberland County and divided the Cumberland Group into four facies (Table 5.1). However, Logan's Divisions are far easier to recognise in the field and were used in this study. Copeland (1958, 1959) also gave an account of the fauna and listed the bivalves Naiadites carbonarius, 'Anthracomya' laevis (=Curvirimula) and 'A'. elongata, concluding that the fauna as a whole indicated an age of Westphalian B. Miospore work by Hacquebard & Donaldson (1964) produced a mid-Westphalian B age for the entire Cumberland Group section in this area, but the correlation must be regarded as being a broad one.

Rogers (1965) and Solem & Yochelson (1979) examined Dawson's collections of shells from Joggins. On the basis of an examination of Cumberland Group faunas Rogers (1965), was able tentatively to correlate the Group with the Similis-Pulchra and Modiolaris Chronozones of Britain. The freshwater snails examined by Solem & Yochelson (1979) are now referred to Dendropupa vetusta, Pupa bigsii and Zonites (Conulus) priscus.

Of peculiar interest in the Joggins section has been the preservation of reptiles mainly preserved in fossil tree stumps (Ferguson 1975). A series of descriptions of these reptiles has been given by Carroll (1963, 1964, 1966 and 1967).

Sedimentological investigations have been made recently by Way (1968) and by Duff & Walton (1973). Pollard and Calver (in Duff & Walton, 1973) gave a list of bivalve and arthropod species collected by those authors as; Curvirimula sp., Naiadites longus, Spirorbis sp., Carbonita altilis, cf. C. salteriana, C. bairdioides, C. pungens., C. elongata and C. evelinae.

Duff & Walton's (1973) detailed study of Logan's Division 4 led them to postulate deposition on a delta plain, the delta

<table>
<tr><th>LOGAN
1845</th><th>FLETCHER
1908</th><th colspan="2">BELL
1914</th><th colspan="3">COPELAND
1959</th></tr>
<tr><td></td><td rowspan="2">SECTION I</td><td rowspan="7">CUMBERLAND GROUP BELL1944</td><td rowspan="4">SHULIE FORMATION</td><td>FACIES D</td><td colspan="2">RED SANDSTONE/SILT.</td></tr>
<tr><td>DIVISION 1</td><td rowspan="3">FACIES C</td><td rowspan="3">NORTH
RED SSTN.
& SHALE</td><td rowspan="3">SOUTH
RED CONGL.
& GR. SSTN.</td></tr>
<tr><td rowspan="2">DIVISION 2</td><td>SECTION IX</td></tr>
<tr><td>SECTION X</td></tr>
<tr><td>DIVISION 3</td><td rowspan="3">SECTION XI</td><td rowspan="3">JOGGINS FORMATION</td><td rowspan="2">FACIES B</td><td colspan="2" rowspan="2">COAL - BEARING ZONE</td></tr>
<tr><td>DIVISION 4</td></tr>
<tr><td>DIVISION 5
-</td><td>FACIES A</td><td>NORTH
RED- GREY
SHALE, SST
& CONGL.</td><td>SOUTH
RED CONGL.
MINOR SSTN.</td></tr>
<tr><td>DIVISION 6</td><td></td><td></td><td colspan="4">BOSS POINT FORMATION</td></tr>
</table>

TABLE 5.1: SECTIONS AND FORMATIONAL NAMES USED FOR THE JOGGINS SECTION.

prograding north-eastwards between the Cobequid and Caledonian highlands into the Fundy basin. In view of more recent studies of other coal-bearing areas in Nova Scotia (Pluim 1980, Gersib & McCabe 1981, Dilles & Rust 1983), this concept has been queried. The absence of thick coarsening-upward sequences and lack of evidence to suggest that the sediment was filling in a large body of water were considered by Gersib & McCabe (1981) to cast doubt on a deltaic model.

The Cumberland Group was examined in the Joggins coastal section (Divisions 5,4 and part of 3) and in cores from two Nova Scotia Department of Mines & Energy boreholes drilled at River Hebert (Figure 5.1).

5.2. The Joggins section.

The classic Joggins section provides remarkably continuous exposure of the Cumberland Group (Figures 5.3 and 5.4.). The coal-bearing part lies in Logan's Division 4 (near the base of the Group) and part of Division 3, whilst Division 5 comprises redbeds (Logan 1845). Fauna appears to be limited to part of Division 4 (cf. Copeland 1958).

The section comprises sandstones which often form long skerries across the intertidal zone (Figure 5.2), shales, coals and calcareous, shelly shales often termed limestone (e.g. Logan 1845, Copeland 1958, Duff & Walton 1973). The shales vary in hue from dark grey through grey-green to red and may often contain rootlets. Sandstones, particularly channel sandstones, are far less common in Divisions 5-3 than at Boss Point, stratigraphically just below the section. The sandstones and their internal structure have been described in detail in Duff & Walton (1973, pp. 370-374).

Five coal seams have been mined in the Joggins-Chignecto area

FIGURES 5.3. & 5.4 : General views of the Joggins section.

(Copeland 1958) but none is being worked at the present time. The seams are mainly thin, laterally impersistent and of poor quality so that correlations prove difficult.

Time did not allow of the section being measured in its entirety but the strata above and below fossiliferous horizons were measured (Figure 5.5). Each coal seam located was numbered according to Logan's scheme (Logan 1845, Figure 5.5) and seam names were given where possible (Copeland 1958).

Faunas occur mainly above coal seams in calcareous mudstones and siltstones and are mainly preserved as crushed shell material effectively forming coquina. This form of preservation seldom allows the collection of whole valves suitable for measurement as fragmentation occurs on breakage of the slabs. Figure 5.5 lists the identified faunas on each fossiliferous horizon and only those horizons at which faunas were collected in a better state of preservation are mentioned below.

Coal Division 44.

Three separate fossiliferous horizons which lie approximately 665 m above the base of the Cumberland Group form the lowest shell-bearing horizon located at Joggins. The 'coal' comprises a shelly, calcareous mudstone intercalated with coaly layers. The fauna is poorly preserved, comprising *Curvirimula* sp., *Carbonita* spp. and abundant plant material.

Some 3 m above the 'coal', a further thin calcareous mudstone occurs. This contains crushed shell material referable to *Curvirimula* sp. and *Carbonita* spp. The dark grey, slightly calcareous mudstone yields *Curvirimula* sp., *Naiadites carbonarius s.l.* and *Carbonita* spp.

Towards the top of this Coal Division, a further limestone occurs containing *Naiadites carbonarius s.l.*, *Curvirimula* sp. and ostracodes.

Coal Division 41.

A thin coally layer is underlain by 20 cm of plant-rich, dark grey mudstone and a thin 'limestone' containing *Curvirimula* sp., *Naiadites* sp., *Carbonita* spp. and fish fragments. The shell material is crushed and fragmented.

Overlying the coal is a 30 cm thick sequence of dark grey, calcareous siltstone containing crushed single valves and articulated shells referable to;

Curvirimula attenuata and *C. corvosa s.l.*,

Naiadites carbonarius, *N. subtruncatus s.l.* and shells resembling *N. longus*,

Spirorbis sp,

Carbonita altilis, *C. elongata* and *Gutschickia ninevehensis*.

Coal Division 38.

A thin coal is overlain by a 15 cm thick 'limestone' which contains single valves of *Curvirimula* spp. including elongate shells referable to *C. trapeziforma s.l.*, *Naiadites* sp. possibly referable to *N. productus s.l.*, *Carbonita altilis* and *Gutschickia ninevehensis*.

Coal Division 28.

A 15 cm thick coal seam is overlain by an 80 cm thick sequence of calcareous mudstone and slightly calcareous, dark grey mudstone. Shells are preserved as single valves both convex-up

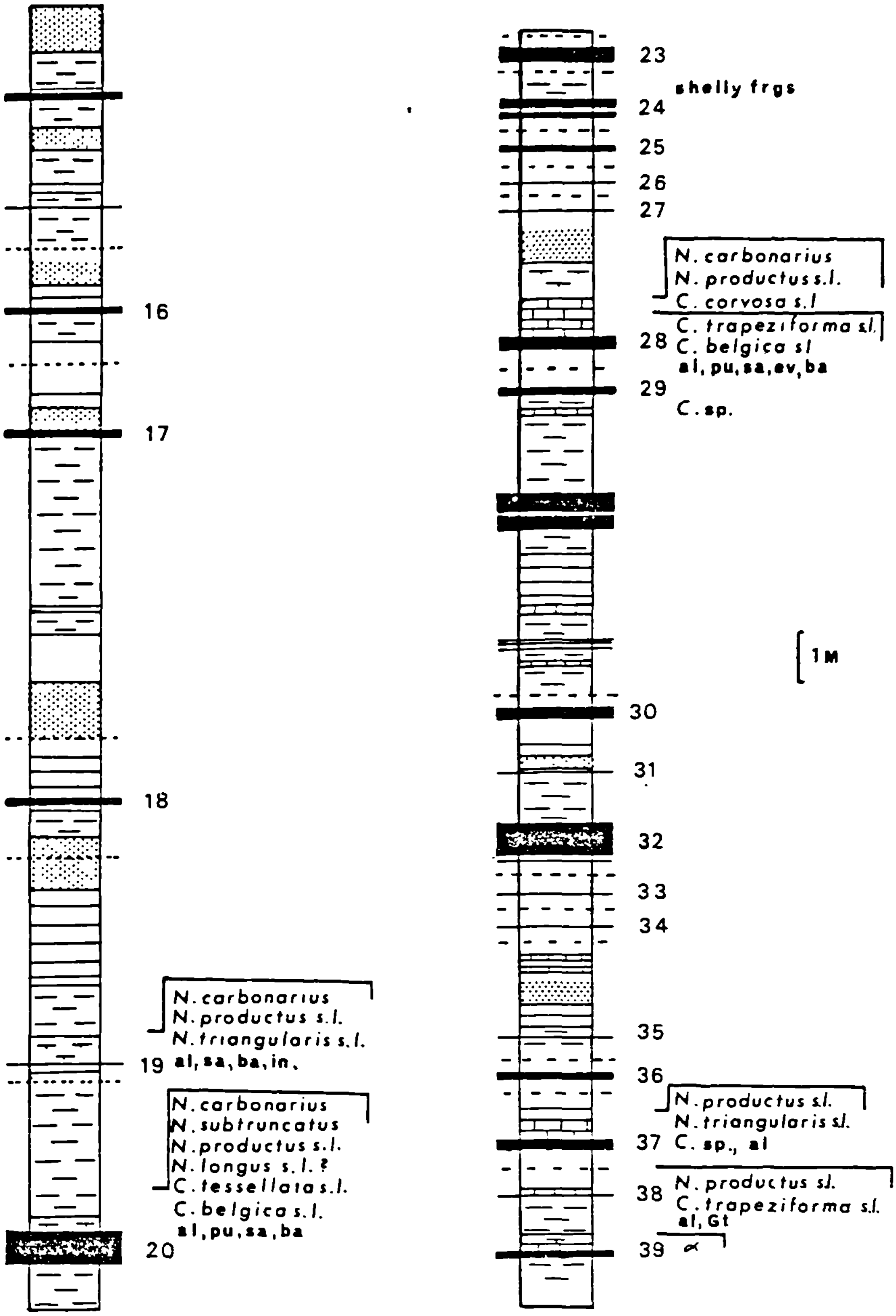


FIGURE 5.5a: THe Joggins section showing major coal seams and faunal horizons. Numbers refer to Logan's (1845) Coal Divisions. Breaks in the section indicated by dashed lines.

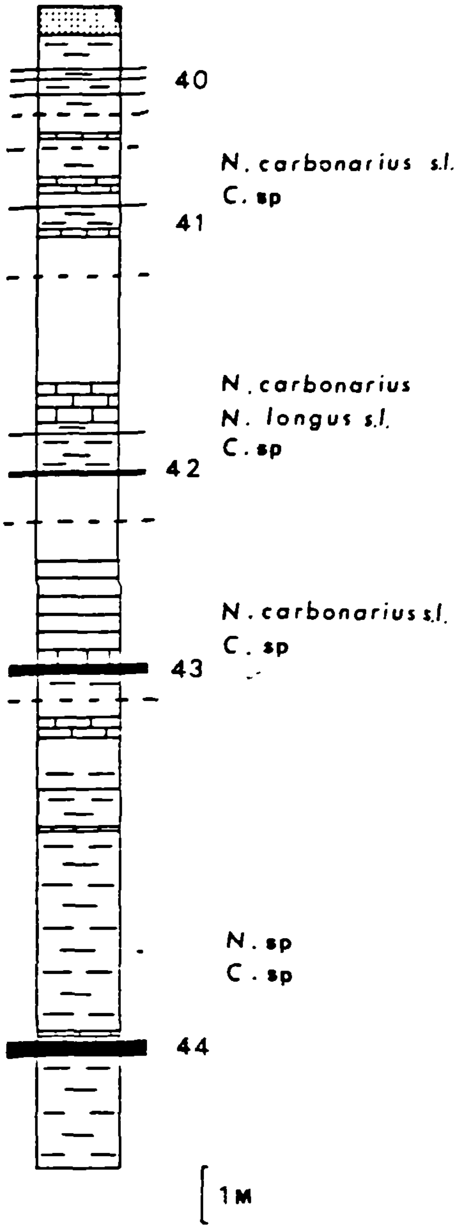


FIGURE 5.5b: The Joggins section continued.

and convex-down. They include;

Curvirimula spp. including *C. corvosa s.l.*, *C. belgica s.l.* and shells resembling *C. tessellata s.l.*,

Naiadites spp. including *N. carbonarius* and variants referable to *N.* sp. cf. *N. productus*,

Carbonita altilis, *C. pungens*, *C.* cf *salteriana*, *C. evelinae* and *C. bairdiodes*.

Coal Division 20.

A thick coal seam, is overlain by a sequence of slightly calcareous muddy shales which contain shells preserved mainly as single valves. The following fauna was recorded;

Naiadites spp. including *N. carbonarius*, *N. subtruncatus s.l.*, *N. productus s.l.* and *N. longus s.l.*,

Curvirimula spp. including *C. tessellata s.l.* and *C. belgica s.l.*,

Carbonita altilis, *C. pungens*, *C.* cf *salteriana* and *C. bairdiodes*.

Coal Division 19.

Coal number 19 is deduced to be the Forty Brine seam of Copeland (1958), though it is very thin - Logan (1845) recorded one inch of coal. The seam is overlain by a calcareous mudstone with a distinctive blocky fracture (cf. Copeland 1958, p.59). Copeland (*ibid*.) recorded the following fauna;

Spirorbis sp.,

Naiadites sp.,

Carbonita sp. and *Candona* sp.

Collections of the roof shale yielded abundant single valves assigned to *Naiadites carbonarius* with variants referable to *N. triangularis s.l.* and *N. productus s.l.*, often encrusted with spirorbids. Shell fragments and crushed single valves of *Curvirimula* occur rarely and ostracodes are represented by *Carbonita altilis*, *C.* cf. *bairdio-des*, *C. inflata* and *C.* cf. *salteriana*.

No faunas were recorded at stratigraphically higher levels in the section and there appears to be no published record of such.[2]

5.1.2. Discussion.

The Joggins fauna is not well preserved and insufficient numbers of measurable shells were collected to allow statistical analysis. The fauna on the whole is indistinguishable from Riversdale faunas previously described, though on floral and microfloral evidence, this section is middle Westphalian B in age. However, three points require consideration;

a. Generally, *Naiadites* progressively increases in abundance at the expense of *Curvirimula*, up through the section. *Carbonita altilis* dominates the lower faunas but ostracode assemblages become more diverse higher in the sequence.

b. *Curvirimula* and *Naiadites* occasionally display a similar relationship in a single faunal horizon (Figure 5.6), *Curvirimula* occurring in calcareous lithologies near the base of a horizon and progressively decreasing in numbers up through the horizon.

[2] BUT SEE DAWSON (1868) WHO RECORDED "*NAIADITES*" FROM COAL DIVISIONS 14, 8, 7, 6, 5 AND 1.

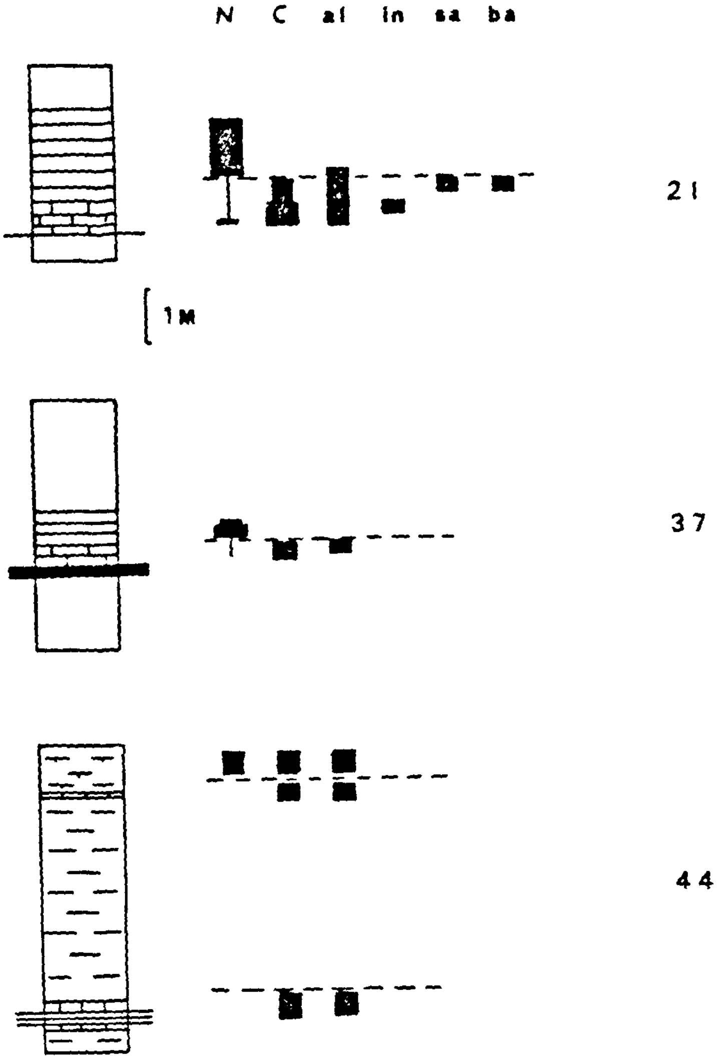


FIGURE 5.6: Distribution of faunas in three selected horizons in the Joggins section.

c. Hacquebard & Donaldson's (1964) microfloral age of middle Weslphalian B appears to have been a general age for the whole of the Cumberland Group section.

Curvirimula faunas occur almost exclusively in calcareous lithologies. In thin section, the 'limestones' comprise varying amounts of angular to subangular quartz grains in a micrite matrix. Shell material is everywhere abundant and may often reach rock-forming proportions. Void spaces, such as the interior of ostracode tests and articulated bivalves, are filled with coarsely crystalline sparite. The micrite matrix contains varying proportions of dark-grey organic material.

Figure 5.6. shows the distribution of fauna in three selected horizons. In each case, the limestone overlies a coal and grades upwards into a slightly calcareous mud or silty shale. *Curvirimula* occurs immediately above the coal often without *Naiadites*, which enters later and gradually dominates the horizon, often occurring without *Curvirimula* at the top of it.

Preservation of the faunas is as single valves and articulated shells and crushing has produced much fragmentation. However, both *Naiadites* and *Curvirimula* occur in a presumed near-life position.

The sequence lacks thick channel sandstones as were present in the stratigraphically lower, Boss Point Formation, and floodplain sediments and crevasse splay deposits predominate in Division 4. Periodically, lakes formed on the floodplain through local subsidence due to differential compaction and were initially without significant clastic input, allowing carbonate deposition. Current activity was low, allowing bivalves to remain at this stage, mainly articulated. The lake bottoms were probably subject to periods of anoxia. Clastic input steadily increased through time in each lake so that carbonate deposition became insignificant. With increased current activity, periods of oxygen deficiency were curtailed and normal floodplain conditions were re-established.

Occasionally an intermediate phase of peat formation occurred before the lacustrine phase. Areas within the peat bog seem to have been subject to local flooding and within the ponds so formed, carbonate deposition occurred (Coal number 44 for example).

The fauna as a whole indicates freshwater conditions (Pollard 1966, Calver 1968a). Curvirimula, though a brackish form in NW Europe (Eagar 1947, Calver 1968a, Weir 1968), was probably inhabiting fresher water in North America (Eagar 1960) and was able to tolerate the conditions in the earlier, calmer carbonate phase of lake formation. Naiadites probably preferred a muddy, organic carbon-rich substratum in an environment of higher clastic sedimentation rates and current activity. Under these higher energy conditions Curvirimula was replaced by Naiadites or alternatively, the thin, delicate shells of Curvirimula were simply not preserved. The most likely limiting factor that was acting on these faunas must be oxygen def-iciency of the lake bottom waters and Naiadites may not have been able to tolerate oxygen deficiency thus, allowing Curvirimula to enter and monopolise the initial phase of lake formation.

No faunas are recorded above Coal Division 19 and 'limestones' become rarer upwards through the section as a whole. Conditions seem to have become generally more favourable to Naiadites, and above Coal Division 19, conditions were mainly unsuitable for either genus.

Correlation.

In Britain, the 'species' of Curvirimula recorded at Joggins mainly range through the Communis Chronozone, though C. belgica ranges into the upper Similis-Pulchra Chronozone in association with marine bands (Weir 1968). The *Naiadites* assemblages recorded display a limited range of variation around the modal *N. carbonarius* and would indicate a somewhat younger correlation. Alternative possibilities are;

a. that *Curvirimula* survived longer in Nova Scotia than in NW Europe (though Eagar & Weir (1971) and Eagar in prep. [1983] have recorded *Curvirimula* from the Spanish Stephanian including forms near *C. belgica*) or

b. that the presence of *Curvirimula* in the faunas does indeed indicate a Westphalian A age for Logan's Divisions 4 & 5.

5.3. Nova Scotia Department of Mines & Energy cores DDNSRH-7 and DDNSRH-8.

The two cores examined came from boreholes drilled near River Hebert (Figure 5.1.) and both cut the Kimberley seam. The strata in both holes lack major sandstone units (though several do occur) and mainly comprise floodplain deposits.

5.3.1. DDNSRH-7.

Two fossiliferous horizons were recorded in this core (Figure 5.7.) both above the Kimberley seam. The lower occurs approximately 6 m above the upper leaf of the coal seam and comprises interlaminated mud and silty shales varying in colour from pale to dark grey (N4-2.5). Bivalves are preserved mainly as crushed, articulated and closed shells and as angular fragments. Juvenile shells are common. The bivalves all belong to *Naiadites* and include *N. carbonarius*, *N. productus s.l.* and shells with short, sharp anterior ends and a broadly triangular shape, referred to *N. triangularis s.l.* Some of the shells assigned to *N. productus s.l.* are strongly carinate.

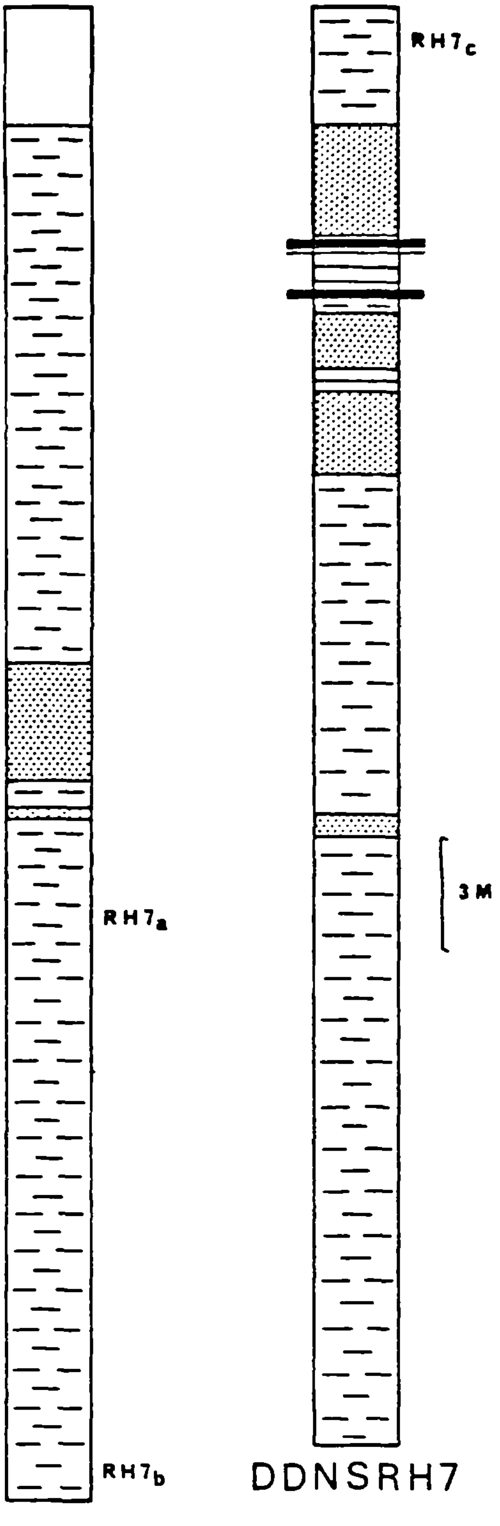


FIGURE 5.7: Log of Nova Scotia Department of Mines & Energy hole D.D.N.S.R.H. - 7. Faunal horizons indicated. See Figure 5.2. for location of hole.

Ostracodes are rare and comprise Carbonita altilis, C. evelinae and C. scal-pellus mainly in the darker, finer-grained lithologies. Fish fragments also characterise these lithologies from which one fragment possibly referable to Pygocephalus sp. was recorded. Spirorbids are ubiquitous, attached to the posterior parts of bivalves (cf. Trueman 1942) and to the substratum.

The higher horizon, some 21 m above the coal comprises grey (N3.5-2) interlaminated silt and muddy shales and contains a similar fauna. Bivalves are preserved as articulated and closed shells, single valves and fragments all belonging to Naiadites. N. subtruncatus and N. productus s.l., were recorded. An internal view of a single shell (Figure 5.9) displays three small muscle scars in the anterior-umbonal part. No pallial line or posterior muscle scars were visible but a thin shallow groove occurs in the hinge fading out posteriorly. The form of the muscle scars closely agrees with the description given by Newell (1940) of the anterior musclature of N. carbonarius (the type species of the genus).

Ostracodes are somewhat rarer at this horizon and are mostly crushed valves or external moulds of Carbonita spp.. Spirorbids occur sporadically attached to the posterior parts of bivalves shells.

5.3.2. DDNSRH-8.

Several horizons occur in this core (Figure 5.8) including one below the Kimberley seam. This horizon contains a rather poorly preserved fauna comprising angular shell fragments of Naiadites sp. with attached Spirorbis sp., Carbonita altilis and C. evelinae. Plant material is abundant.

Just above the coal, in a sequence of interlaminated mud and silty shales varying in colour from dark to medium grey (N3-2),

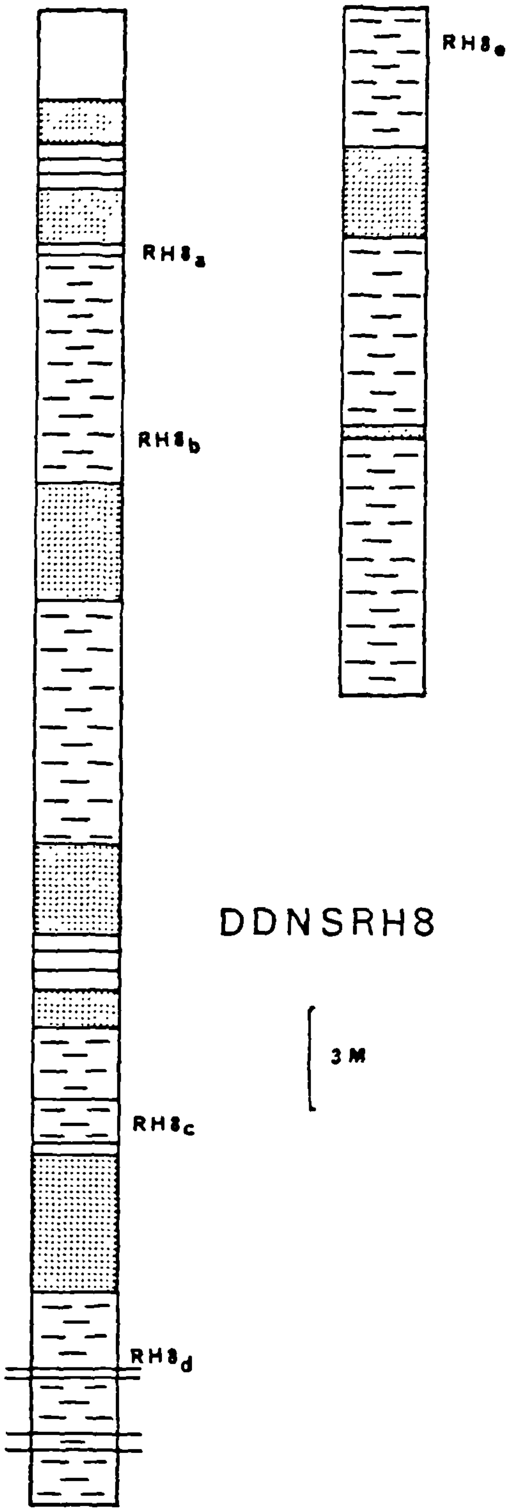


FIGURE 5.8: Log of Nova Scotia Department of Mines & Energy core D.D.N.S.R.H. - 8. Faunal horizons indicated. See Figure 5.2. for hole location.

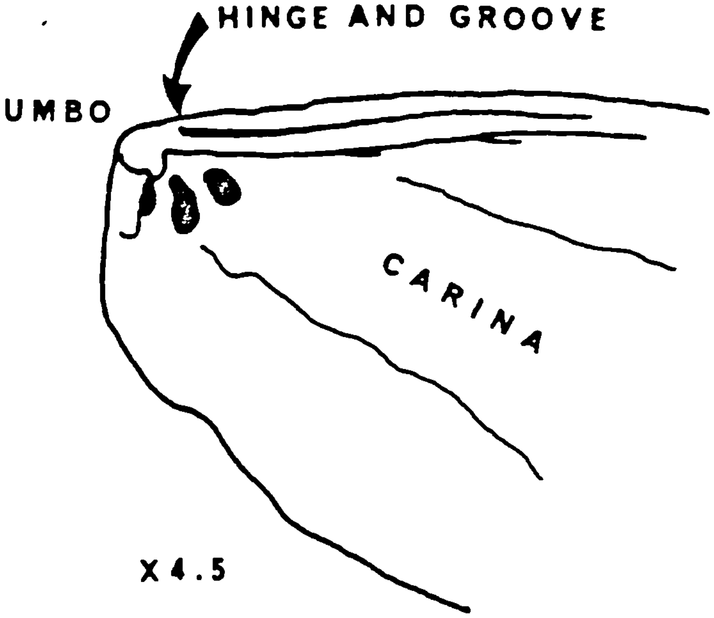


FIGURE 5.9: Internal view of a Naiadites sp. showing hinge line and anterior muscle scars.

crushed single valves and angular fragments of Naiadites occur. Naiadites carbonarius, N. productus and N. quadratus s.l. were recorded along with Carbonita altilis, fish fragments and Spirorbis sp.

Some 8 m above the coal a fauna comprising single valves and fragments of Naiadites spp., ostracodes including Carbonita altilis and Spirorbis are present in a similar lithology.

Naiadites subtruncatus s.l., often preserved articulated and closed, occurs in great abundance at 26 m above the coal. Ostracodes including Carbonita altilis and C. evelinae are also present along with fish fragments and spirorbids.

Towards the top of the core, in a dark-grey (N3-2.5), silty shale, shell fragments and single valves of Naiadites sp. were recorded together with Carbonita altilis and Spirorbis sp.

Discussion.

The River Hebert cores from several kilometres to the east of the Joggins section (Figure 5.2), contain bivalve faunas which lack Curvirimula. The boreholes cut strata which are stratigraphically slightly younger than those seen in the highest part of the Joggins section.

Thick sandstone units are rare and the sequence mainly comprises floodplain deposits (Figure 5.7 and 5.8) suggesting that the river channels were moving into another area which was subsiding more rapidly. Shell beds occur within floodplain sequences suggesting that lakes formed on the floodplain, mainly without an intermediate phase of peat formation. The relatively short distance between the boreholes (Figure 5.2) implies that the lakes were not of great lateral extent as shell beds cannot be confidently correlated between them.

The faunas suggest a freshwater environment (Pollard 1966, Calver 1968a, Bless & Pollard 1973). Organic carbon-content of che lithologies is quite high and their grainsize generally low. Carbonate, except for shell material, is absent and plant material fairly common.

Small, shallow floodplain lakes are envisaged; sedimentation rate and current activity were generally low enough to allow preservation of the shells as single valves or as articulated shells, but high enough to preclude carbonate deposition.

Correlation.

In Britain, the morphological varieties of *Naiadites* recorded in these two cores would indicate an upper Modiolaris to lower Similis-Pulchra Chronozone age. The ostracode assemblage contains two common forms, *Carbonita altilis* and *C. evelinae*. *C. altilis* is the dominant form in Riversdale Group assemblages whilst *C. evelinae* dominates in the Pictou/Morien Group assemblages (Chapter 6). Thus, the ostracode assemblage would seem to indicate a transitional age.

A clear assignment to the Westphalian B can be made on a homotaxial basis for this portion of the Cumberland Group, though it may be that *Curvirimula* is absent from the shell beds due to physical restriction rather than for biostratigraphic reasons.

5.4. Palaeogeographical and palaeoenvironmental considerations.

The Cumberland Group of the Cumberland Basin is diachronous (not only as regards to its base) and youngs to the east (Bell 1944). The Joggins area was relatively closer to the depocentre than the River Hebert area and sedimentation may have been more or less continuous from the Boss Point Formation which was followed by redbeds of Logan's Division 5. The rivers which deposited the thick often stacked, channel sandstones of the Boss Point Formation were diverted to an area of more rapid subsidence whilst subsidence in the Joggins area slowed allowing subaerial weathering and later, peat and lake formation.

The Cumberland Basin began to spread in lateral terms at about the start of Logan's Division 4 and coals in the Joggins area are separated by thicker intervals of floodplain sediments than to the east.

Lakes forming on the floodplain in the River Hebert area were probably closer to the sediment source and thus, clastic input was always sufficient to preclude carbonate deposition. At Joggins, a paucity of clastic material allowed carbonate deposition in lakes until the close of Logan's Division 4.

5.4.1. Correlation.

The correlations provided by the faunas in the Boss Point Formation and the strata above the Kimberley seam provides an upper and lower limit for the age of the Joggins section which, on this basis, must represent most of the Modiolaris Chronozone of the British area.

Logan's Division 5 which is about 710 m thick and mainly comprises redbeds contains no fauna and the earliest recorded faunas occur in the roof shales of coal 44. This provides the earliest record of Naiadites in this area. The lower part of Division 4 (Coal Divisions 44- 21) is relatively rich in Curvirimula and the Naiadites assemblages are not diverse. In the upper part of the Division, Naiadites both dominates the assemblages and displays more variation. Curvirimula disappears altogether in the higher parts of the section.

Through comparison with the British area, Logan's Divisions 4 & 5 represent the modiolaris Chronozone and is on this basis

Westphalian A and lower Westphalian B.

The faunal age does not markedly disagree with the microfloral age which is a general age for the whole section, but allows finer divisions of the section. Barss (in Hacquebard 1979) shows the Joggins section ranging through the top of the Riversdale Group and into the Cumberland Group (i.e. upper Westphalian A - Westphalian B) which is closely similar to the proposed faunal age (see Chapter 7).

The positioning of the Westphalian A/B boundary is itself a problem and is probably impossible to determine without the presence of the appropriate marine band. However, on the basis of considerations of stratal thickness, it must lie in the interval between Coal Divisions 28 and 20.

CHAPTER 6

FAUNAS OF THE PICTOU/MORIEN GROUP.

The Pictou/Morien Group has previously been described in Chapter two and the main areas of outcrop are shown in Figure 6.1. Four main areas were examined: the Sydney coalfield, the Mabou Mines section (MMs), the Inverness coalfield and the Pictou coalfield, which was examined in core only.

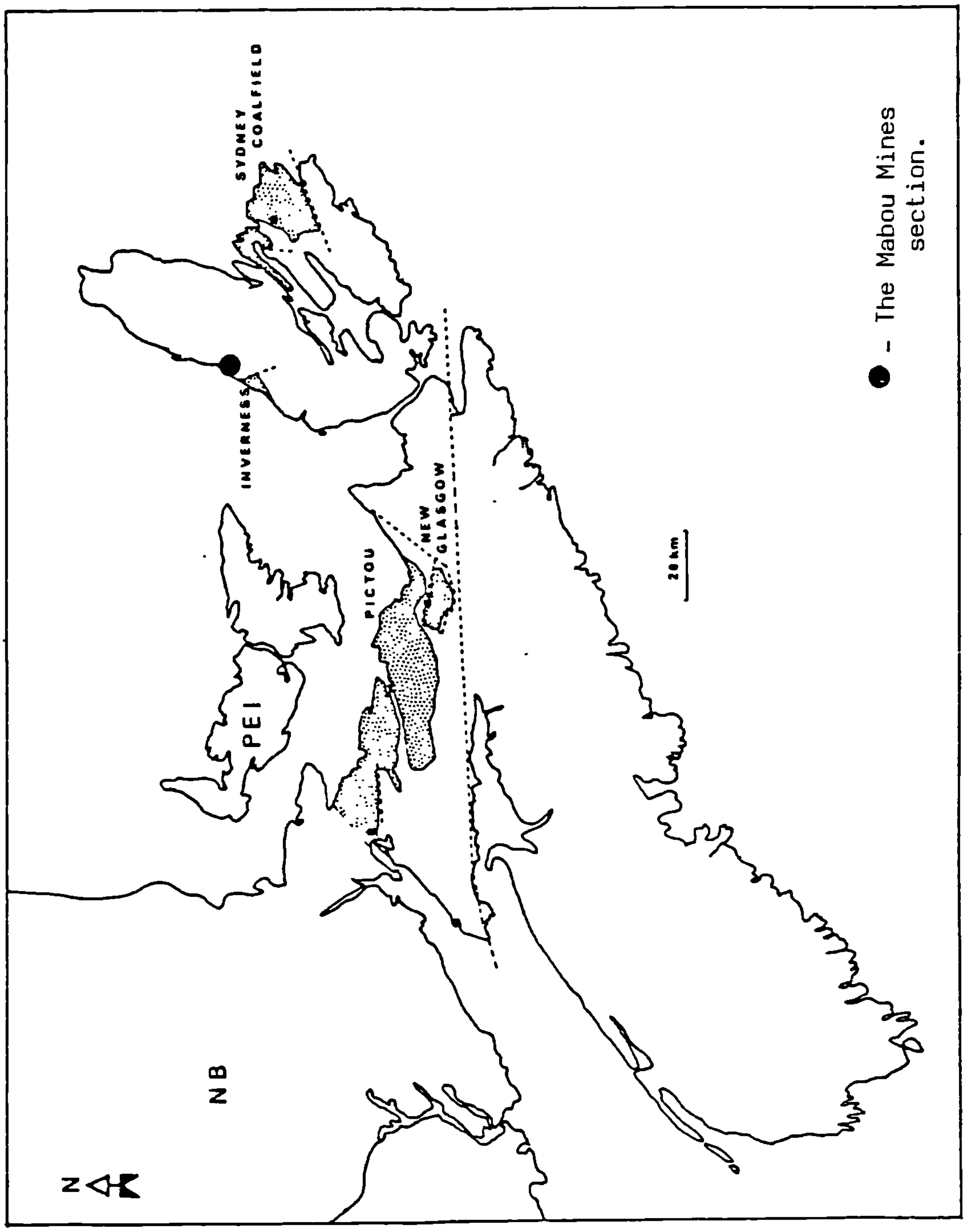
Faunas are quite different from those of the Riversdale and Cumberland Groups in that they comprise several species of Anthraconauta and Anthraconaia. Carbonita evelinae is the dominant ostracode. In the Sydney coalfield, there is a tendency for the two bivalve genera to be mutually exclusive and because of this, reference is made to 'Anthraconauta facies' and to 'Anthraconaia facies'.

6.1. The Sydney coalfield.

The Sydney coalfield is situated on the northeastern coast of Cape Breton Island (Figure 6.2, inset) and contains the largest coal reserves of any of the Nova Scotian coalfields (Hacquebard 1979). The coalfield comprises two parts; a small land area of about 520 km^2 and a region where mining is carried out below the sea. Both areas form part of a large basin that extends nearly as far as Newfoundland, occupying some 36300 km^2 and is referred to as the Sydney Basin (King & MacLean 1976).

Early work was carried out by Brown (1871) and Dawson (1891) who recorded flora and fauna from the coalfield including

FIGURE 6.1: PICTOU/MORIEN GROUP IN NOVA SCOTIA.



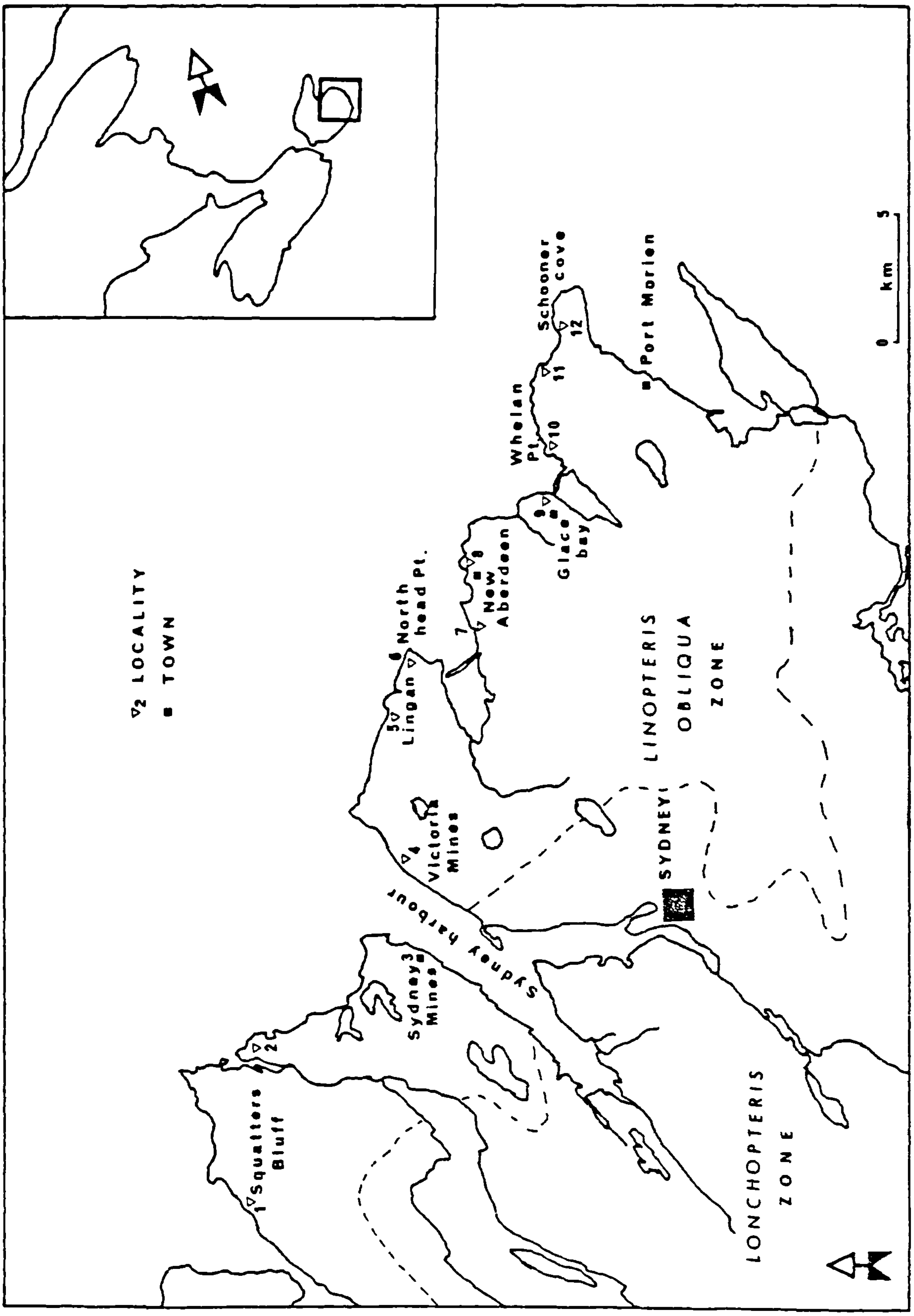


FIGURE 6.2: The Sydney coalfield - localities and floral Zones. Locality numbers correspond to text section numbers.

"*Naiadites*, *Cythere*, *Spirorbis* sp. and fish remains". Early mapping was carried out by Robb (1872-75) and Fletcher (1895-97) and general geological studies made by Hyde (1912), Hayes & Bell (1923) and Gray & Gray (1941). Hyde (1912) recorded a fauna of *Leaia* sp., *Anthraconauta* and ostracodes in "grey shales".

Bell (1938) was able to divide the Morien Group into three floral Zones (Table 6.1). Bell (*ibid*.) correlated the lower two of his Zones with the Westphalian C, and the upper Zone with the Westphalian D of NW Europe. Bell also recorded the presence of thin, freshwater limestones within the coalfield listing their fauna as comprising "*Leaia*, *Estheria* and *Carbonicola*".

Bell's floral correlations were later emended by Zodrow & McCandlish (1978) when the opening of two new mines in the upper parts of the Morien Group provided much new floral information. These authors eliminated the *Ptychocarpus unitus* Zone (Table 6.1) of Bell (1938) on the basis of:-

a. The occurrence of *Linopteris obliqua* in Bells' *Ptychocarpus unitus* Zone and,

b. the occurrence of other plant species associated with *Linopteris obliqua* in the *Ptychocarpus unitus* Zone.

The Westphalian C/D boundary was therefore lowered from the roof of the Emery seam to the roof of the Tracy seam (Table 6.1). In addition to this revision, Zodrow & McCandlish (1980) catalogued all the fossil plant genera and species recorded and collected from the coalfield and subsequently, described a new species of *Oligocarpia* (Zodrow & McCandlish 1982). Recently, floral evidence has been cited in the speculation that the upper parts of the onshore sequence may be Stephanian in age (Zodrow & Gastaldo 1982, Zodrow 1982, and see earlier palynological conclusions below) and a series of floral 'events' were recognised in the sequence (Zodrow, in prep. [1983]). The Westphalian

SPORE ZONES Barss in Hacquebard 1979	AGE		BIVALVE CHRONOZONE	AGE	FLORAL ZONES$	AGE
E	lower PERMIAN		N/A	?	?	?
D	STEPHANIAN			STEPHANIAN —?—?—?— ?CANTABRIAN	Linopteris obliqua	STEPH
C	WESTPHALIAN	D	TENUIS	—?—?—?—		D
B		C		D		
A		C	PHILLIPSII	C	Lonchopteris	C

$ ZODROW (1982)
) HACQUEBARD (1979)

PA – POINT ACONI SEAM
H – HUB
E – EMERY
T – TRACY
LC – Lloyd Cove
P – PHALEN

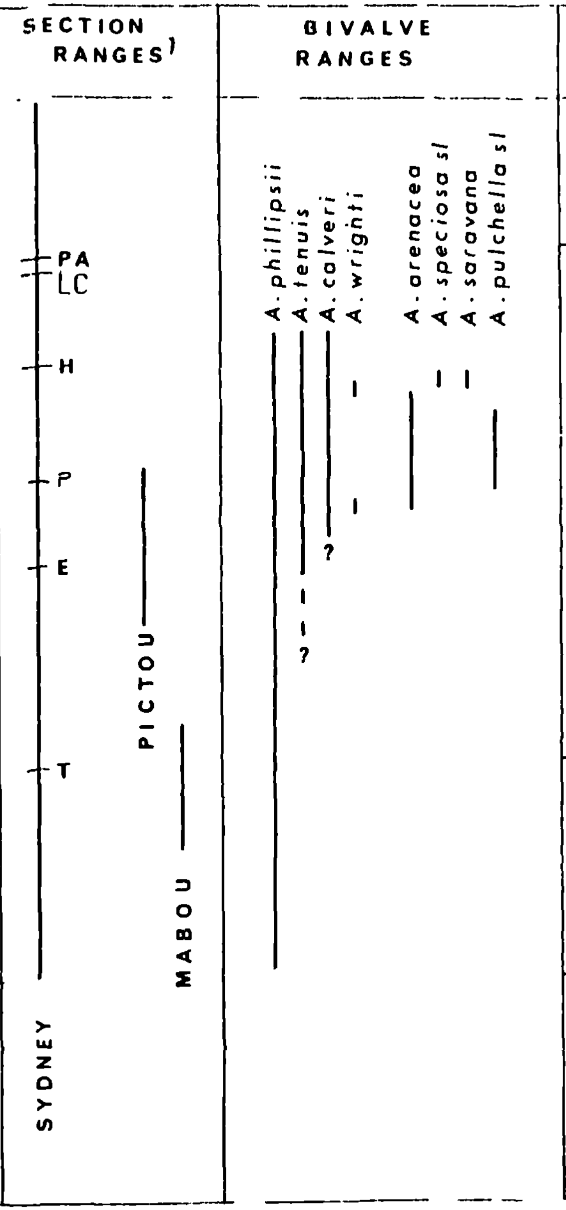


TABLE 6.1: Late Westphalian stratigraphy of Nova Scotia

D/Stephanian boundary was provisionally placed by Zodrow (1982) in the roof shales of the Hub seam (Table 6.1).

Coal petrographic and microfloral work has been carried out by Hacquebard and others (Hacquebard 1952, 1972, 1979, 1983, Hacquebard *et. al.* 1960, Barss & Hacquebard 1967, Hacquebard & Donaldson 1969). On the basis of this work, Barss & Hacquebard (1967) erected five miospore Zones (Table 6.1) which they considered to range in age from the Westphalian C to the lower Permian. The lower three Zones were believed to correspond with Bell's (1938) floral Zones and were therefore correlated with the Westphalian C and D. However, as Bell's Zones have been recently emended (Zodrow & McCandlish 1978), then it follows that the miospore zonation should probably also be emended in a similar way.

Using coal petrographic and palynological data, Hacquebard and Donaldson (1969) compared the depositional environments of the Sydney coals and those of the Pictou coalfield. Rapid subsidence and the early burial of peat beds in a floodplain environment with interaction between fluvial sedimentation and peat deposition was concluded for the Sydney coals. The Pictou coals were considered to be limnic in origin.

In a series of publications, Zodrow and others have compared the geochemistry of the Sydney coals and associated strata with those of coalfields in the USA and in Britain. Hydrated sulphates associated with the breakdown of pyrite in coal were also studied (Zodrow & McCandlish 1978b, Zodrow *et. al.* 1979, Zodrow & Zentilli 1979). Recently, geochemical analyses of the roof and seat rocks of ten coal seams was carried out and the results reported in Zodrow (1983), who concluded that the sediments either had a common sedimentary source or a similar diagenetic history.

Work of a sedimentological nature was until recently, rather limited. A series of investigations by Haites (1951, 1952a, 1952b) and Hayes & Bell (1923) being the only work available. However, a project was started by the Nova Scotia Department of Mines & Energy in 1981 and some of the preliminary results have been published recently (Dilles & Rust 1983, Rust et. al. 1983). In addition, Duff et. al. (1982) published on the western part of the coalfield.

The lower parts of the Morien Group were investigated by Dilles & Rust (1983) who suggested an upward change from deposition on a sandy braidplain to an alluvial plain with fewer, larger high sinuosity channels. Local sediment compaction was considered to be important in producing depression on the floodplain in which peat accumulated. Rust et. al. (1983) recognised three facies associations in the Morien Group, including the two mentioned above. Palaeocurrent studies indicate a consistent northeastwards transport direction through space and time (Duff et. al. 1982, Rust et. al. 1983).

The structure of the Sydney Basin is relatively simple (King & MacLean 1967, Hacquebard 1983) and except for local folding, is essentially saucer-shaped with the strata dipping towards the deeper and central parts of the Basin. Along its southern boundary however, a marginal fold belt is present, which is manifested by folding and faulting on the land area of the Sydney coalfield (Figure 6.3a). In the landward part of the coalfield, the beds are flexed in open folds that trend northeasterly with prevailing dips of 4° - 15°. Hacquebard (ibid.) attributed the folding to warping during deposition as the coal seams display greater thicknesses in the synclines. Apart from the two boundary faults located at the western and southeastern corners of the coalfield, only minor faulting has been observed. The main structural feature in the western part of the coalfield is the Boisdale anticline, which separates the Ingonish and Glace Bay subbasins (Figure 6.3a).

The Morien Group of the Sydney coalfield is naturally

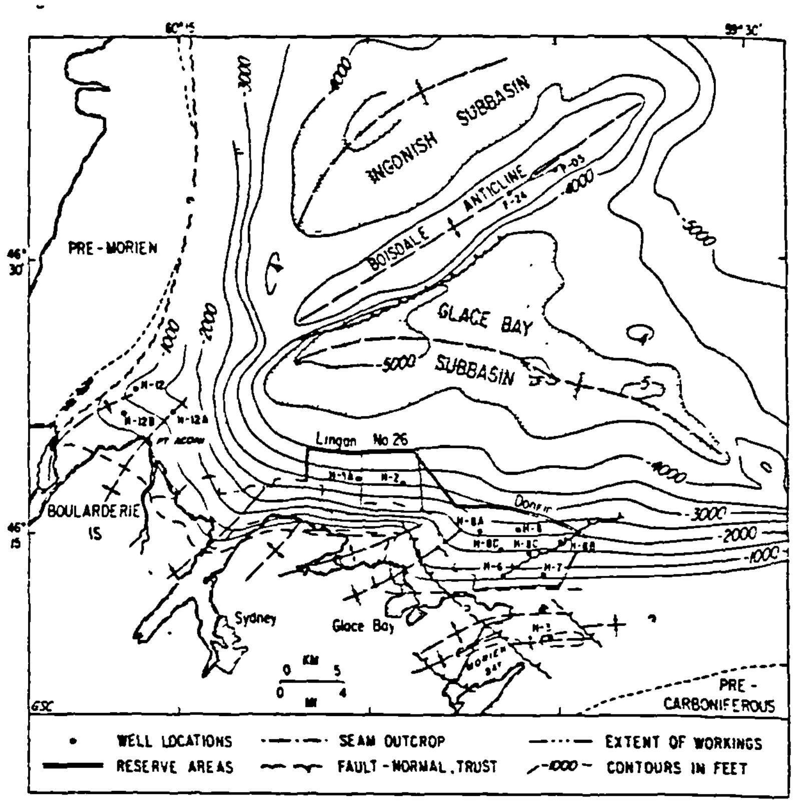


FIGURE 6.3a: The Sydney Basin, folds faults and subbasins. (From Hacquebard 1983).

divisible into three parts. The upper and lower parts (Lloyd Cove-Point Aconi seam interval and from the base of the Group to the Emery seam) comprise mainly coarse-grained lithologies. Large channel sandstones make up much of the sequence and floodplain sediments are quite rare (Duff et. al. 1982, Dilles & Rust 1983). The middle part of the sequence contains most of the major workable coal seams and floodplain deposits are common. In addition, lacustrine deposits occur as thin, freshwater limestones and as dark grey, fine-grained clastic intervals.

Fauna is largely unrecorded in the upper and lower coarse facies, although a sample from a borehole provided by Mr. S. Forgeron contained Anthraconauta phillipsii s.s.. The stratigraphic position of this sample was recorded as approximately 2000 m below the Emery seam. For this reason, the following account deals only with the fossiliferous Emery-Lloyd Cove seam interval (Table 6.1, Figure 6.3b). Descriptions of sections and faunas are made locality by locality moving across the coalfield from west to east. Some of the sections are continuous and to treat the localities stratigraphically would prove confusing.

6.1.1. The Black Rock - Squatter's Bluff section.

The Black Rock seam (Backpit seam) crops out in the westernmost part of the coalfield between Black Rock and Squatter's Bluff (Figure 6.2). Here, the seam has a thickness of about 1 m and is overlain by a sequence of floodplain and lacustrine sediments. Thick channel sandstones form the Squatter's Bluff and Black Rock promontories. Part of the section is shown in Figure 6.4.

The roof shales of the seam comprise muddy and silty shales which are often calcareous, and thin micritic limestones. The basal part of the roof shales comprise typical Anthraconauta facies with dark to medium-grey muddy and silt shales containing

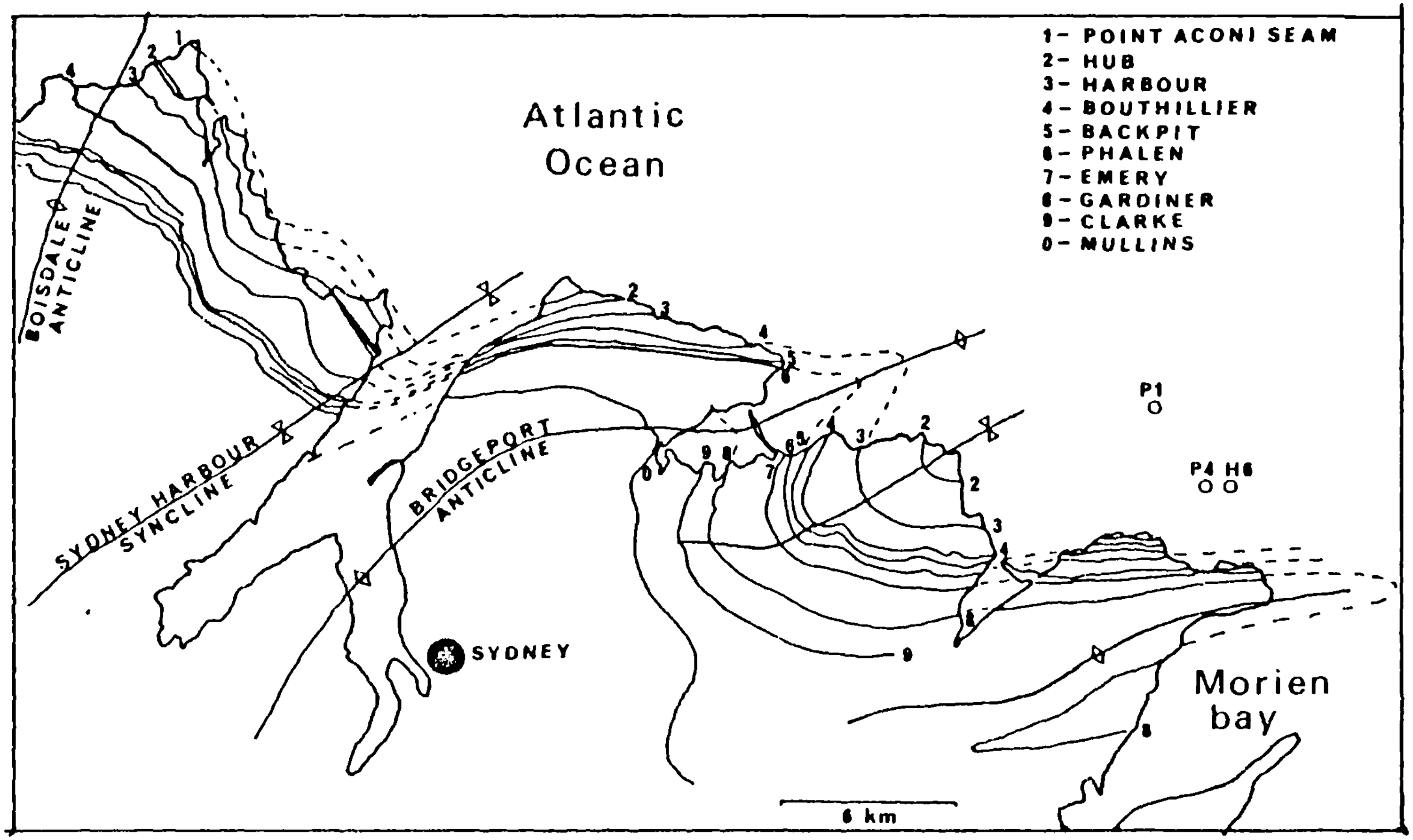


FIGURE 6. 3b: The Sydney Basin (onshore) - Distribution of coal seams.

Anthraconauta phillipsii, *A. tenuis s.l.* and *A. calveri s.l.*. Bivalves are preserved as crushed articulated and closed shells often reaching shell-bed proportions and representing a life assemblage. Locally, ostracodes referable to *Carbonita evelinae*, *C. pungens* and *C. secans*, and fish remains occur.

Figure 6.4 (inset) shows the distribution of fauna in the roof shales and there is a noticeable tendency for elongate shells of the *A. tenuis* group to occur in the darker, finer-grained lithologies whilst *A. calveri s.l.* tends to occur in the paler silty horizons towards the base of the sequence.

In the upper part of the horizon, abundant but poorly preserved, bivalve impressions referable to *Anthraconaia* sp. occur in a thin pale grey micrite.

Discussion: A period of peat formation gave way to lacustrine conditions. The lake was subject to periods of low clastic input allowing carbonate formation. The *Anthraconauta* facies probably represents a well oxygenated lake in which current activities were strong enough to ensure oxygenation of the bottom waters, but with low rate of deposition, not too great to allow preservation of bivalves in situ as mainly articulated shells.

Later, a period of low current activity and insignificant clastic input allowed micrite deposition. The bottom waters were probably anoxic, limiting fauna to a small number of small-shelled *Anthraconaia*. Associated fauna is absent and this particular lithology and its reduced fauna is typical of the *Anthraconaia* facies.

6.1.2. The Aconi Brook section.

A thin fossiliferous horizon occurs just east of Aconi Brook mouth (Figure 6.2), which is stratigraphically between the Harbour and Hub seams (Grid reference 043333). A thin, poor coal is

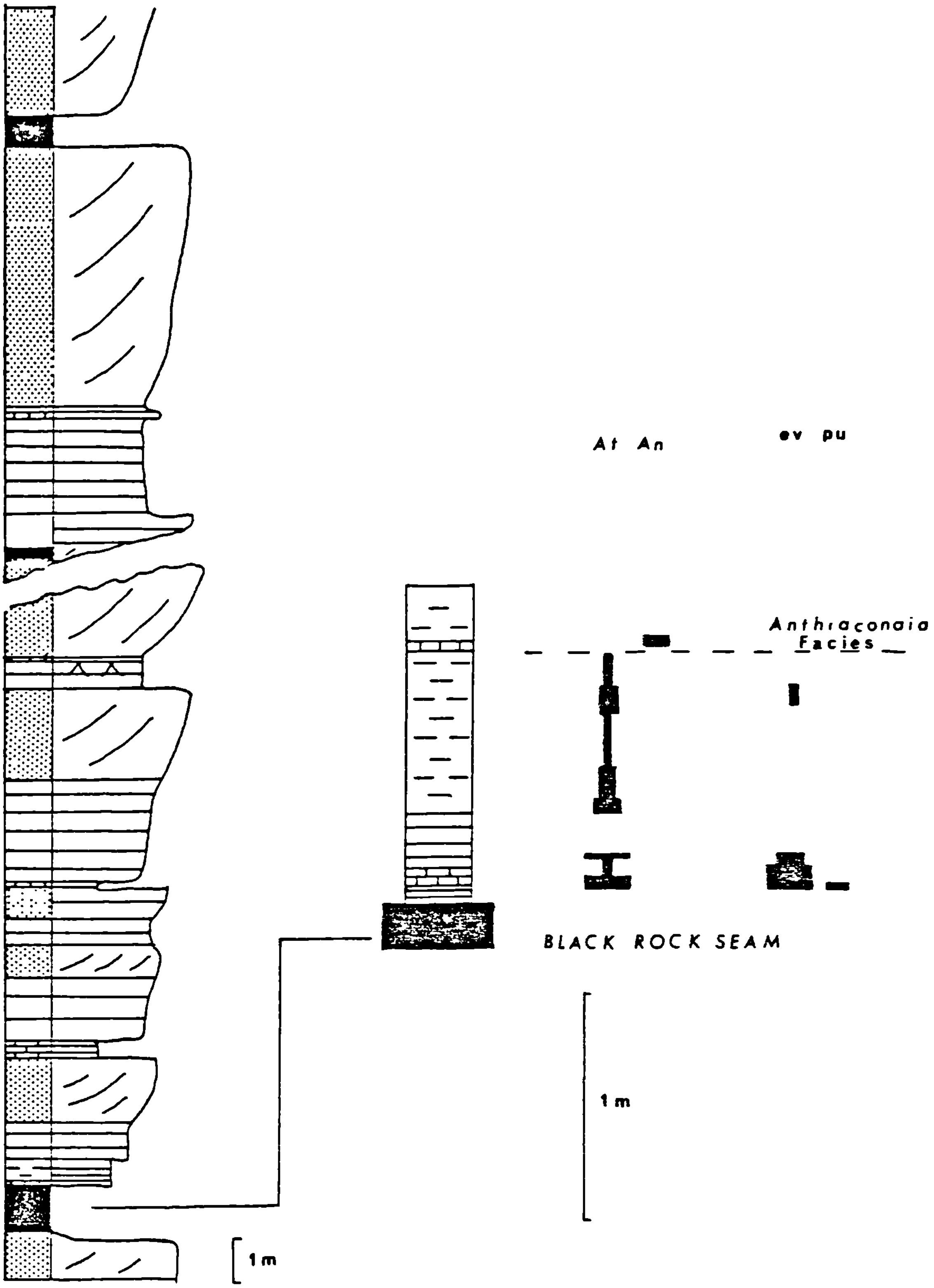


FIGURE 6.4: The Squatter's Bluff coastal section and inset showing distribution of fauna above the Black Rock seam.

overlain by dark grey muddy shales and pale grey calcareous mudstones of lacustrine origin. Bivalves comprising Anthraconauta phillipsii, A. tenuis and possibly, A. calveri s.l. occur in a tightly packed shell bed.

Ostracodes and fish remains occur rarely and comprise Carbonita salteriana, C. evelinae and C. pungens. Fish scales referable to Rhadinichthys sp. were recorded.

6.1.3. The Sydney Mines section.

The Linopteris obliqua Zone (sensu Zodrow & McCandlish 1978) of the Morien Group is well exposed along the Sydney Mines shore from Stubbert point (grid ref. 225137) to Lloyd Cove (250150 approx.) although, in places access is dificult and sewage outfall makes the task unpleasant (Figure 6.2). The section (Figure 6.5) comprises thick channel sandstones, crevasse splay sandstones, floodplain and lacustrine deposits. Several coal seams crop out along the section including most of the major named seams from the Phalen to the Lloyd Cove seam (Table 6.1). Thin cannel coals are common, particularly in the Harbour-Hub seam interval.

Several fossiliferous bands were recorded in the section and collected. These are dealt with stratigraphically below:-

6.1.3.1. The Phalen seam.

Several thin seams separated by muddy shales form the Phalen seam. A 10 cm thick pale grey micrite 60 cm below the lower leaf of the seam, is overlain by dark to medium-grey calcareous silt shales. These contain rare shell fragments, common fish debris and abundant ostracodes including Carbonita bairdiodes, C. evelinae, C. humilis and C. salteriana.

The domination of the ostracode assemblage by C. bairdiodes is typical of silty, calcareous lithologies and it normally occurs

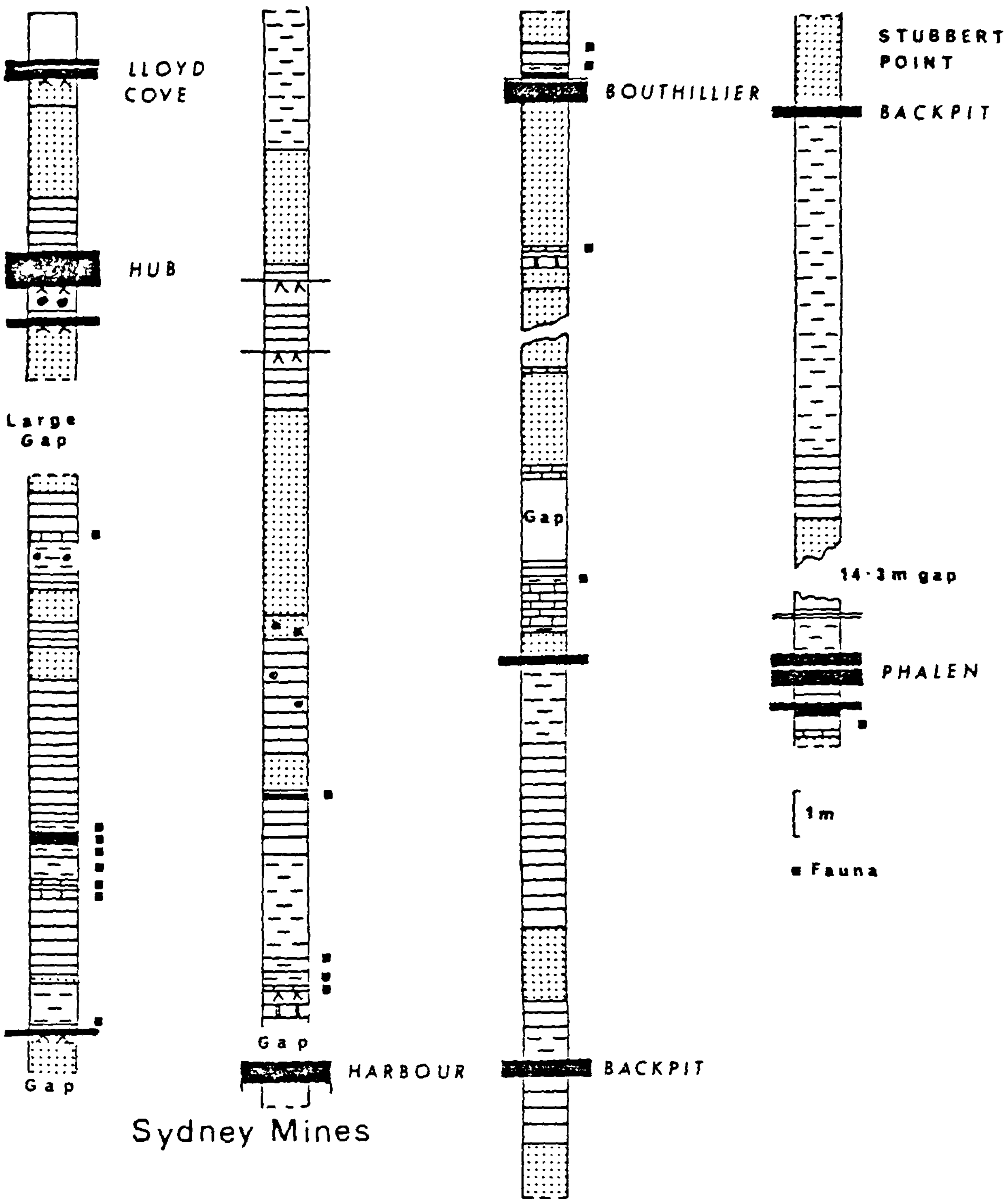


FIGURE 6.5: The Sydney Mines coastal section (see Figure 6.2). Faunal horizons indicated.

with the small-shelled Anthraconaia group. However, although shell fragments do occur, they could not be identified.

6.1.3.2. Between the Backpit and Bouthillier seams.

Eight metres above the Backpit seam, a sequence of calcareous siltstones and silty shales occurs. An unnamed seam is overlain by 50 cm of rootleted sandstone which is in turn overlain by a laminated calcareous lithology (Figure 6.5). Laminae vary in thickness from 1 to 20 mm and comprise silty micrite, calcareous siltstone and fine-grained, pale grey, calcareous sandstone.

The fauna comprises articulated and open shells, impressions of Anthraconaia sp. indet., abraded shell fragments referable to Anthraconauta spp., fish fragments and rare ostracodes including Carbonita evelinae, C. bairdiodes and C. humilis. In addition, rootlets are common and lie subhorizontal to the bedding.

The small, sub-ovate shells identified as Anthraconaia sp. are difficult to name with any certainty due to their rarity and rather poor preservation. Abraded shell fragments occur on the coarser bedding planes and the Anthraconaia, ostracodes and fish remains occur in the finer, micritic horizons.

The horizon is of lacustrine origin, periods of very low clastic sedimentation allowing carbonate deposition. Small Anthraconaia, ostracodes and fish inhabited the lake. Periodic influxes of rather coarse sediment and abraded shell debris are suggestive of episodically high current activity.

Several thin micrite horizons occur some metres above this (Figure 6.5) within a thick channel sandstone which forms the Mines point. These comprise subangular quartz grains held in a carbonate cement and appear to contain no fauna. Rootlets however, are quite common and the limestones are inferred to be calcretes.

6.1.3.3. Above the Bouthillier seam.

At the top of the thick channel sandstone mentioned above, the Bouthillier seam crops out. The seam is 45 cm thick and rests on a typical seatearth with rootlets of over 1.5 m thickness. Overlying the coal is a 12 cm thick cannel coal containing *Lioestheria striata*, fish remains, *Carbonita evelinae* and *Spirorbis* sp. which becomes increasingly silty upwards grading into a dark grey (N1.5) silty shale.
The silty shale contains a few single valves referable to *Anthraconauta* spp, as well as *Lioestheria* sp., *Carbonita evelinae*, fish remains and spirorbids. The fossiliferous sequence is overlain by muddy shales which contain abraded shell fragments in the basal few centimetres.

The section (Figure 6.5) displays a typical peat swamp to floodplain sequence such as commonly occurs in the Emery-Lloyd Cove seam interval. Plant growth commenced on the top of an abandoned river channel and with subsidence, developed into a peat swamp. Increased subsidence (or a rise in the level of the groundwater, or both) probably gave rise to a shallow and highly eutrophic lake. The cannel coal may have been deposited in acidic water. Such a substrate requires anoxic or oxygen deficient bottom waters in order to preserve the high proportions of organic material and was probably unsuitable for colonisation by *Anthraconauta*. Fauna was limited to estheriids and ostracodes.

Increased current activity and some clastic input provided for both a firmer substrate and an enhanced oxygen supply such that bivalves were able to to inhabitate this environment. The lake finally silted up and floodplain conditions were reintroduced.

6.1.3.4. The Harbour - Hub seam interval.

There are several fossiliferous horizons in this interval.

The first occurs above the Harbour seam which is poorly exposed due to local mining, but is at least 40 cm thick. Overlying the seam are several metres of channel sandstone. The top of the sandstone comprises a thick, well developed rootleted calcrete. This is overlain by a sequence of medium to pale grey (N3-4) silty shales with darker (N2-3) often cannelly, horizons (Figure 6.5).

The first horizon contains a fauna of well-preserved, crushed shells identified as *Anthraconauta phillipsii*, *A. tenuis*, *A. calveri s.l.* and *A. wrighti s.l.* with associated *Carbonita evelinae*, *C. humilis*, *C. salteriana*, *C. pungens* and occasional *C. bairdiodes*. Fish remains and spirorbids are rare whilst estheriids are abundant in the cannelly shales.

Bivalves are preserved as articulated and closed shells and as single valves. *Anthraconauta phillipsii* and *A. tenuis* are common occurring mainly in the finer-grained, darker lithologies whilst *A. calveri s.l.* and *A. wrighti s.l.* occur in paler, silty shale.

6.1.4. The Victoria Mines section.

A section was measured through the Phalen - Lloyd Cove seam interval of the Morien Group along the shore from a point just north of McGillvray Point (242179) to just north of Petrie Point (252187), Victoria Mines (Figure 6.2 and 6.6). Rust *et. al.* (1983) examined the entire 900 m thick section from South Bar to Victoria Mines (Figure 6.2). The basal 105 m is dominated by sandstones with only 3 m of mudrocks present. Thin pebble conglomerates commonly occur above erosional surfaces (Figure 6.7a) and coals are absent. The next 630 m continue to be sandstone dominated but mudstones are more common as are thin coal seams (Figure 6.7b). The upper parts of the section are characterised by an alternation of mudrocks and sandstones.

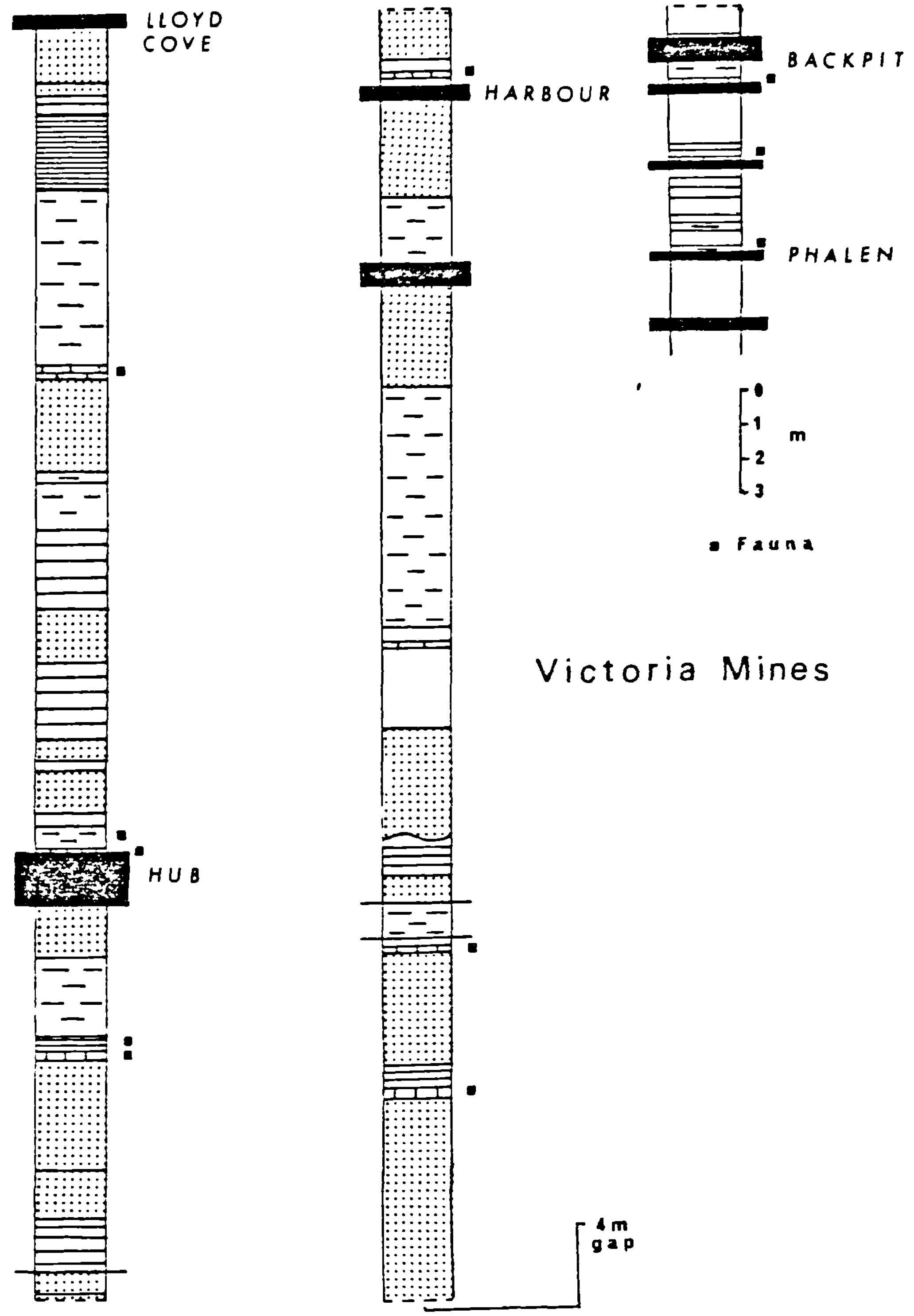


FIGURE 6.6: The Victoria Mines coastal section. Seams and faunal horizons indicated.

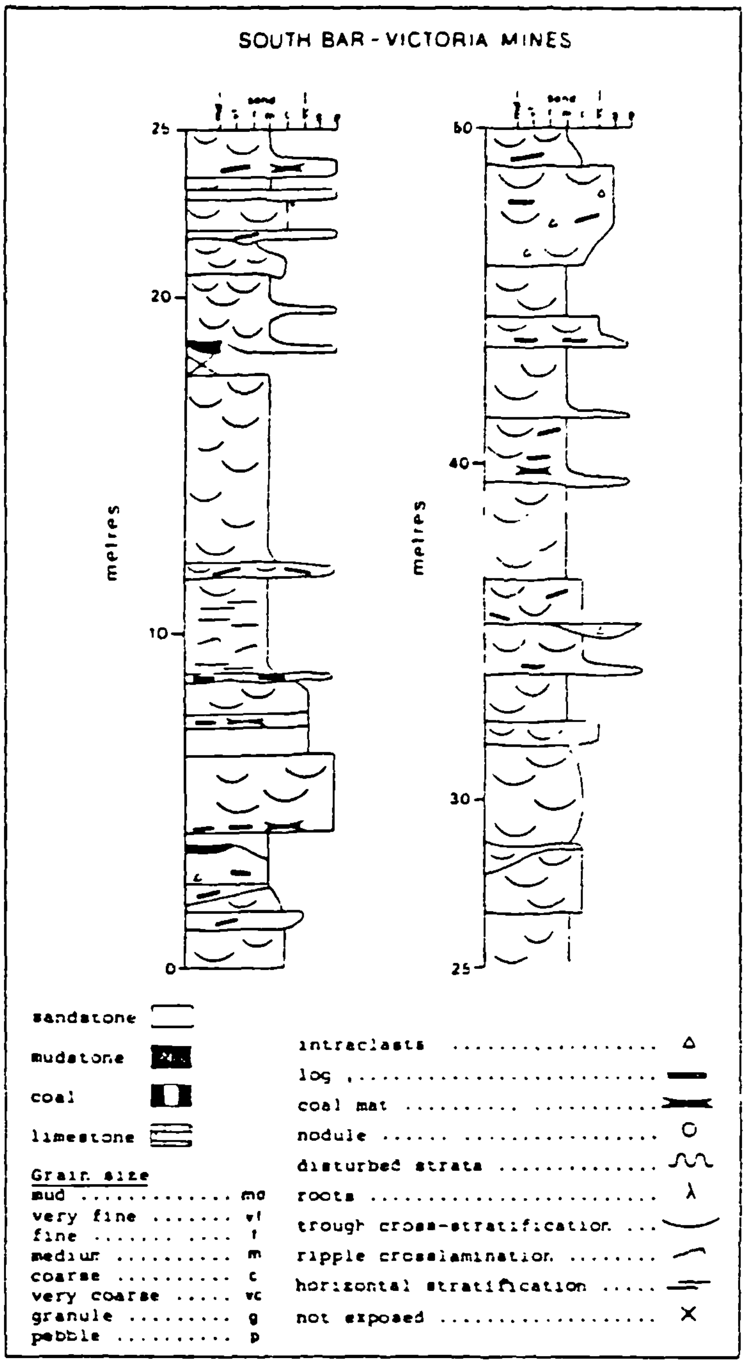


FIGURE 6.7a: South Bar - Victoria Mines section of Rust et. al. (1983). Basal part of the Morien Group.

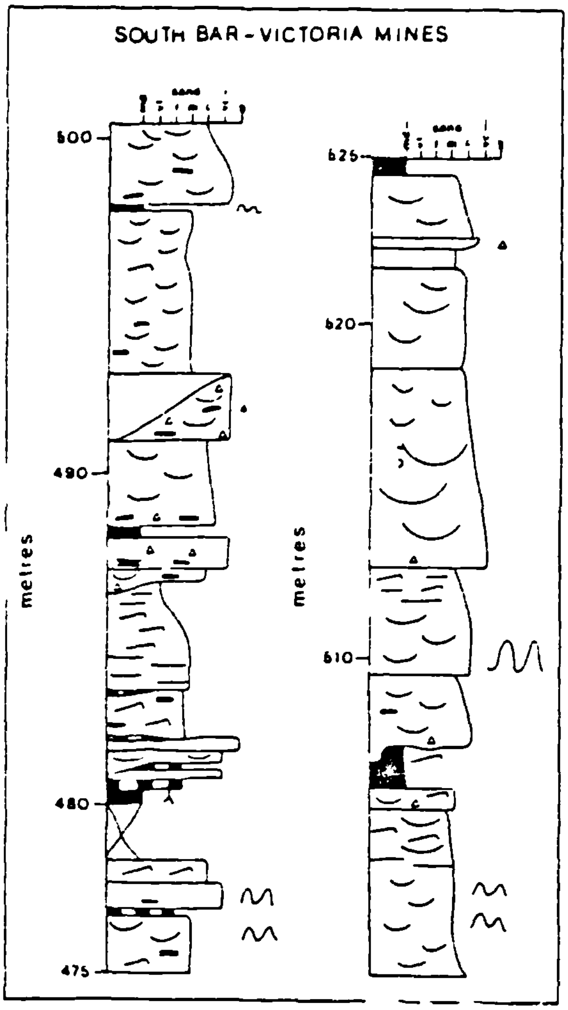


FIGURE 6.7b: South Bar - Victoria Mines section of Rust et. al. (1983) continued. See Figure 6.7a for key.

The upper part of the section measured by Rust et. al. (ibid.) includes the section examined in this study and comprises channel and crevasse splay sandstones, silty and muddy floodplain deposits, limestones and mudrocks of lacustrine origin and thick coals. Fossiliferous horizons occur above coals and at the top of fining-upward channel sandstones.

6.1.4.1. Above the Phalen seam.

The Phalen seam comprises several thin seams having a total thickness of about 700 mm in a 4 metre interval. The uppermost seam is overlain by a sequence of dark and medium grey (N3.5-2.5) calcareous silty shales which grade into dark grey, silty muddy shales.

The basal calcareous beds comprise silt-sized, subangular quartz grains in a micrite matrix in which ostracodes are abundant and include Carbonita bairdiodes, C. pungens and C. inflata. About 10 cm above the top of the coal, bivalves enter the sequence. They are preserved as crushed, articulated and closed shells which reach shell-bed proportions in a medium to dark grey silty mudstone. The shells are often difficult to identify due to crushing but Anthraconauta phillipsii, A. tenuis and A. calveri were recorded with associated Carbonita evelinae, fish fragments and spirorbids.

6.1.4.2. Above the Backpit seam.

The Backpit seam has a total thickness of 90 cm at this locality and is split into two seams (Figure 6.6). The lower leaf is overlain by a thin micrite containing abundant fish fragments, coprolites, spirorbids and rare ostracodes.

6.1.4.3. Between the Backpit and Bouthillier seams.

An 11 metre thick sandstone sequence overlies the Backpit seam. The top of the sandstone comprises a greenish-grey, fine-grained sandstone with calcite and siderite nodules often replacing fossil rootlets. A thin micrite follows this abandoned channel deposit but contains only *Spirorbis* sp..

Overlying the micrite is a coarsening-upward sequence of micaceous muddy and silty shales containing common articulated shells and single valves near the base. Bivalves comprise *Anthraconauta phillipsii* and *A. tenuis*. Abundant fish fragments including those of *Rhizodopsis* sp. and *Elonichthys* sp. occur with rare ostracodes.

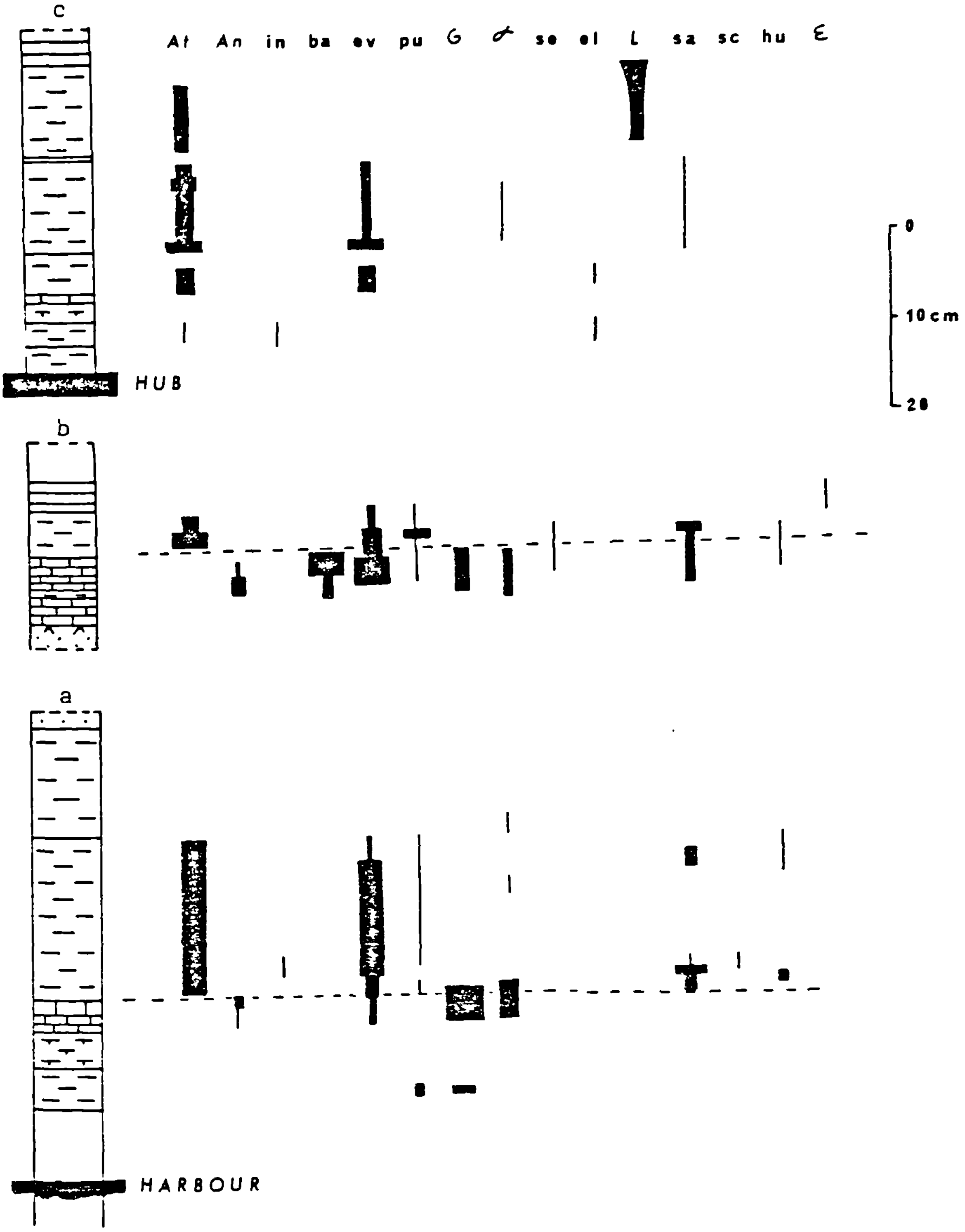
6.1.4.4. Above the Harbour seam.

A lacustrine sequence of micrite, calcareous, muddy and silty shales overlies the Harbour seam. The basal micritic part of the horizon contains shell fragments and impressions of small anthracosiid-like *Anthraconaia* (see Figure 6.32), *Spirorbis* sp., fish remains and rare ostracodes. Such an assemblage is typical of the *Anthraconaia* facies.

The overlying shales contain a fauna including common to abundant *Anthraconauta* spp. preserved as articulated shells, single valves and rarely, as fragments. *A. phillipsii*, *A. tenuis*, *A. calveri s.l.* and *A.* sp. cf. *A. wrighti* were recorded along with an ostracode assemblage which included *Carbonita evelinae*, *C. pungens*, *C. inflata*, *C. salteriana*, *C. scalpellus* and *C. humilis*. Fish fragments and spirorbids also occur (Figure 6.8a).

6.1.4.5. Between the Harbour and Hub seams.

Approximately 7.5 m above the Harbour seam, a further micrite occurs overlying a fining-upward channel sandstone (Figure 6.8). The micrite overlies the abandoned rootleted, seatearth-like top of the sandstone and is overlain by medium to dark grey muddy and silty shales.



FIGURES 6.8a-c: Distribution of fauna (a) above the Harbour seam, (b) between the Harbour and Hub seams and (c) above the Hub seam at Victoria Mines (see Figures 6.2 & 6.6)

Figure 7.8b shows the horizon and the distribution of fauna within it. The calcareous, basal part contains a typical *Anthraconaia* facies assemblage and is followed by an *Anthraconauta* facies fauna. Small, anthracosiid-like *Anthraconaia* are preserved as shell fragments and poorly defined impressions which are difficult to identify. The *Anthraconauta* however, are well preserved as crushed articulated shells and single valves and include *A. phillipsii*, *A. tenuis* and *A. calveri*.

6.1.4.6. Above the Hub seam.

The roof shales of the Hub seam (Figure 6.8) comprise a sequence of mainly dark grey, muddy and silty shales. Shells occur both articulated and single valves. Preservation is as thin calcite 'films' and as impressions. Shell morphology is difficult to determine due to slip between the two valves on crushing. However some elongate shells referable to *Anthraconauta tenuis* are common and occur with rarer *A. phillipsii* *s.l.* and *A. calveri*.

Ostracodes occur commonly and are dominated by *Carbonita evelinae*. *C. pungens*, *C. salteriana*, *C. inflata*, *C. elongata* and *C. humilis* were also recorded (Figure 6.8c). Fish fragments and spirorbids are rare and, towards the top of the roof shales, *Leaia* sp. is present.

6.1.5. The Lingan section.

A two metre thick section was measured in detail at Lingan, between the Harbour and Hub seams (Figures 6.9). The basal limestone in the section (Figure 6.9) was estimated to lie 10 m stratigraphically above the Harbour seam, which crops out on the shore near David Head (Figure 6.2).

The section comprises two coarsening-upward sequences

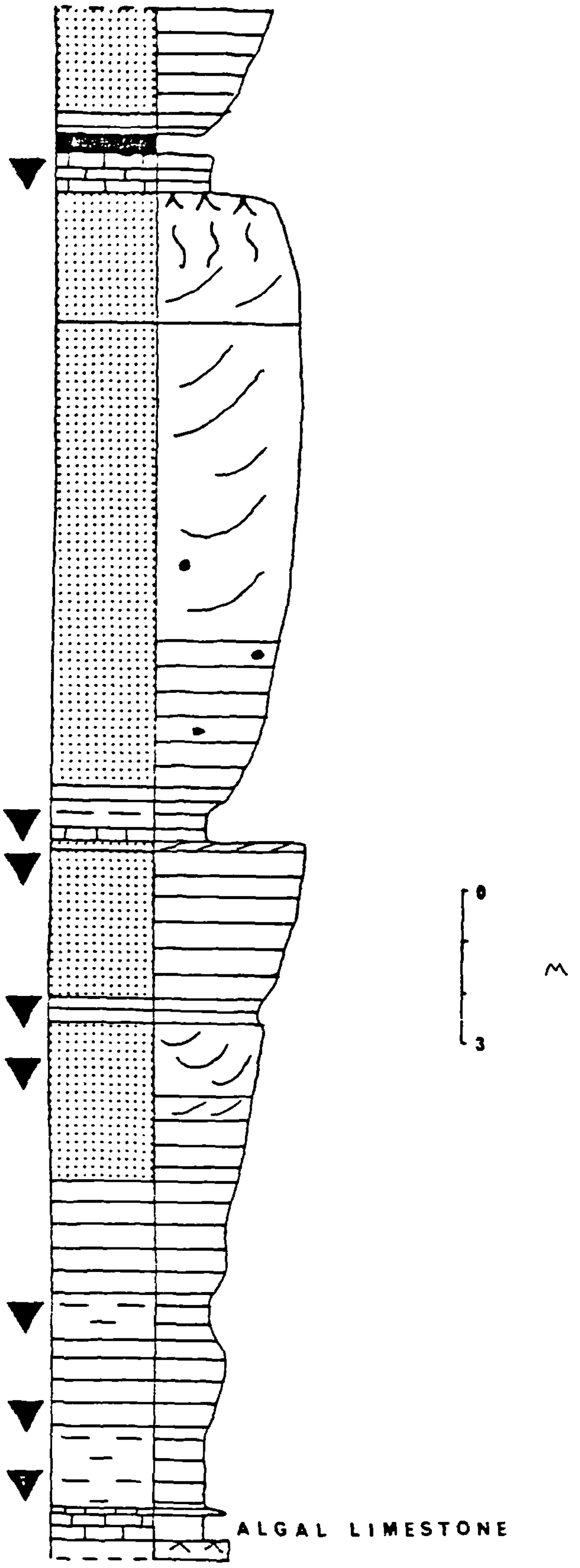


FIGURE 6.9: The Lingan coastal section after Vasey & Zodrow (1983). Algal limestone at base of the section. Faunal horizons indicated with a triangle.

interpreted as lacustrine deltas and crevasse splay deposits (Figure 6.9). Each sequence begins with a micrite resting on a rootleted sandstone, passes through an organic carbon-rich lacustrine shale sequence which coarsens-upward through a lake delta into a crevasse splay sandstone. Faunas are present very commonly throughout most of the basal 5 metres of the section.

The basal limestone has been studied in detail by Vasey & Zodrow (1983) (see also Masson & Rust 1982) and is 20 cm thick, comprising a microsparitic-micritic limestone. It rests on a structureless calcareous siltstone which contains autochthonous Stigmaria sp. Vasey & Zodrow (ibid.) termed this limestone the "algal limestone (ALS)" as it is the only limestone in which undoubted stromatolites have been identified in the Sydney coalfield, though other limestones are probably of algal origin (e.g. Masson & Rust 1983).

The algal limestone contains various lithoclasts including small and large clasts of calcareous siltstone, micrite, birdseye micrite, micrite peloids, quartz grains and angular stromatolite fragments. Large lithoclasts (greater than 2 cm in diameter) are restricted to the basal part of the limestone and there is a general fining-upward trend in the lithoclasts (Figure 6.10). Quartz silt however, becomes increasingly abundant up through the limestone (Table 6.2 - SiO_2). The stratigraphic variation of lithoclasts, fauna, elements and stromatolite morphologies is shown in Figure 6.10.

The stromatolites (Figure 6.11) display cryptalgal lamination (Monty 1976) which can be observed with the naked eye. The laminations consist of two alternating sets of laminae:-

a. Orange-brown, radially-fibrous calcite containing common inclusions as well as occasional quartz grains, ostracodes and spirorbids. The laminae rarely exceed a thickness of 8

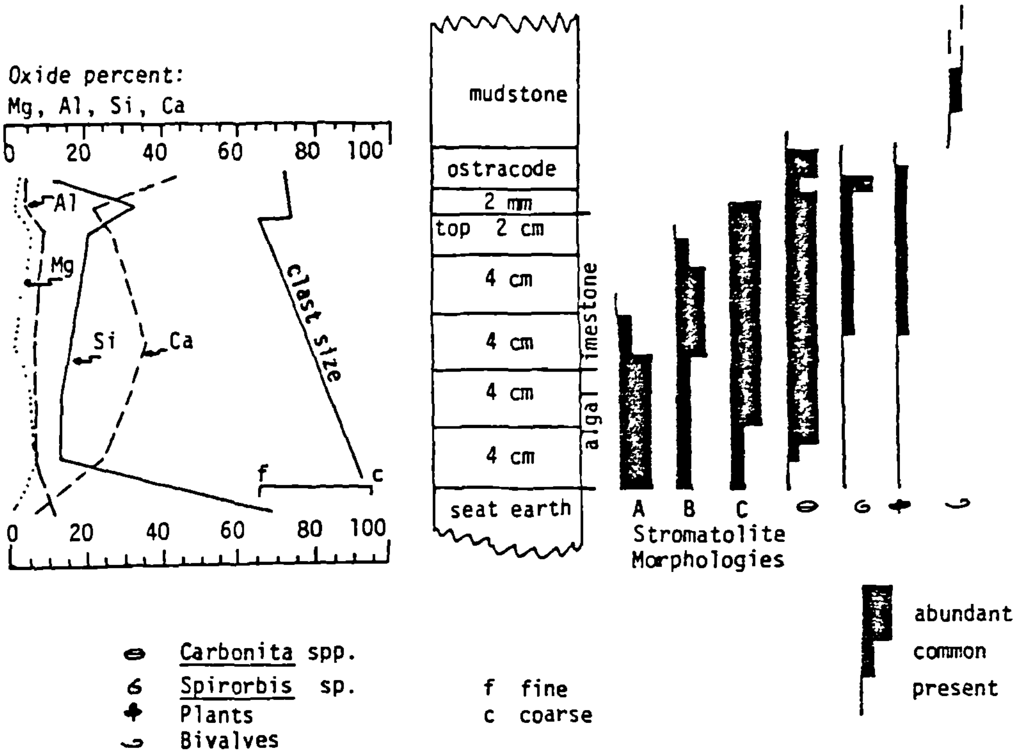


FIGURE 6.10: Distribution and size of lithoclasts, distribution of fauna and elements through the algal limestone at Lingan. (From Vasey & Zodrow (1983, Figure 8).

mm.

b. Darker micritic layers containing relatively more quartz silt, ostracodes and spirorbids than layer (a). Algal filaments have been observed in this layer (Figure 6. 12b). The layers vary from 0 - 5 mm in thickness and may be discontinuous. Bituminous films (50 um thick) frequently separate the two sets of laminae.

Chemical analysis of an 8 cm diameter pinnacle-type stromatolite (see below, Table 6.2) shows them to be high in $CaCO_3$ (85-90%) and low in lithophile elements.

There are three distinct stromatolite morphologies in the algal limestone;

a. Colonies of pinnacle-shaped stromatolites (SH-V structure of Logan <u>et</u>. <u>al</u>. 1964, 1974) - differential weathering of the limestone shows that the colonies occur as distinct clusters and that individual colonies may measure upto 45 cm in diameter and 16 cm in height. The colonies, oval or domal in shape, are attached to the top of the calcareous siltstone and do not protrude through the enclosing limestone. Individual stromatolite heads are frequently brecciated and the resultant voids are filled with micrite, or more rarely by sparite. Internally they comprise pinnacle-shaped stromatolites (Figure 6.11) that grew upward and outward from the area of attachment.

b. Mat-type stromatolites (LLH-C structure of Logan <u>et</u>. <u>al</u>. (<u>ibid</u>.). - these are mat forms which are upto 3 cm in length and 2 mm high. The mats form thin crusts over the top and sides of substrate irregularities and extend away from their area of attachment (Figure 6. 12a).

c. Detached-type stromatolites (oncolites) - small oncolites occur within the main mass of the limestone and rarely exceed 10 cm in

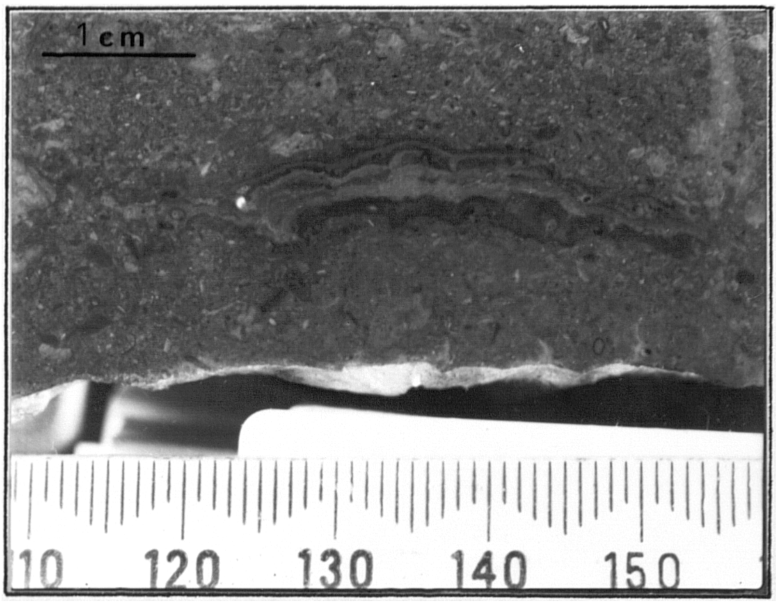


FIGURE 6.12: Mat-type stromatolite encrusting a siltstone clast. From the algal limestone.

FIGURE 6.11: Pinnacle-type stromatolite colony from the algal limestone. Note cryptalgal lamination.

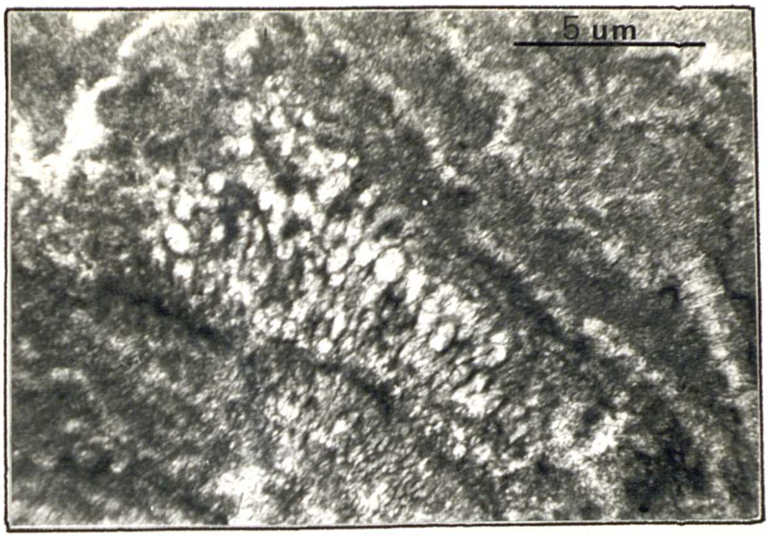


FIGURE 6.12b: Algal filaments of unknown affinities within the ALS.

FIGURE 6.12c: The algal limestone at Lingan, field view. Note dome-shaped pinnacle-type colony resting on seatearth. The ALS totally encases the colony and is c. 20 cm thick. (Hammer length - 18 cm).

TABLE 6.2: Geochemical results of the analysis of the algal limestone of Lingan (From Vasey & Zodrow 1983).

Fig. 2	$CaCO_3$#	C*	OXIDE PERCENT												Boron ppm
			Si	Al	Fe^{3+}	Ca	Mg	Na	K	Ti	Mn	P	LOI**	TOTAL	
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.

diameter. The oncolites totally encase lithoclasts, ostracodes and spirorbids. Quartz silt appears to be totally absent from the encasing growths.

Discussion: Recent studies have shown that small changes in environment produce correspondingly large changes in stromatolite morphology (Gunatilaka 1975, Horodski & Haar 1975, Monty & Hardie 1976). As algae form the primary source of food for many organisms, the environment in which the stromatolites accumulated must have been unusual, restricting fauna to a few ostracodes and fish and allowing the preservation of the stromatolites themselves.

The algal limestone was deposited in a freshwater lake which formed through local subsidence or a rise in the groundwater level (or both), on the top of a channel sandstone. This interpretation is supported by (a) the presence of Carbonita spp., (b) the absence of a hypersaline tolerant fauna and of evaporite minerals or their pseudomorphs (Hudson 1970), and (c) the low boron contents (Eagar & Spears 1966, Bouska et. al. 1977).

It is suggested that local subsidence allowed flooding of an area upon which some soil development and plant growth had occurred. The pinnacle- and mat - type stromatolite morphologies were initiated on this irregular substrate, large seatearth clasts providing suitable substrates for mat forms. Periodic emergence allowed the brecciation and desiccation of stromatolite heads.

The limestone itself is of algal origin. Clastic sediment supply was initially low (Table 6.2) allowing the accumulation of algal carbonate material perhaps in a similar way to that observed by Monty & Hardy (1976, p. 453) in the freshwater calcareous marshes of Florida.

Increasing water turbulence and clastic sedimentation accounts for the upward increase in lithophile elements (Figure 6.

10) and provides the mechanism required for the decrease of mat-type stromatolites and concomitant increase in detached forms. Stromatolite accumulation was finally terminated at the top of the limestone with a rapid increase in clastic input (Figure 6.10, Table 6.2 'ostracode-rich unit') and the lake may silt up. This would account for the abundance of ostracodes and spirorbids at the top of the limestone via 'ponding', and reflects the reintroduction of clastic dominated, floodplain conditions.

The limestone and its fauna is similar to the limestones previously described and assigned to the *Anthraconaia* facies however, bivalves are absent from the algal limestone and indeed, this may provide an explanation as to how the stromatolites were preserved.

The overlying shale sequence (Figure 6.9) varies in lithology from dark grey muddy shales to pale-grey, fine-grained sandstones (V2.5-4). Shells referable to *Anthraconauta* occur commonly as crushed articulated and closed shells or single valves lying with their commisural planes subhorizontal in dark grey shales. In paler grey, silty shales and sandy horizons, the shells are often preserved in an anterior-end downwards position with their commissural planes subvertical. Shell shape changes associated with changes in environment and mode of life are discussed later (Chapter 7).

Anthraconauta phillipsii is the commonest form at this horizon occurring with *A. tenuis*, *A. calveri* *s.l.*, and more rarely, forms referable to *A.* sp. cf. *A. wrighti*. Estheriids are common to abundant at certain horizons (Figure 6.9), but these bands are not laterally traceable. On darker, finer-grained horizons, ostracodes including *Carbonita evelinae*, *C. pungens* and *C. salteriana* occur.

Towards the top of the section, a thin coal occurs (Figure 6.9) overlying a *Spirorbis*-bearing limestone. The top of the limestone has an undulating, eroded appearance suggesting that the thin coal is allochthonous (Zodrow 1983).

6.1.6. The David Head - North Head section.

A section was examined along the shore from David Head (257278) to just south of North Head (252291) (Figure 6.2). The section was not measured in detail as much of it is composed of thick channel sandstones; however, short sections were measured around major coal seams and fossiliferous horizons (Figure 6.13).

6.1.6.1. Above the Phalen seam.

The Phalen seam crops out at North Head and comprises two seams split by a 2.5 m thick silty shale parting. The total thickness of the seam at this locality is 1. 45 m, the lower leaf being 1.11 m thick. Erosion of the headland, which is composed mainly of a thick channel sandstone with an erosional base, allowed examination of the upper leaf of the seam on both sides of the headland.

The lower seam rests on a calcareous siltstone seatearth and is overlain by 31 cm of dark grey (N2.5), calcareous siltstone which contains common to abundant *Anthraconauta* spp. The bivalves are preserved as thin, brownish calcite films and it is not possible to determine whether they are single valves or articulated shells. The bivalves attain shell-bed proportions just above the coal and comprise *A. calveri*, *A. phillipsii* *s.l.* and *A.* *tenuis* *s.l.*. Ostracodes including *Carbonita* *evelinae* and *C. pungens*, as well as fish (*Rhizodopsis* sp. and *Rhabdoderma* sp.), occur rarely.

The overlying silty shales contain a few crushed and fragmented shells towards the base and become calcareous and rootleted towards the top (Figure 6. 13).

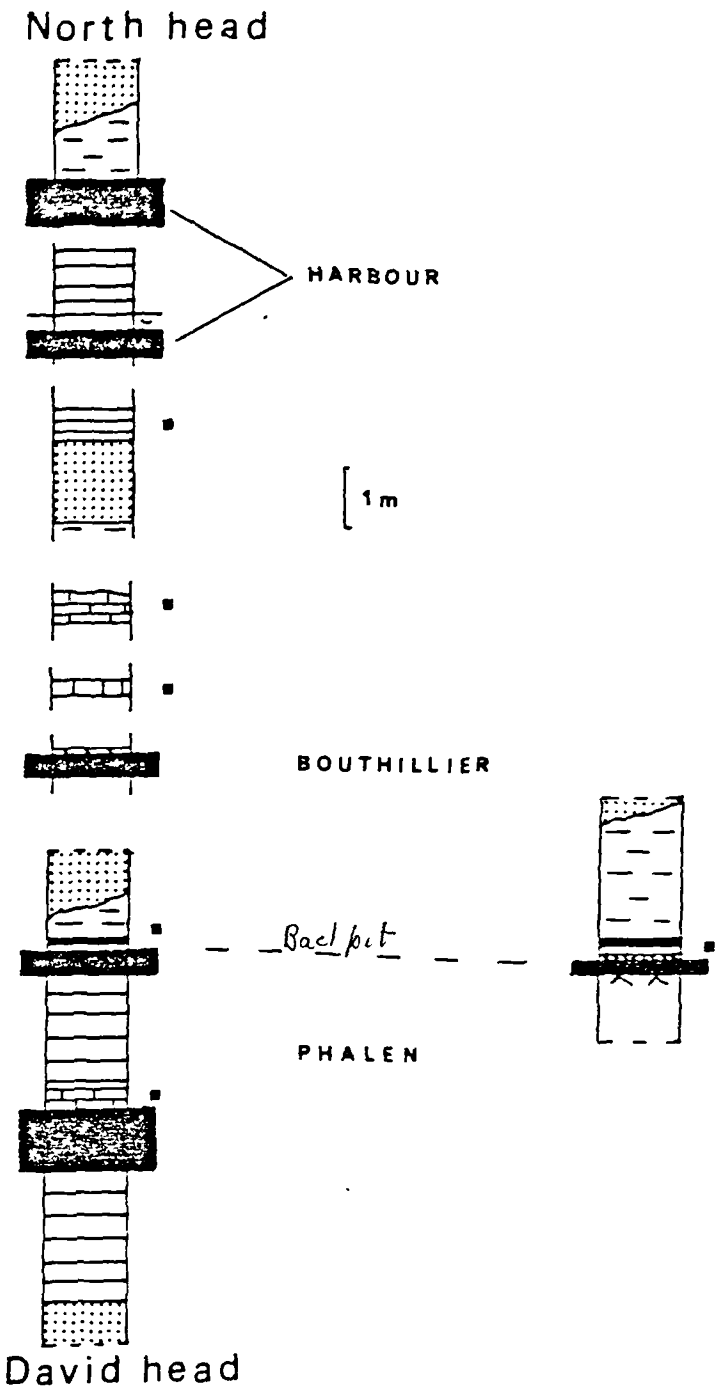


FIGURE 6.13: The North Head - David Head coastal section.
Faunal horizon indicated with a square.

The upper seam has slightly different roof shales on either side of the headland (Figure 6.13) but in both cases a few metres of roof shale is erosively overlain by a channel sandstone. On the north side of the headland, the coal is overlain by a 6 cm thick dark grey (N2.5), pyritic and calcareous siltstone containing abundant ostracodes, fish remains and some rare bivalves. The shells are poorly preserved as internal moulds and are small in size with a long anterior end and a concave antero-umbonal slope suggesting reference to Anthraconaia sp.. This bed is absent on the south side of the headland and appears to be of limited lateral extent.

Overlying the coal on the south side of the headland and overlying the Anthraconaia-bearing bed on the north side, is the following sequence;

silt and muddy shales - 10cm +

cannel coal - 12 cm

pale grey clay - 11-13 cm

The cannel coal contains a few pyritised ostracodes (Carbonita evelinae, C. pungens and C. salteriana), fish remains and rare bivalve fragments possibly referable to Anthraconauta sp..

Discussion: Lake formation followed deposition of the lower leaf of the Phalen seam. The lake was freshwater on the basis of its fauna (Calver 1968a, Pollard 1969, Bless & Pollard 1973) and had an organic carbon-rich substrate. Current activity and clastic input were moderate and increased through time to fill the lake and allow a period of further peat formation.

The Anthraconaia facies above the upper leaf of the seam apparently indicates low current activity and clastic sedimentation with 'in-situ' sulphide formation just beneath the sediment/water interface. Th local nature of this bed suggests deposition in a stagnant pool, perhaps in an area of peat bog. Peat formation was terminated by a rapid influx of clastic sediment and was later followed by cannel coal formation in an algal bog. Conditions in the algal bog were unsuited to Anthraconauta.

6.1.6.2. Above the Backpit seam.

Overlying the Backpit seam, which crops out just north of North Head, is a thin sequence of dark grey (N2.5) muddy and silty shales containing abundant crushed shells referable to Anthraconauta. Specific identification is impossible due to their abundance and their preservation as calcite films.

6.1.6.3. Between the Bouthillier and Harbour seams.

The strata above the Bouthillier seam comprises mainly thick channel sandstones. The sandstones usually have a finer calcareous upper part which may be rootleted and contain calcareous nodules. Occasionally, the sequence may culminate in a micrite of possible lacustrine origin (Figure 6. 13). The micrites are cream-weathering and commonly contain a fauna of rare ostracodes and fish remains as well as abundant Spirorbis sp..

Thin sections of the limestones show them to be divisible broadly into two main types:-

a. Micrites, often peloidal with areas of orange-brownish bitumen. The groundmass is usually partially recrystallised and may contain small euhedral rhombs of dolomite which is more likely to be diagenetic. Subangular quartz silt is rare. (Figure 6.14a).

b. Quartz silt and other clasts are held in a

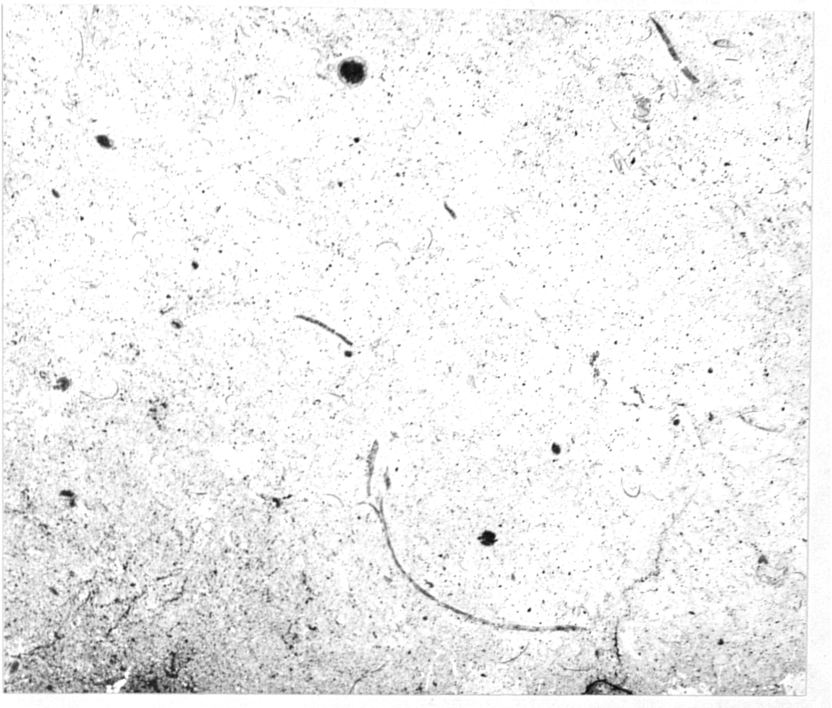


FIGURE 6.14a: Photonegative of a thin section - micrite.

FIGURE 6.14b: Photonegative of a thin section - Quartz-rich limestone.

micrite-microsparitic matrix. Void spaces are filled with sparite (Figure 6.14b).

The two distinct lithologies may be interlaminated and the limestones themselves may reach up to 50 cm in thickness. They are however, nodular and rather impersistent.

Approximately 1 m below the Harbour seam (Figure 6.13), a 55 cm thick dark grey (N2.5-3.5), micaceous siltstone occurs overlying a 1.5 m thick ripple-laminated fine-grained sandstone. The sitstones contains mainly fragments and abraded single valves of *Anthraconauta* spp. including *A*. sp. cf. *A. wrighti* and *A*. sp. aff. *A. tenuis*. Ostracodes, fish remains and spirorbids (attached to the posterior lobes of bivalves) also occur.

Figure 6.15 shows the distribution and preservation of this fauna. The abraded and fragmented nature of the shells indicates transport. Current activity and sedimentation rates were probably high, washing in silt-sized quartz, muscovite flakes and shell material.

6.1.6. The Dominion section.

The Dominion coast from Lingan beach (220291) to Brian Point (227310) was examined. Sections were measured around major coal seams and around fossiliferous horizons (Figure 6. 16).

Two fossiliferous horizons were recorded in the Backpit-Bouthillier seam interval (Figure 6. 16). The faunas comprise poorly preserved single valves referable to *Anthraconauta* spp., ostracodes, spirorbids and fish remains as shown in Figure 6.16). Both horizons are composed of calcareous siltstone overlain by muddy shales.

Figure 6. 17 shows a log of the Bouthillier seam, its roof

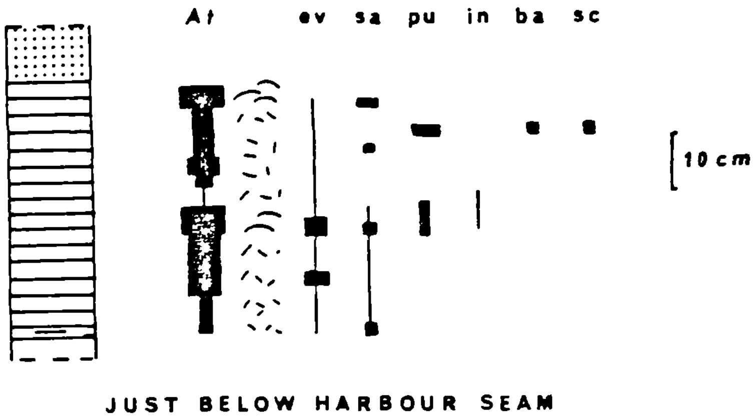


FIGURE 6.15: Distribution of fauna below the Harbour seam at David Head. Preservation also indicated as follows - ⌒ single valves, ⁖ - fragments.

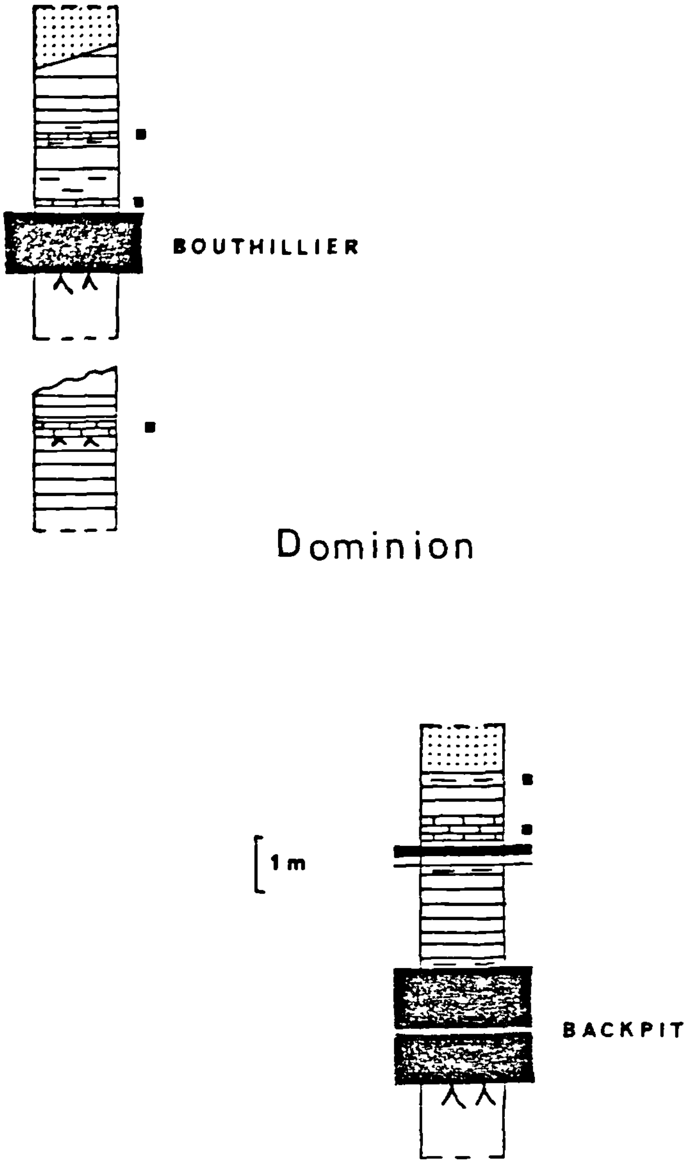


FIGURE 6.16: The Dominion coastal section. Faunal Horizons indicated with a square.

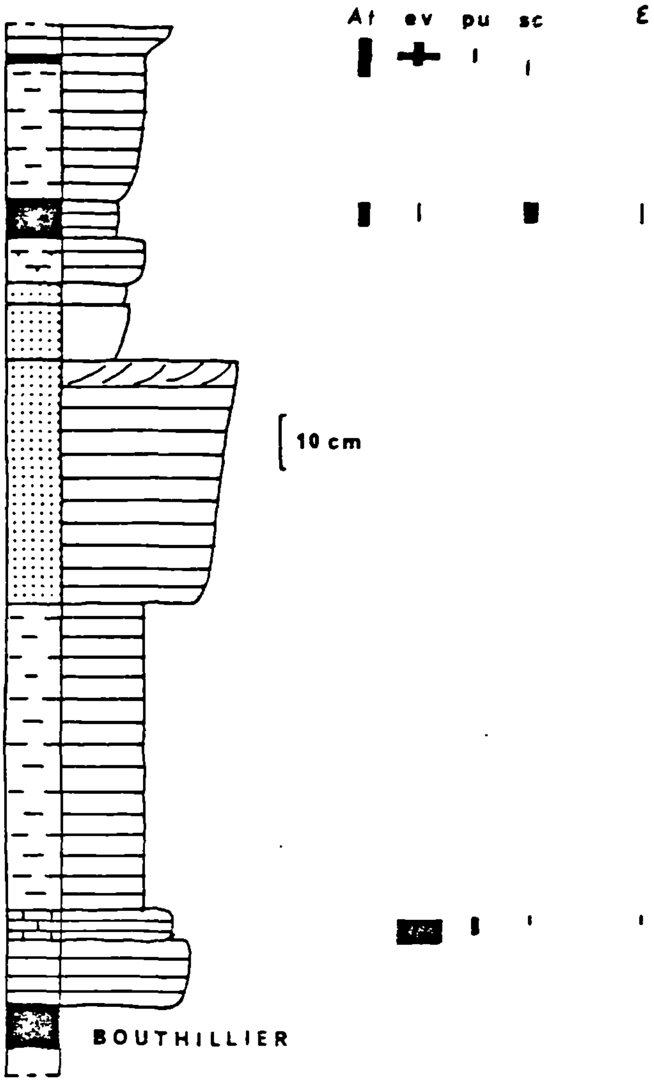


FIGURE 6.17: Distribution of fauna above the Bouthillier seam at Dominion.

shales and the distribution of fauna within them. The sequence is a typical coal - lake - delta sequence with the fauna in the lacustrine phase overlying the coal. The basal fossiliferous horizon documents a gradual decrease in oxygenation of the lake with macroscopic pyrite occurring in the top few millimetres. The fauna also becomes limited to fish fragments at the top of the section suggesting that the benthonic environment was unsuitable for bivalves and ostracodes (Figure 6. 17).

Between the Bouthillier and Harbour seams, no faunas were recorded. However, just above the Harbour seam which crops out in Deadman's Cove (Figure 6.2), a sequence of mudstones, siltstones and micrites yielded a poorly preserved fauna of Anthraconauta spp. including A. phillipsii, ostracodes dominated by Carbonita evelinae, fish remains and spirorbids. The fauna is probably allochthonous occurring in a ripple-laminated mudstone (Figure 6.18).

6.1.8. The New Aberdeen section.

The New Aberdeen section is situated at grid reference 336324 (Figure 6.2), on the coast northeast of the town of New Aberdeen. The section is estimated to lie about 10 m above the Harbour seam and comprises a greenish-grey, calcareous siltstone seatearth containing rootlets and calcareous nodules. A nodular micrite and medium grey (N3.5), muddy shales displaying 'cone-in-cone' structure overlie the seatearth and are followed by a typical coarsening-upward sequence of lacustrine muddy and silty shales (Figure 6.19).

The upper 4 cm of the seatearth comprises a greenish-grey silty limestone which contains carbonized roots, rare ostracodes dominated by Carbonita bairdiodes, and common bivalves identified as Anthraconaia spp. The overlying nodular limestone contains a similar, but impoverished fauna. A large collection of shells was

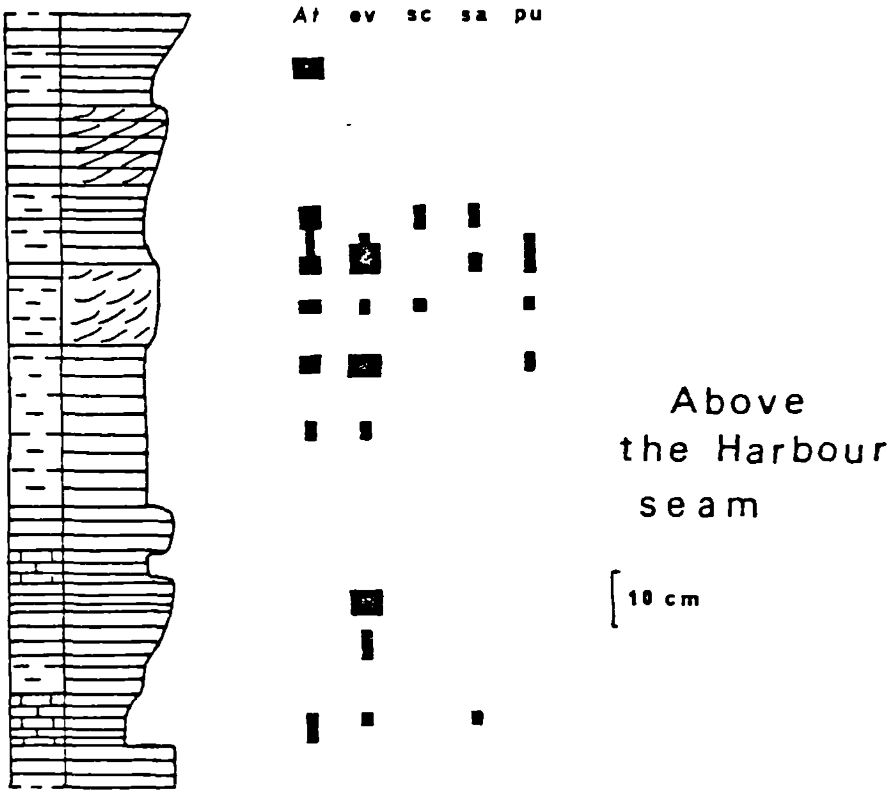


FIGURE 6.18: Distribution of fauna above the Harbour seam at Dominion.

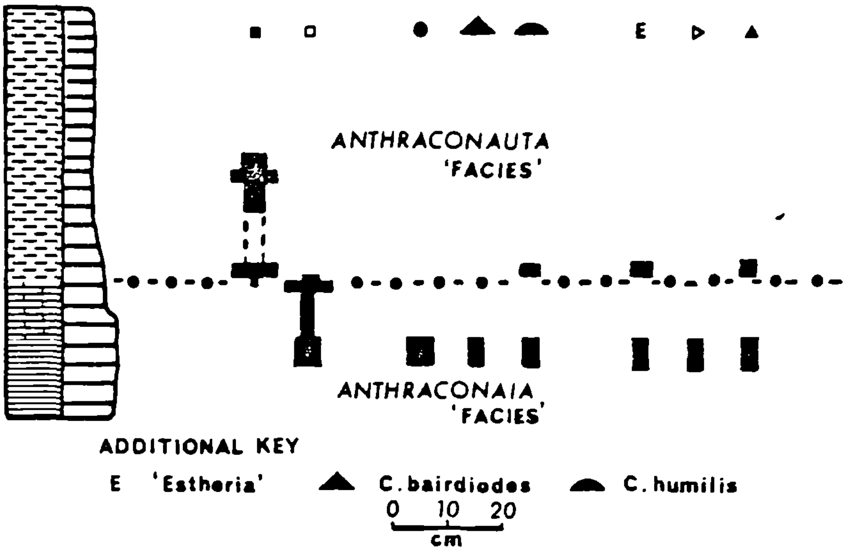


FIGURE 6.19: The New Aberdeen coastal section and distribution of fauna. See Figure 6.22 for key.

made from this locality and *Anthraconaia* sp. aff. *A*. *speciosa* Eagar, *A*. sp. cf. *A. saravana* (Schmidt), *Anthraconaia* sp. nov. *A,* and a form comparable to *A, palatina* (Schmidt), but of much smaller size than this morphological variety, were recorded.

The overlying medium-grey muddy and silty shales contain a poorly preserved fauna which includes single valves and articulated shells referable to *Anthraconauta phillipsii* *s.l.* and *A,* sp. cf. *A, wrighti*. Ostracodes, fish remains and estheriids were also recorded (Figure 6.19).

Discussion:

The New Aberdeen section provides an excellent example of the *Anthraconauta* and *Anthraconaia* facies types. The small *Anthraconaia* are never found on the same bedding planes as *Anthraconauta* and the two appear to be mutually exclusive.

In thin section, the silty limestone comprises subangular to angular quartz grains of varying grainsize, shell material and ostracodes in a micrite - microspar cement (Figure 6. 20a). The underlying limestone comprises an organic carbon-rich micrite in which crushed micrite 'peloids' are totally encased with a thin veneer of brownish, opaque organic material (Figure 6.20b). Quartz silt is present but in much smaller proportions. Both lithologies contain common dark-grey, near-opaque, micrite peloids which may be faecal in origin.

Interpretation - The seatearth forms the abandonment facies of a thick channel sandstone. The occurrence of fauna in what appears to be the top few millimetres of the seatearth and the continuation of the fauna into the nodular limestone suggests that the bivalves initially inhabitated a marginal lacustrine environment colonised by small plants. The carbonate content of the upper part of the seatearth may be algal in origin (cf. Monty & Hardy 1976), algal mats similar to those at Lingan, having been subsequently destroyed by rainfall or grazing.

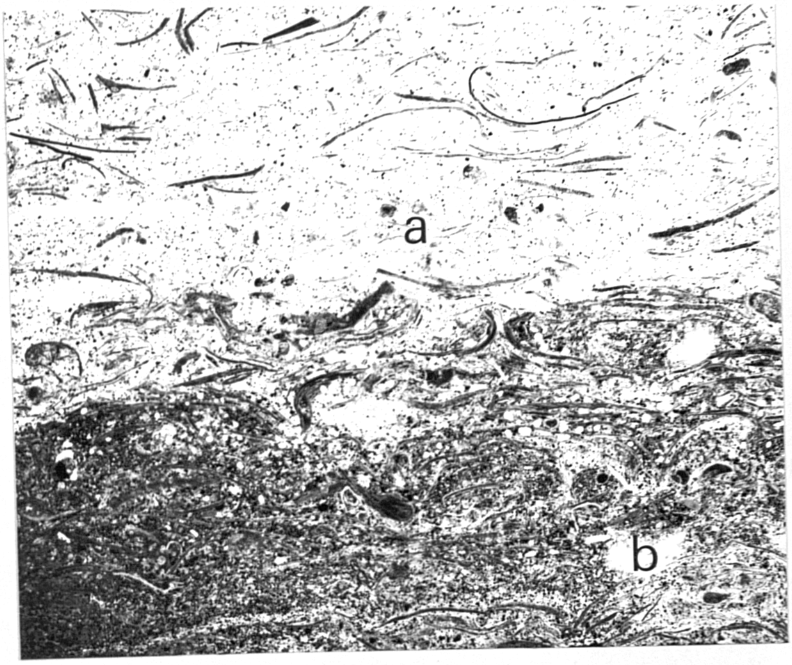


FIGURE 6.20: Anthraconaia - bearing limestone from New Aberdeen. Photonegative of a thin section. (a) - Micrite - microspar containing quartz silt and shelly debris. (b) - Shelly micrite containing also micrite peloids.

Influx of clastic material occurred later perhaps through overbank flooding, providing a eutrophic lacustrine environment. The coarsening-upward nature of the *Anthraconauta* facies probably reflects deposition by a lake delta. The section culminates in a crevasse splay sandstone.

6.1.9. A section between the Backpit and Bouthillier seams east of Glace Bay.

The Phalen and Backpit seams are exposed in the coastal section south of Whelan Point (Figure 6.2, grid reference 192389 to 187398). The section comprises mainly sandstones which consist of alternating sequences of 2-3 m thick medium-grained cross-bedded sandstones and 2-6 m thick fine-grained, ripple laminated sandstones (Figure 6.21). Thin floodplain and lacustrine muddy and silty shales occur, often overlying calcretes. Both of the seams are overlain by thin lacustrine sequences containing well preserved bivalve faunas.

6.1.9.1. The Phalen seam.

The Phalen seam was located at grid reference 187398 through the presence of old pit props in the cliff and wave-cut platform. The seam itself can only be examined through excavation of the base of the cliff and thus, neither the seams thickness nor its seatearth can be commented on.

Figure 6.22 shows the roof shales of the Phalen seam at this locality and the distribution of fauna within them. The basal 25 cm are composed of pale blue-grey clay shales and dark grey (N2.5), muddy shales which contain a distinctive fauna of *Anthraconaia* sp. cf. *A. pulchella* Broadhurst, *Carbonita evelinae* and rare fish remains. Macroscopic pyrite is common and much of the dark tone of the darker shales is due to the presence of

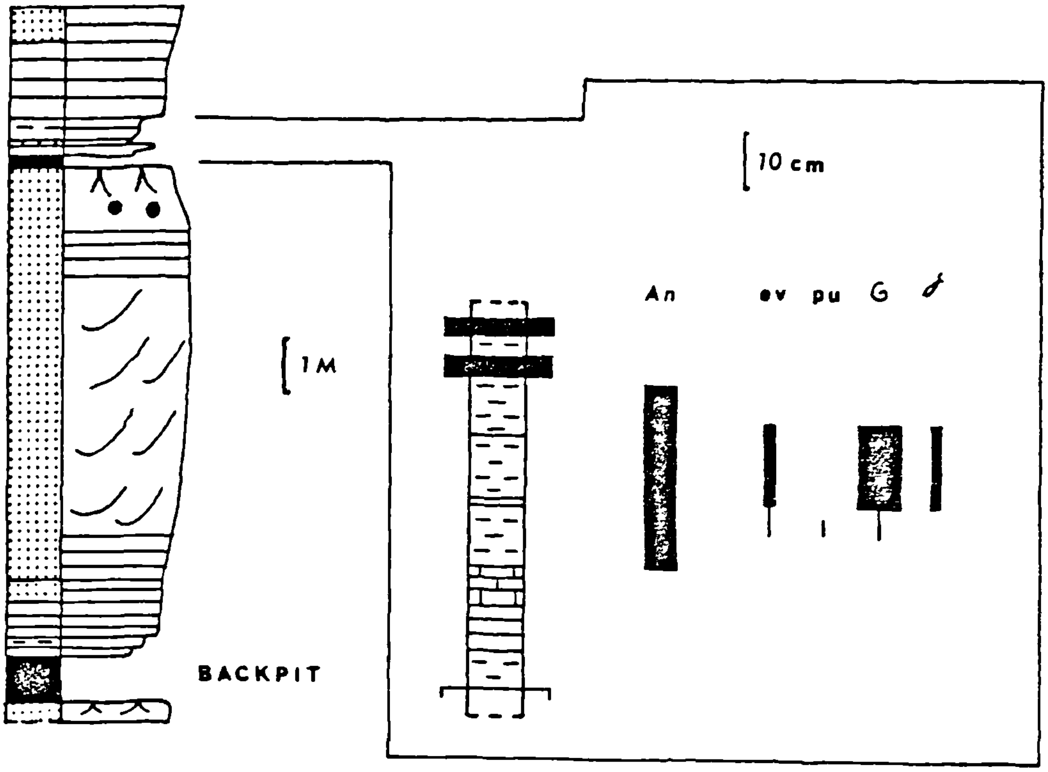


FIGURE 6.21: The Glace Bay coastal section and inset showing the distribution of fauna between the Backpit and Bouthillier seams.

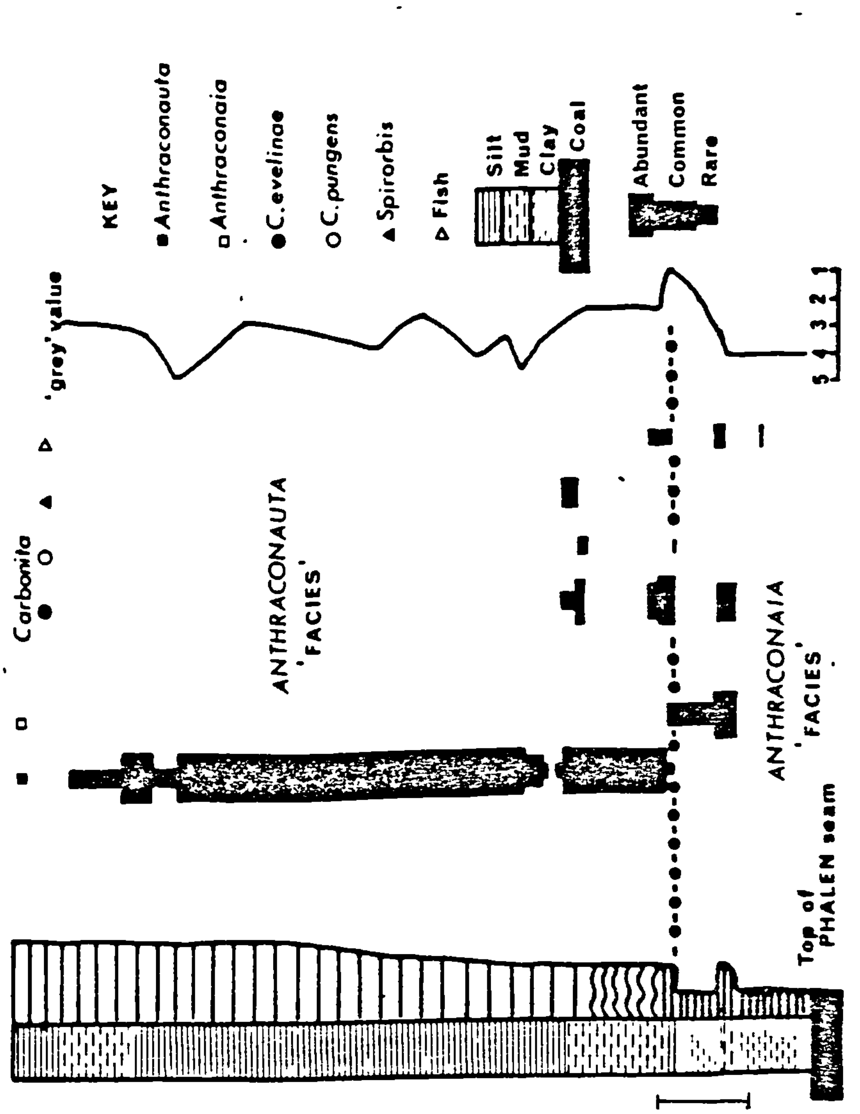


FIGURE 6.22: The distribution of fauna above the Phalen seam south of Whelan Point (Figure 6.2). Note the occurrence of both the Anthraconaia and Anthraconauta facies which do not overlap. Scale bar = 10 cm.

finely disseminated pyrite rather than to organic carbon. Plant material and roots are however, very common.

The bivalves are mainly poorly preserved as internal moulds and internal impressions and may have been articulated. Ostracodes are preserved as internal moulds.

A coarsening-upward sequence of dark to medium-grey (N2.5-4), muddy and silty shales overlies the *Anthraconaia* facies and contains abundant *Anthraconauta* spp.. The bivalves are well preserved as crushed, articulated shells towards the base of the sequence but are predominantly preserved as single valves in the higher, coarser parts of the horizon. *A. phillipsii*, *A. tenuis*, *A. calveri* (type locality of this morphological variety) and *A.* sp. cf. *A. phillipsii* (Figure 6.28) were recorded with *Carbonita evelinae* and *C. pungens* occurring in the darker, finer-grained horizons.

Discussion - Sediments of the *Anthraconaia* facies overlying the coal are believed to have been deposited in a marginal lacustrine environment. Supporting this hypothesis is the high proportion of pyrite in the lithology suggestive of periods of stagnation, and evidence that the sediment below the sediment/water interface was anoxic. In addition, the presence of common plant debris and rootlets and the apparently high articulation ratios amongst these small shells tends to suggest that low energy conditions prevailed.

The *Anthraconauta* facies are considered to represent a larger, well oxygenated lake into which clastic sediment accumulated. The high articulation ratio of the shells in the lower part of the horizon implies that the shells occur in a near-life position.

6.1.9.2. The Backpit seam.

The Backpit seam is exposed at grid reference 192389 and has a measured thickness of 56 cm, where it rests on the rootleted top of a channel sandstone. The overlying dark to medium grey (N2-4), muddy shales contain a fauna of crushed bivalves mainly preserved in the form of external impressions, ostracodes and spirorbids. Where shell material is preserved, the bivalves are articulated and closed lying subparallel to the bedding. Towards the top of the fossiliferous roof shales preservation is as angular fragments and single valves indicating perhaps, an increase in current strength.

The fauna comprises shells identified as *Anthraconauta phillipsii*, *A. tenuis* *s.l.*, *A. calveri* *s.l.*. Ostracodes include *Carbonita evelinae*, *C. pungens*, *C. salteriana* and *C. bairdiodes*.

6.1.10. The coastal section at Donkin.

The coastal section in MacDonald Cove, near Donkin was examined (Figure 6.2). Here, both the Phalen and Backpit seams are shown to crop out on the N.S. Department of Mines and Resources geological map (191425, sheet 362A). The outcrop of a thin coal seam (15 cm thick) was located on the wavecut platform at grid reference 191425 which owing to its geographical position, may represent the Backpit seam or part of it. However, in view of the Backpit seam having a measured thickness in excess of 0.5 m just 3 km along its strike to the east, it is by no means certain which seam this represents.

The coal rests on a rootleted silty seatearth which contains autochthonous *Sigillaria* sp. and is overlain by a thin (30 cm) sequence of dark grey (N2-3) muddy shales. Poorly preserved

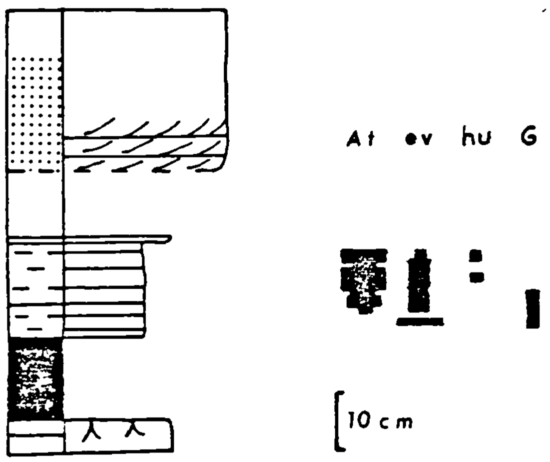


FIGURE 6. 23: The Donkin coastal section and distribution of fauna.

shells referable to Anthraconauta spp. were recorded and often reach shell-bed proportions as crushed and articulated shells. Carbonita evelinae and more rarely, C. humilis ? occur with the bivalves (Figure 6.23).

6.1.11. The Schooner Cove sections.

Sections were examined along both the western and eastern shores of Schooner Cove (Figure 6.2). The Emery seam was correlated across the cove as was a thin seam some metres above it (Figure 6. 24).

Anthraconauta spp. including A. phillipsii s.l. and A . sp. cf. A. wrighti occur as crushed shells and external impressions with ostracodes and occasional estheriids.

6.1.12. Offshore boreholes.

Three cores from the Donkin offshore area of the coalfield (Figure 6.3b) were examined and collected from. In addition, hole P5 (the Murphy well) is shown in Figure 6.3a as this hole was used by Hacquebard (1979) and Barss et. al. (1979) for correlational purposes. The holes were drilled in order to investigate future coal resources (Hacquebard 1979, 1983, Zodrow et. al. 1983). Although all three cores were sampled, the small size and poor vertical and lateral distribution of the samples allows only stratigraphic consideration.

Each fauna is recorded in Figures 6. 25, 6. 26 and 6. 27. Information on strata younger than that obtainable onshore was gained from all three holes as well as additional information on faunas above the Phalen (H6 and P4) and Backpit seams (P4 only).

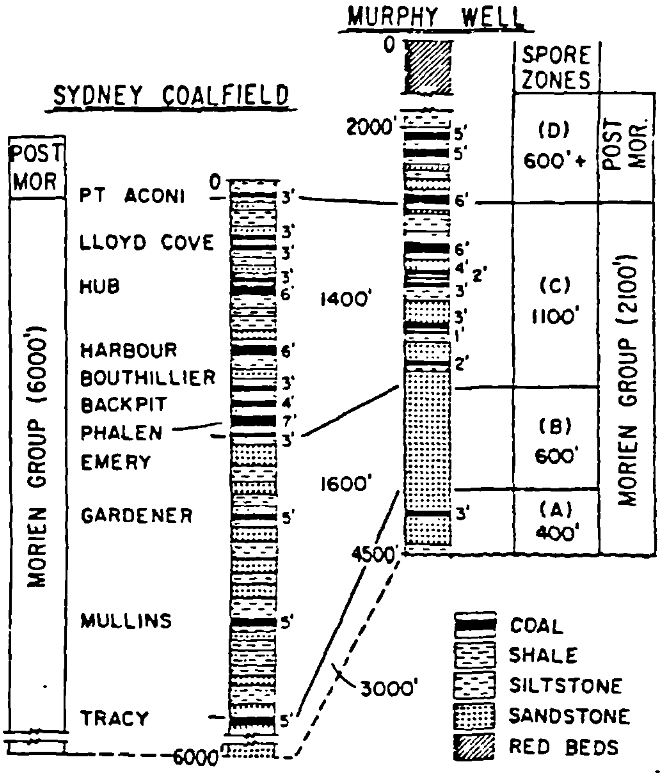


FIGURE 6:24: Correlation of the offshore Murphy Well with the onshore sequence (From Hacquebard 1983, Figure 9.2).

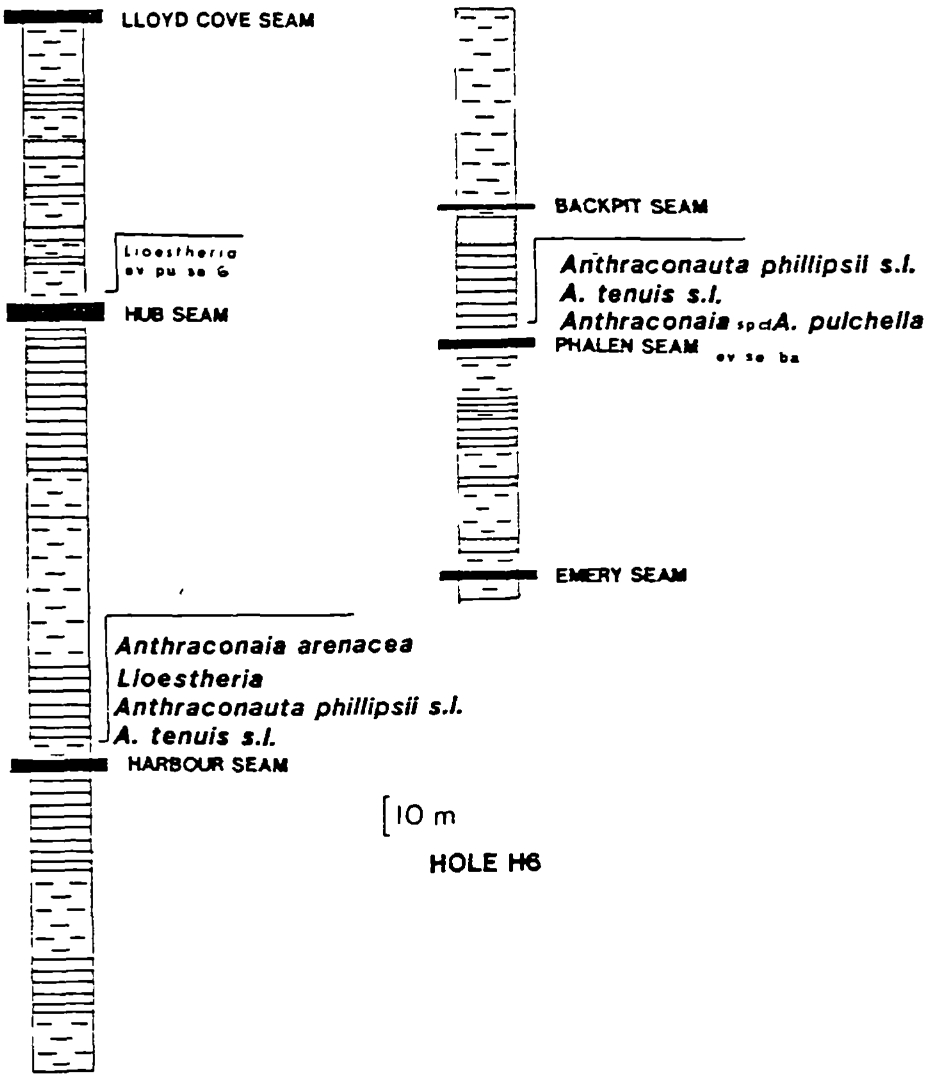


FIGURE 6.25: Log of Hole H6. Faunal horizons and faunas indicated.

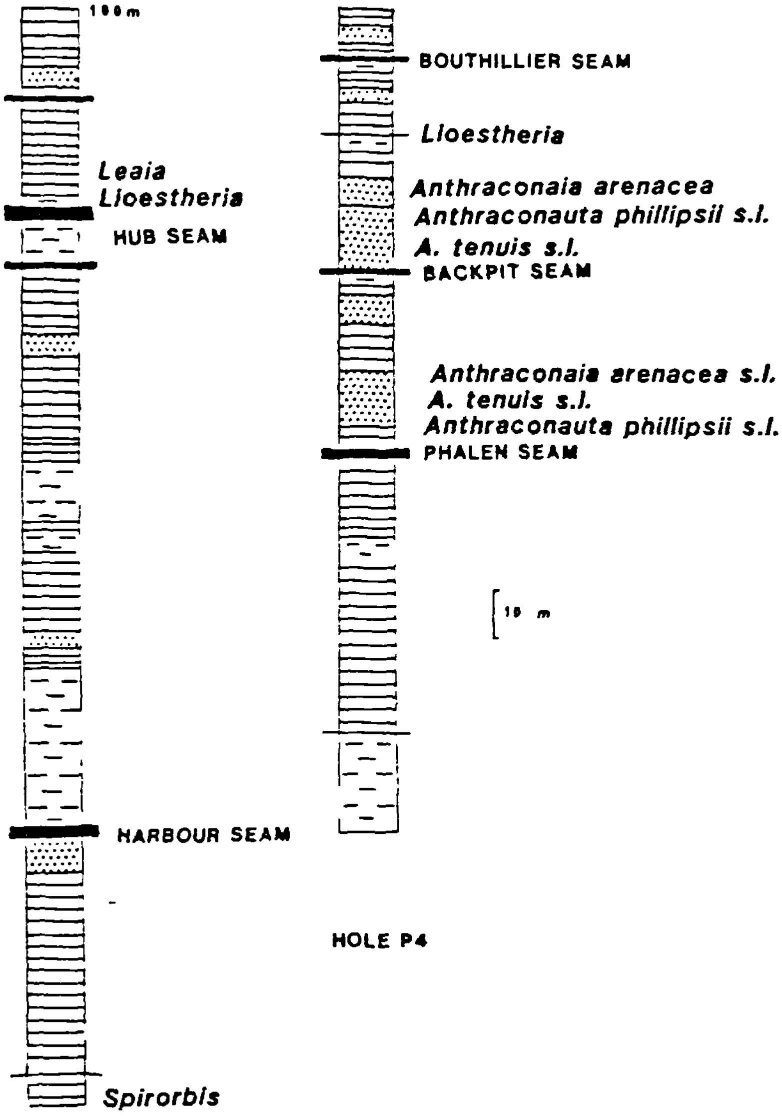


FIGURE 6.26: Log of Hole P4. Faunal horizons and faunas indicated.

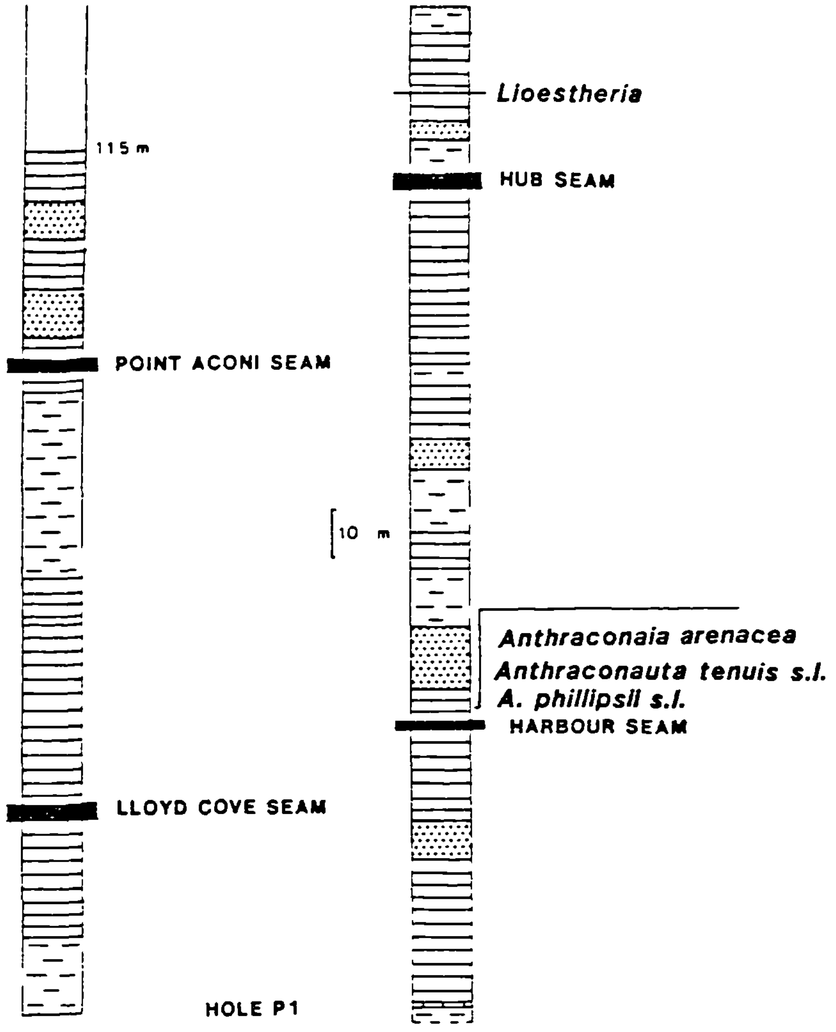


FIGURE 6.27: Log of Hole P1. Faunal horizons and faunas indicated.

6.1.12.1. Above the Phalen seam.

The fauna and its distribution recorded in Hole H6 differs from that observed above the Phalen seam south of Whelan point (Section 6.1.10) only in the addition of a thin *Anthraconauta*-bearing sequence directly above the coal. *Anthraconaia* sp. cf. *A. pulchella* was recorded in dark grey, pyritiferous muddy shales in this hole. In P4 the *A.* sp. cf. *A. pulchella* horizon is absent and the roof of the coal is characterised by silty shales bearing *Anthraconauta* spp. and *Anthraconaia arenacea* (Dawson). An interesting distribution of bivalves was observed where *Anthraconauta* spp. was recorded from darker, finer lithologies and the articulated and open *Anthraconaia arenacea* tended to occur in the paler, coarser horizons.

6.1.12.2. Above the Backpit seam.

Sampled only in P4, the roof shale of the Backpit seam comprises a coarsening-upward sequence of muddy and silty shales. *Anthraconauta* spp. and articulated, open *Anthraconaia arenacea s.l.* were recorded and showed a distribution similar to that observed above the Phalen seam.

6.1.12.3. Above the Harbour seam.

Faunas were sampled in holes H6 and P1 and again comprise *Anthraconauta* spp. and *Anthraconaia arenacea s.l* which appear to be foundin differing substrate types.

6.1.12.4. Above the Hub seam.

The fauna above the Hub seam was sampled in all three holes and shows a remarkable uniformity. No bivalves were recorded however, ostracodes, fish remains and estheriids occur in a series of cannels interbedded with muddy and silty shales.

6.2. A stratigraphical review of the Sydney faunas.

Cluster analyses were performed where sufficient numbers of measurable shells were collected. In view of the reasonable stratigraphic control already available using named and correlated coal seams (Figure 6.3b), and so as to utilise as many measurable shells as possible, cluster analysis was performed on collections from different stratigraphic horizons.

6.2.1. Results of the cluster analysis of Anthraconauta spp..

Cluster analysis was performed on shells collected from two horizons, from above the Phalen seam and from between the Harbour and Hub seams;

6.2.1.1. Cluster analysis of 89 measured shells from above the Phalen seam.

A collection of 89 measured shells collected from the roof shales of the Phalen seam, was clustered (Appendix A). Four significant clusters were obtained and identified as representing the Anthraconauta phillipsii, A.tenuis, A. calveri and A. sp. cf. A. phillipsii groups (Figure 6.28).

Variation within the A. phillipsii group.

The holotype of A. phillipsii proves to be a near-modal form within this cluster. There is some variation within the group towards attenuated forms but without the longer dorsal margin and shorter anterior end of A. tenuis (2037, L20, L59, L37 and 196 of Figure 6.28a). An opposite trend towards but not reaching A.

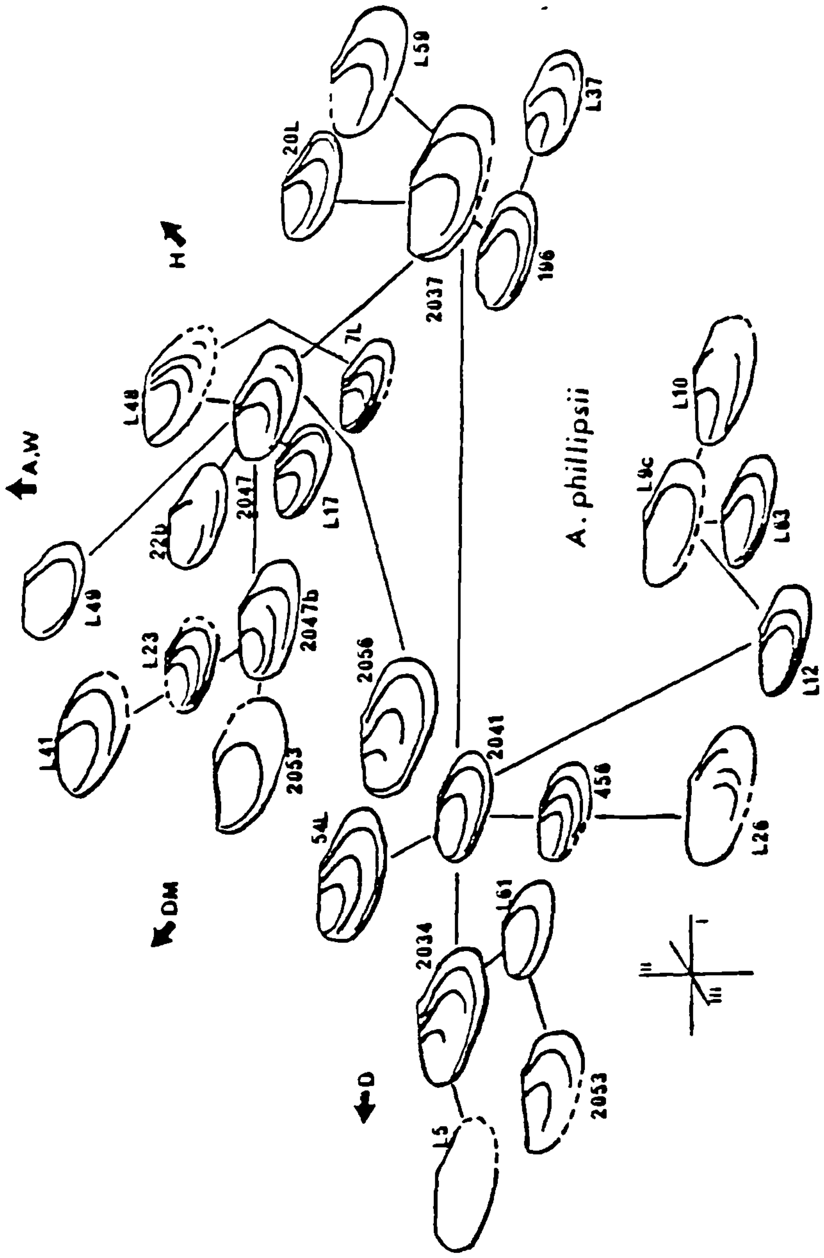
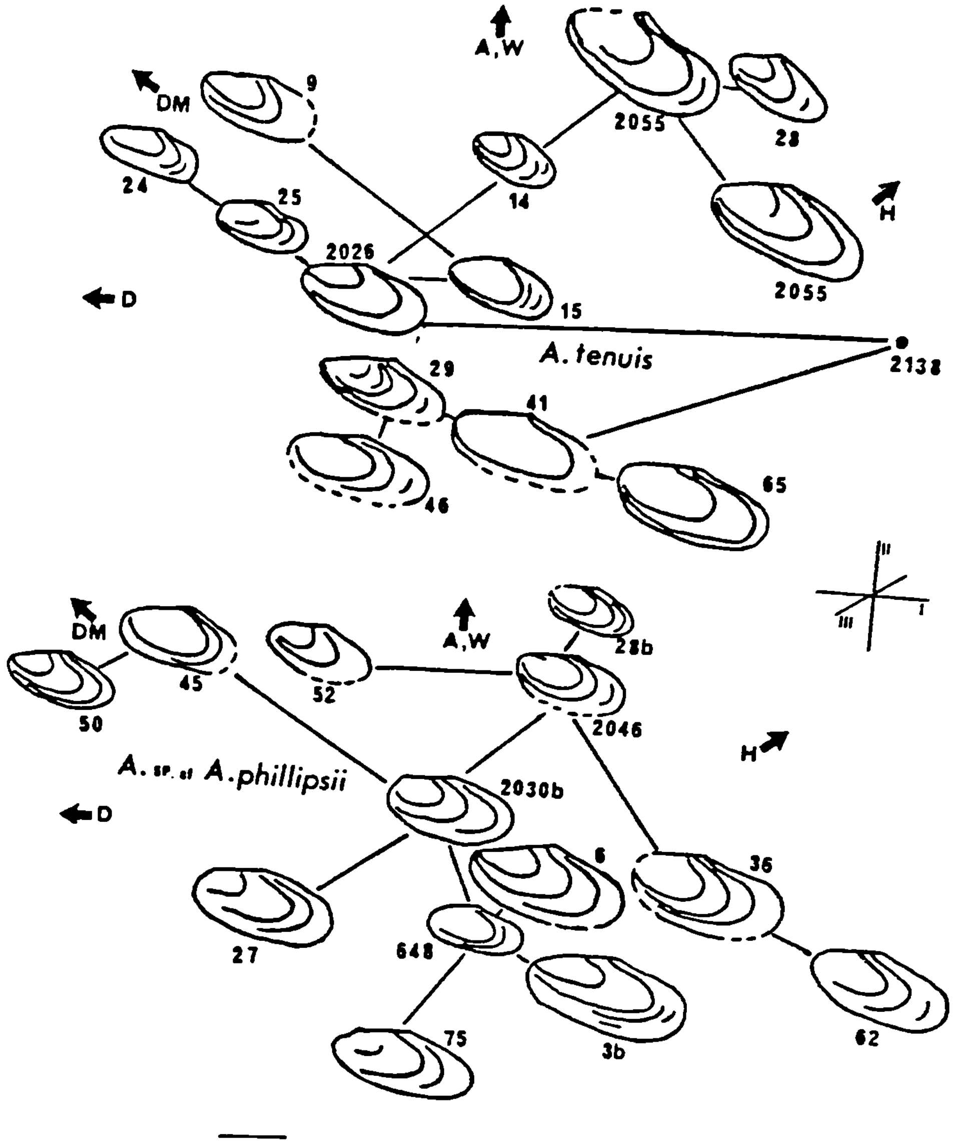


FIGURE 6.28a: Pictograph of the A. phillipsii group from above the Phalen seam. Variational trends as shown. Scale bar = 1 cm.



FIGURF 6.28b: Pictographs of the A. tenuis and A. sp. cf. A. phillipsii groups from above the Phalen seam. Variational trends as shown. Scale bar = 1 cm.

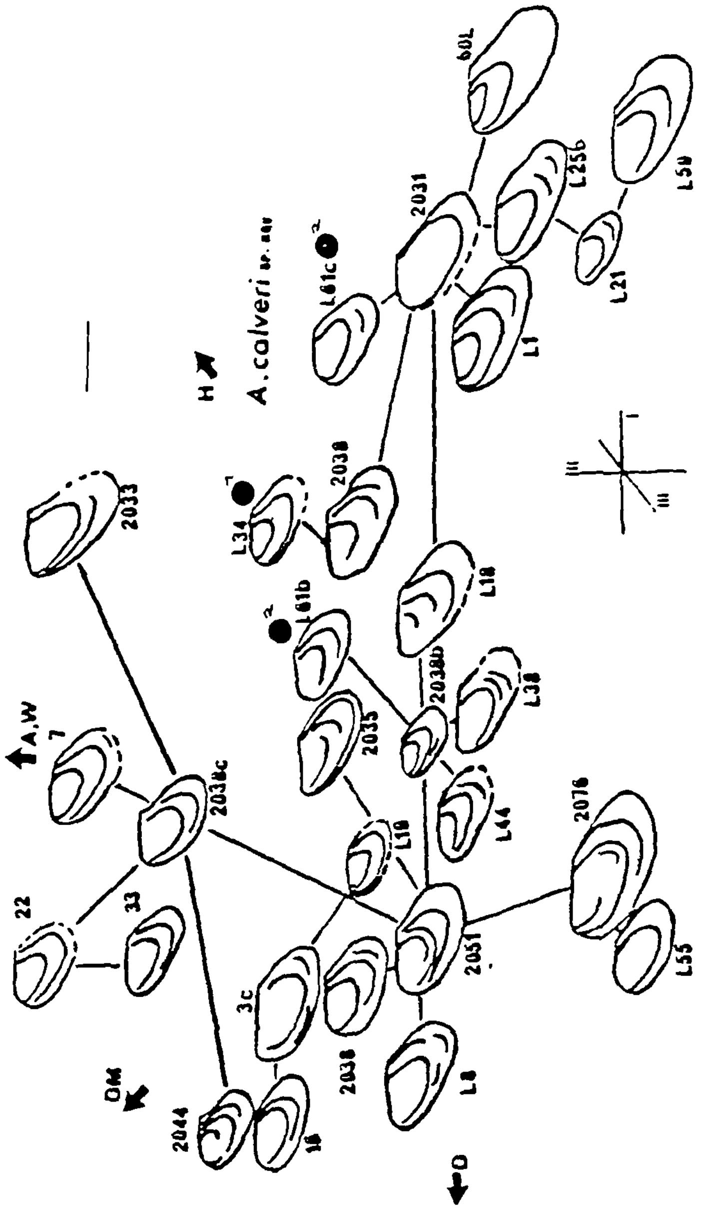


FIGURE 6.28c: Pictograph of the type assemblage of A. calveri sp. nov. from above the Phalen seam. Variational trends as shown. Scale bar = 1 cm. ●¹- holotype, ●²- paratypes.

wrighti, occurs in which the length of the dorsal margin and the D/L ratio are increased with a concomitant decrease in the H/L ratio.

Variation within the *A. tenuis* group.

The holotype of *A. tenuis* is an extreme variant in this cluster. Figure 6.28b; shells L46 and L65 are the nearest forms to the holotype. Comparatively few shells referable to *A. tenuis* are found above the Phalen seam and the mode of the cluster proves to be smaller and more obliquely attenuated than the type. Included in the cluster are forms with a larger H/L ratio and smaller beta angle (see Figure 6.28b; shells L24, L25 and L15).

Variation within the *A*. sp. cf. *A. phillipsii* group.

This small cluster overlaps slightly with the *A. phillipsii* cluster (Figure 6.28c) and in practice, is not easily distinguishable from the *A. phillipsii* group variants by eye. The cluster has a higher mean D/L ratio and slightly higher A/L ratios than the *A. phillipsii* cluster (Appendix A) and is therefore provisionally referred to *A*. sp. cf. *A. phillipsii*.

Variation within the *A. calveri* group.

The holotype (GMV 2844, Figure 6.28d) was chosen as being a near-modal form in this cluster and the paratypes as representing some limited variation around it. For a full discussion of variation see the systematic part of this thesis.

6.2.1.2. Results of the analysis of 91 measured shells from between the Harbour and Hub seams.

A collection of 91 measured shells from between the Harbour and Hub seams was clustered and four significant clusters identified as representing the *Anthraconauta phillipsii*, *A.*

tenuis, *A. calveri* and *A*. sp. cf. *A. wrighti* groups (Figure 6.29).

Variation within the *A. phillipsii* group.

The majority of the shells in this cluster display rather limited variation around forms comparable with *A. phillipsii* *s.s.* and is similar to the Phalen cluster. However, a more pronounced trend towards forms similar to *A. wrighti* than is seen in the Phalen cluster occurs through increased length of dorsal margin and anterior end (Figure 6.29^{a}; shells 200 , 1849, L28, 477 and 1872).

Variation within the *A. tenuis* group.

Variation within this cluster is closely similar to that observed in the Phalen cluster and is again quite limited. A major trend is one of increasing W/L ratios to produce forms similar to *A. phillipsii*, but displaying much greater postero-ventral attenuation than this form.

Variation within the *A. calveri* group.

This cluster is comparable to that found from above the Phalen seam except that the more attenuated variants are absent.

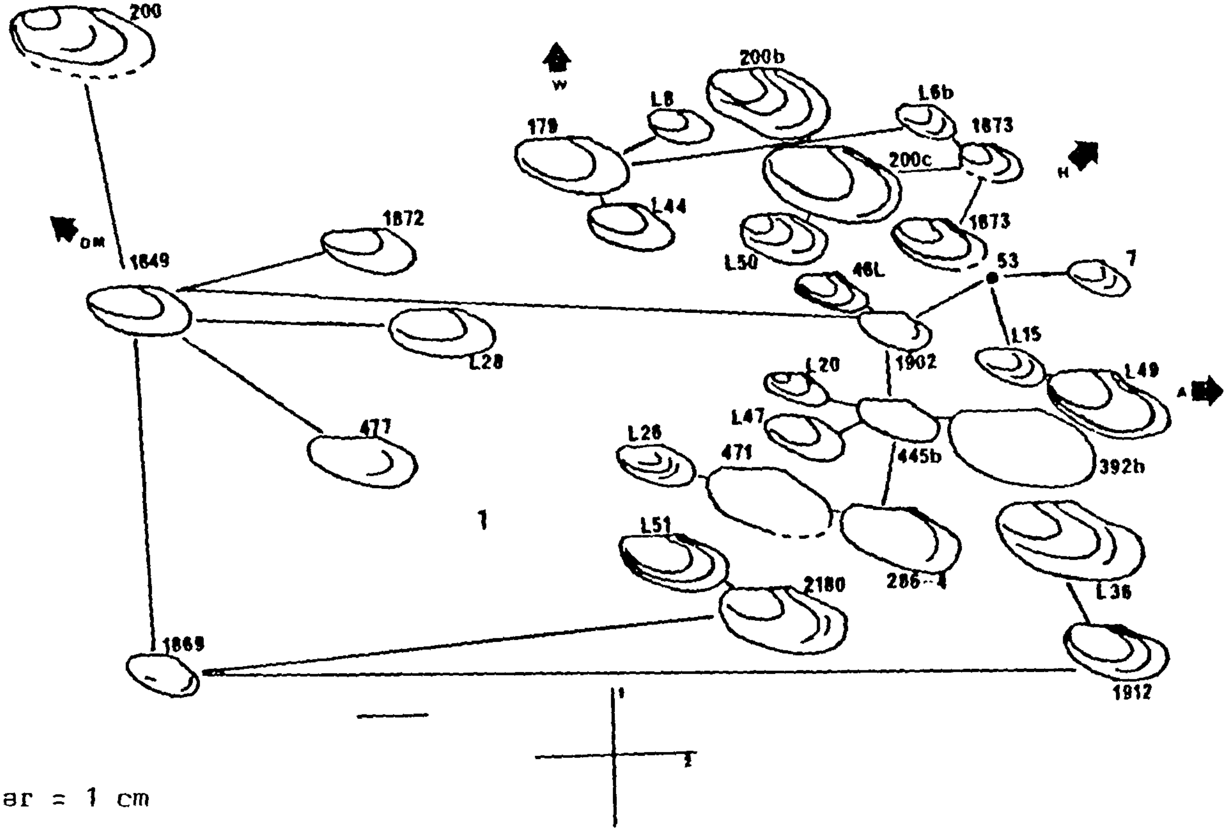
Variation within the *A*. sp. cf. *A. wrighti* group.

Variation is limited in this cluster in which *A. wrighti* is probably an extreme variant.

6.2.1.3. Comparison of results.

The results of the analyses of these two stratigraphically widely separated faunas shows a surprising uniformity. The three major clusters (*A. phillipsii*, *A. tenuis* and *A. calveri*) show

FIGURE 6.29a: THe Anthraconauta phillipsii group from between the Harbour and Hub seams.



Scale bar = 1 cm

PCA1 v PCA2

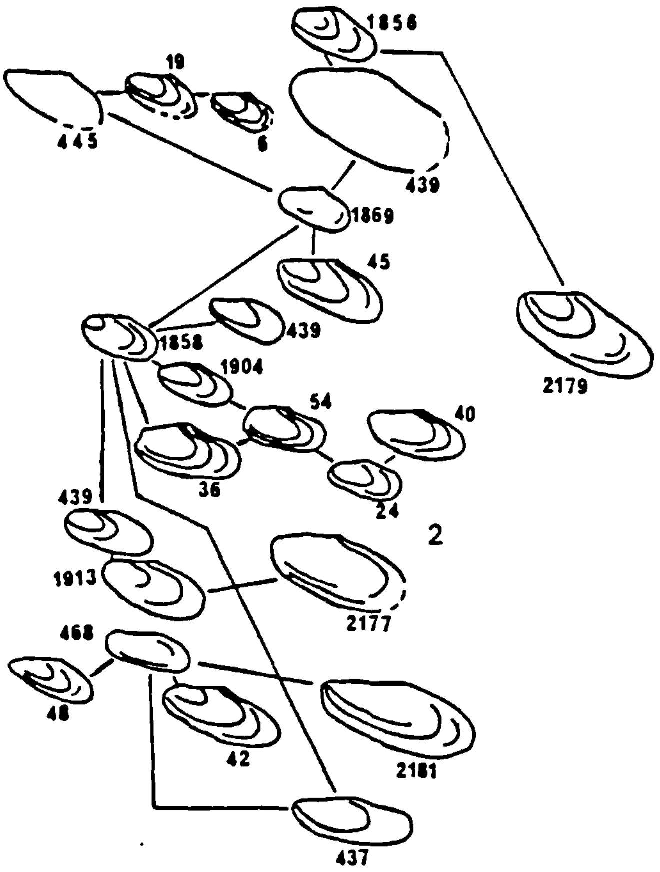


FIGURE 6.29b: The *A. tenuis* group between the Harbour and Hub seams. Variational trends as in Figure 6.29a.

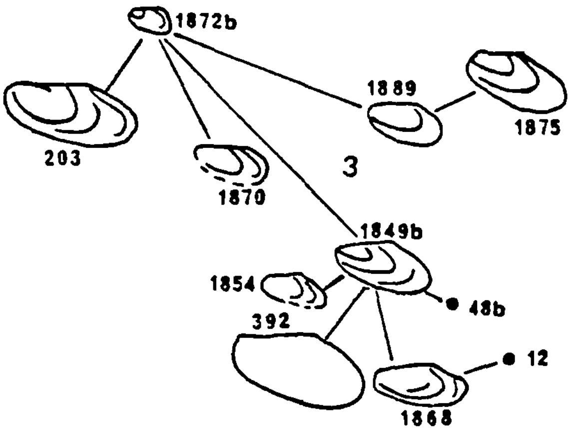


FIGURE 6.29c: The *A.* sp. cf. *A. wrighti* group between the Harbour and Hub seams. Variational trends as in Figure 6.29a.

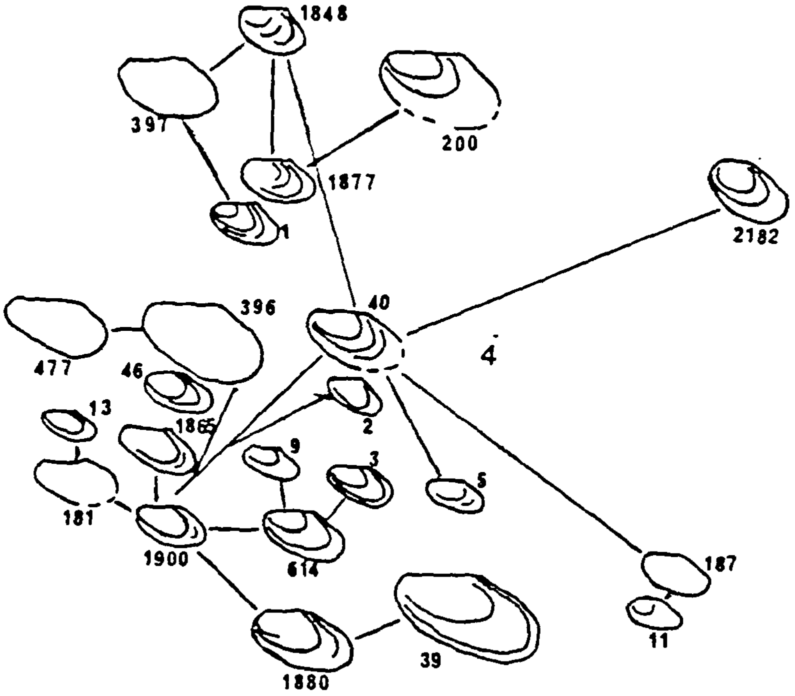


FIGURE6.29d: Pictograph of *Anthraconauta* spp. between the Harbour and Hub seams continued. The *A. calveri* sp. nov. group. Variation as in Figure 6. 29a.

closely similar intracluster variation patterns and have closely similar cluster means (Appendix A). The fourth cluster in both cases is rather different and is related to local environmental rather than stratigraphical differences (Chapter 7). Of possible stratigraphic importance is the decrease in numbers of A. calveri and concomitant increase in numbers of A. tenuis between the two stratigraphic levels.

6.2.2. Results of the cluster analysis of Anthraconaia spp.

Sufficient numbers of measurable shells were collected at three different stratigraphic levels.

6.2.2.1. Cluster analysis of 16 measured shells from above the Phalen seam.

The total number of shells used in this analysis is admittedly small but in view of the limited variation shown in the single cluster obtained, it is considered that the results are probably quite valid. The cluster (Figure 6. 30) was identified as Anthraconaia sp. cf. A. pulchella and a full account is given in the systematic part of this thesis.

6.2.2.2. Cluster analysis of 32 measured shells from between the Backpit and Bouthillier seams.

Three clusters were obtained, however the shells used in this analysis were collected from markedly different lithologies ranging from micrites to dark grey, pyritic muddy shales. The three clusters were identified as representing the A. arenacea, A. sp. cf. A pulchella and the A. sp. nov. A groups. Intracluster variation is limited (Figure 6.31) and mainly reflects a trend towards elongation and an opposite trend towards more subovate, anthracosiid-like shells (and see Chapter 7).

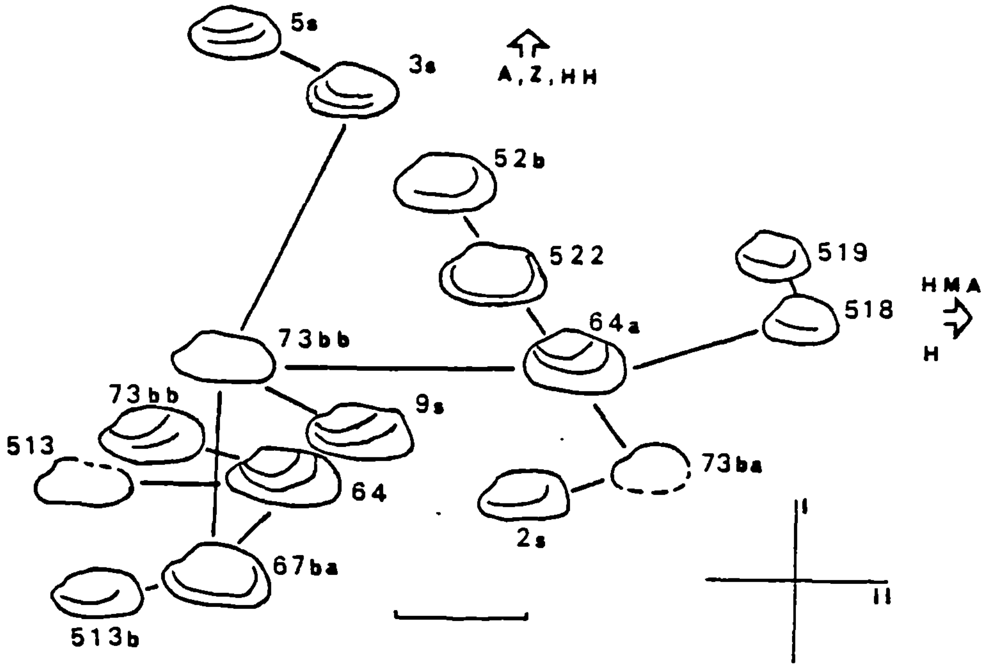


FIGURE 6.30: Pictograph of the Anthraconaia sp. cf. A. pulchella group from above the Phalen seam. Variational trends indicated. Scale bar = 1 cm.

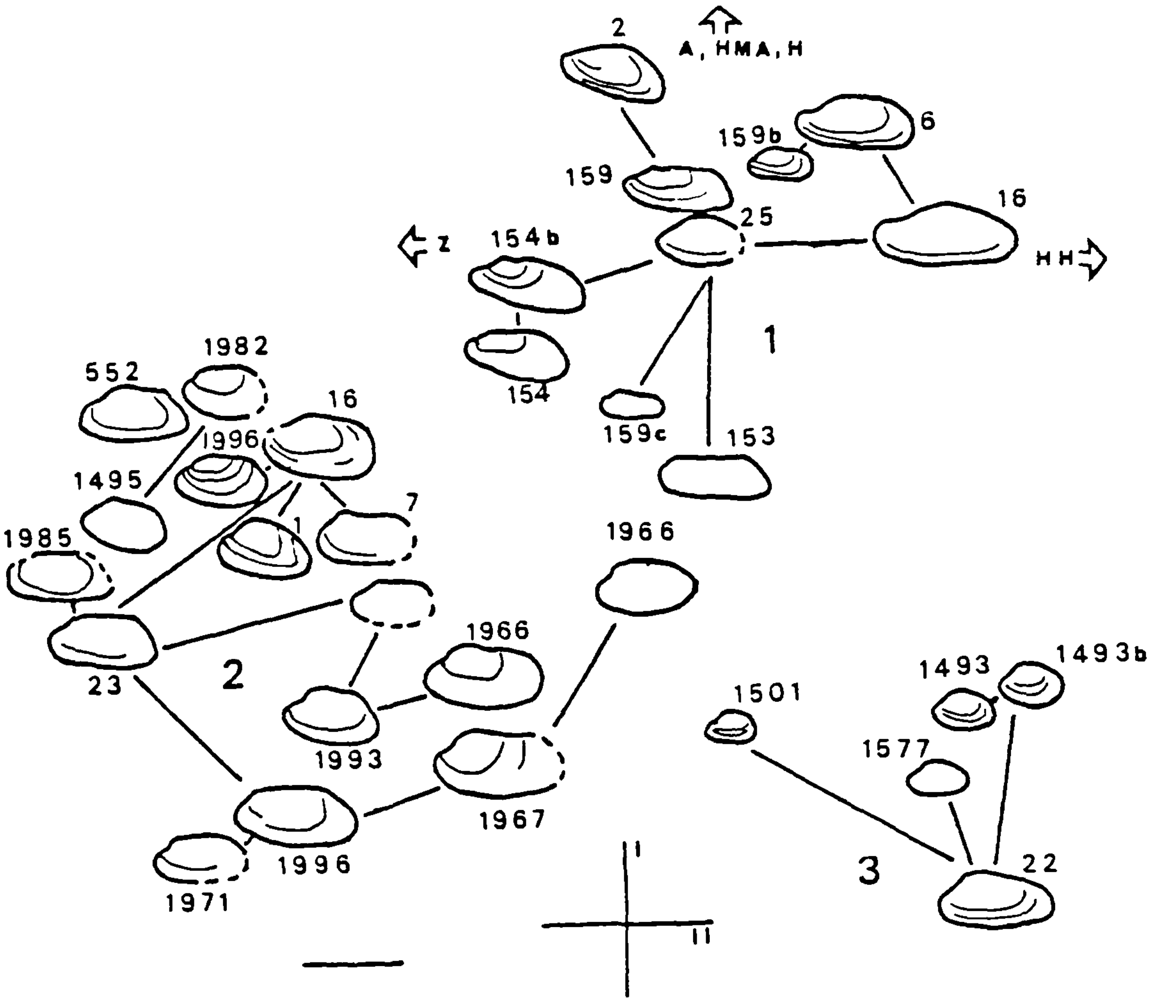


FIGURE 6.31: Pictograph of *Anthraconaia* spp. between the Backpit and Bouthillier seams. Variational trends as in cluster #1. Scale bar = 1 cm. 1 - The *A. arenacea* group, 2 - *A.* sp. cf. *A. pulchella* group, 3 - *A.* sp.

6.2.2.3. Cluster analysis of 54 measured shells from between the Harbour and Hub seams.

All the shells used in this analysis were collected from the New Aberdeen section (see 6.1.8) and thus, represent an analysis of shells from the same depositional environment. Five clusters were obtained and identified as representing the A. sp. cf. A. saravana group, the A. sp aff. A. speciosa group, the A. sp. nov. cf. A. palatina group, the A. sp. nov. A group and a small group of shells were referred to A. sp. indet.. Variation within the sample is large and may be bimodal in terms of A/L ratios (Figure 6.32). Intracluster variation is however, limited and trends are observed similar to those seen in the Backpit-Bouthillier fauna.

6.2.2.4. Comparison.

In order to compare the results of the three analyses, a principal components analysis was run using each of the cluster means as input parameters. A second run was performed using an additional input parameter to represent stratigraphic horizon. The results (Figure 6.33) show that there is much wider variation in shell shape with decreasing age of the assemblages (and that this variation appears not to be related to the number of differing localities and Palaeoenvironments sampled - though it may be related to the increasing sample size associated with the three horizons). When a time parameter is used in addition to the cluster means, it can be seen that the principal trend is one of an increase in the A/L ratios of the shells coupled with wider variation in the H/L and HMA/L ratios. The stratigraphic implications of these conclusions is clearcut and following Eagar (in press [1979]), it may prove possible to utilise these younger assemblages of small-shelled Anthraconaia in a zonal scheme. For the moment however, the shells occur in too few horizons which are thin and laterally impersistent, to be of more than local stratigraphic value.

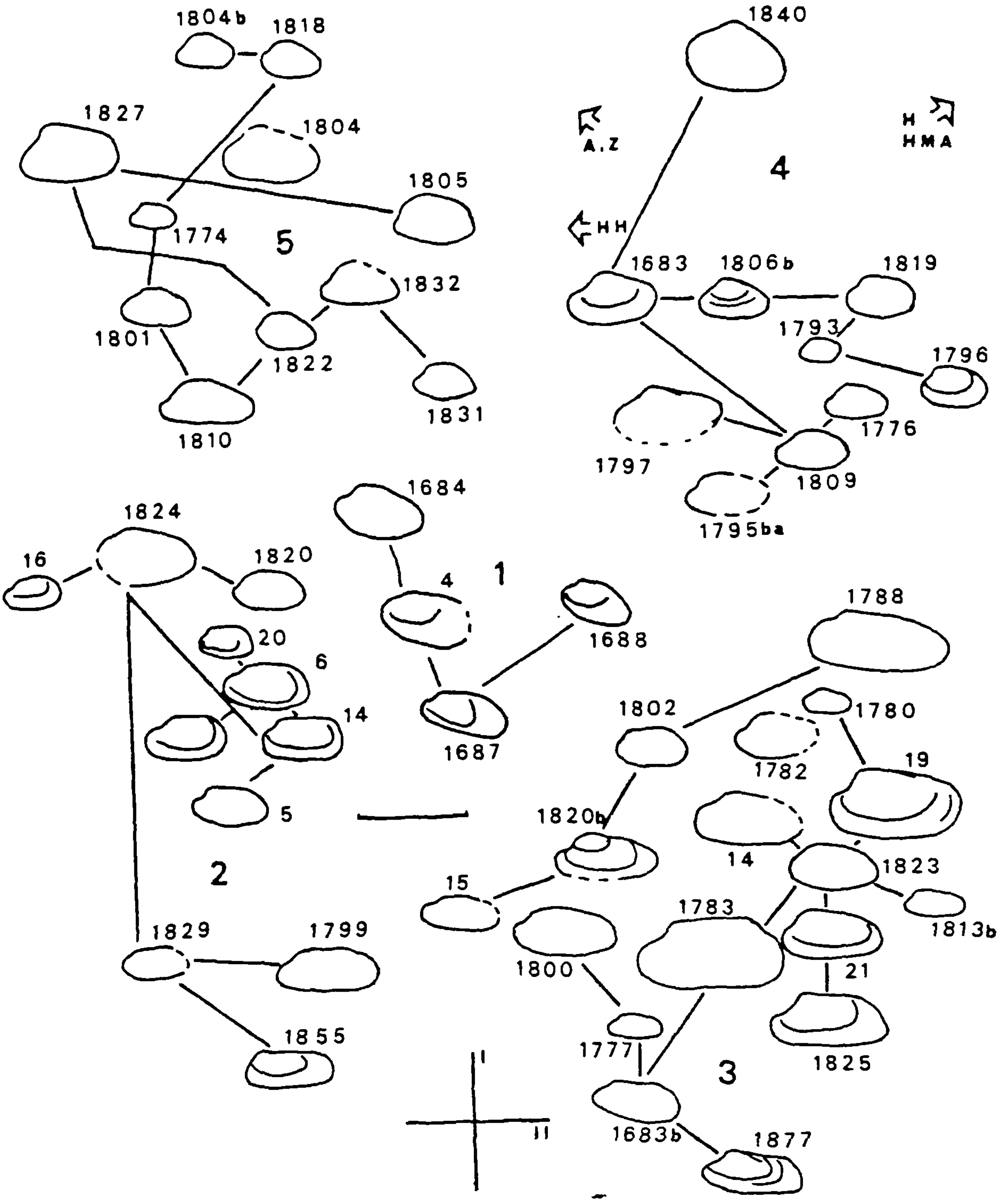


FIGURE 6.32: Pictograph of Anthraconaia between the Harbour and Hub seams. Variational trends as in cluster 4. Scale bar = 1 cm. 1 - A. sp., 2 - A. sp. cf. A. saravana group, 3 - A. sp. aff. A. speciosa group, 4 - A. sp. nov A group, 5 - A. sp. cf. A. palatina group

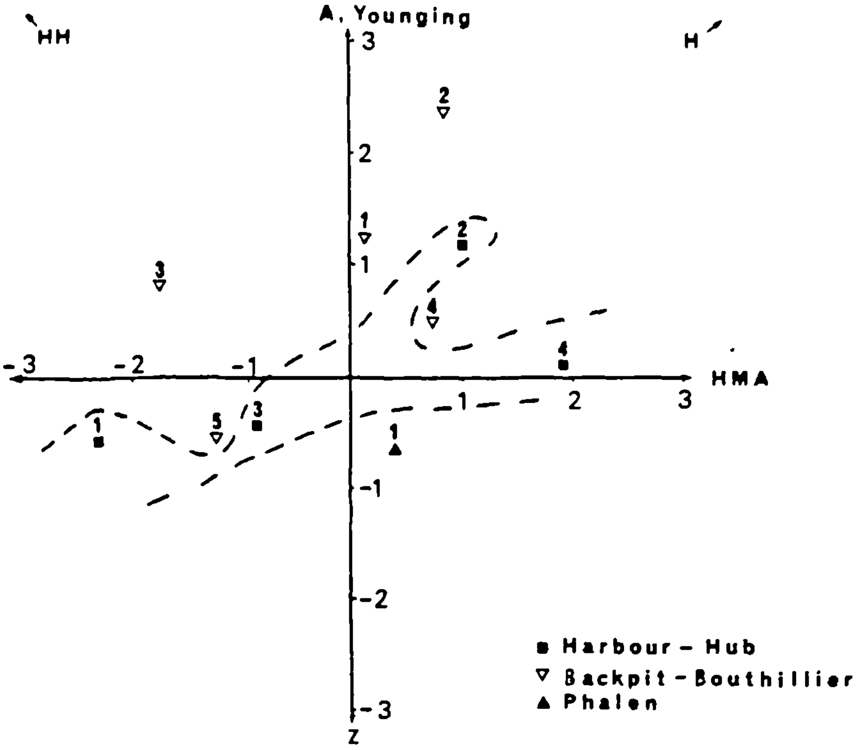


FIGURE 6.33: PCA plot of Anthraconaia clusters from three stratigraphic horizons (see key above). Variational trends indicated including 'younging' or decreasing stratigraphic level. The faunas display a distinct pattern of morphological changes with 'younging' - see text.

6.3. Palaeoenvironmental considerations.

The Sydney palaeoenvironment comprised large meandering river channels crossing a muddy floodplain. Lakes, which often attained sizes in excess of 5 km (see later) formed on the floodplain probably due to local differential subsidence.

Several phases of lake formation are indicated by both the faunas and the lithologies in which they occur. In general, they were probably fresh to slightly brackish. Clastic input was limited to fine-grained clastics and lake bottoms may have been prone to oxygen deficiency having a high organic carbon-content. Lake deltas marked by coarsening-upward sequences are common and reflect crevasse splay deposition and increasing proximity to the river channel.

Several marginal environments are also indicated and these include shallow areas of limited clastic input where carbonate deposition occurred and occasionally, stromatolites accumulated, where the pools were subject to stagnation, and interplant areas.

No evidence was found of any marine influence and the postulated occurrence of marine faunas further out into the Sydney Basin (Duff *et*. *al*. 1982) is considered to be unlikely on the grounds of the general shape of the basin, its palaeoegeographical setting (see Chapter 8) and the general retreat of seas elsewhere at this time. The term 'paralic', applied by Hacquebard & Donaldson (1969) cannot be used to describe the Sydney basin as it was not a relatively flat-lying coastal area affected by fluctuating sealevels, but rather an intracontinental basin in which fluviolacustrine sedimentation took place.

6.4. Correlational aspects of the Sydney faunas.

The correlational aspects of the faunas are more fully discussed in the following chapter. Table 6.1 shows the ranges of the bivalves in the Sydney coalfield and suggested correlations. Following Vasey & Zodrow (1983), a correlation with the Tenuis Chronozone of Britain is suggested, though some of the younger Anthraconaia faunas indicate a possible Cantabrian or younger assignment through comparison with some north American (Eagar in press [1979]) and Spanish faunas (Eagar in prep. [1983]).

6.5. The Mabou Mines section.

The block-faulted, land-based portion of the Mabou coalfield (less than 0.25 km^2) contains over 600 m of coal measures (Figure 6.34) and is referred to as the Mabou Mines section (MMs).

The geology and stratigraphy of the MMs were investigated by Keating (1950), Copeland (1957) and by Belt (1965), although studies of a regional nature were carried out by Fletcher between 1880-82. Bell (1944, p.31) referred to the MMs as being equivalent to his Linopteris obliqua floral Zone (Westphalian C). However on the basis of detailed microfloral work, Hacquebard (1962) assigned the section the Torispora Zone of the Westphalian D.

6.5.1. Material.

Bivalves occur mainly in the darker grey mudstones and more rarely in the paler coloured mud- and siltstones. They are typically preserved as crushed and fragmented valves although, articulated shells do occur lying subparallel to bedding planes. Preserved shell material consists of pale, yellow-brown sparite. Ostracodes characterise only the darker grey lithologies and occasionally, calcareous beds.

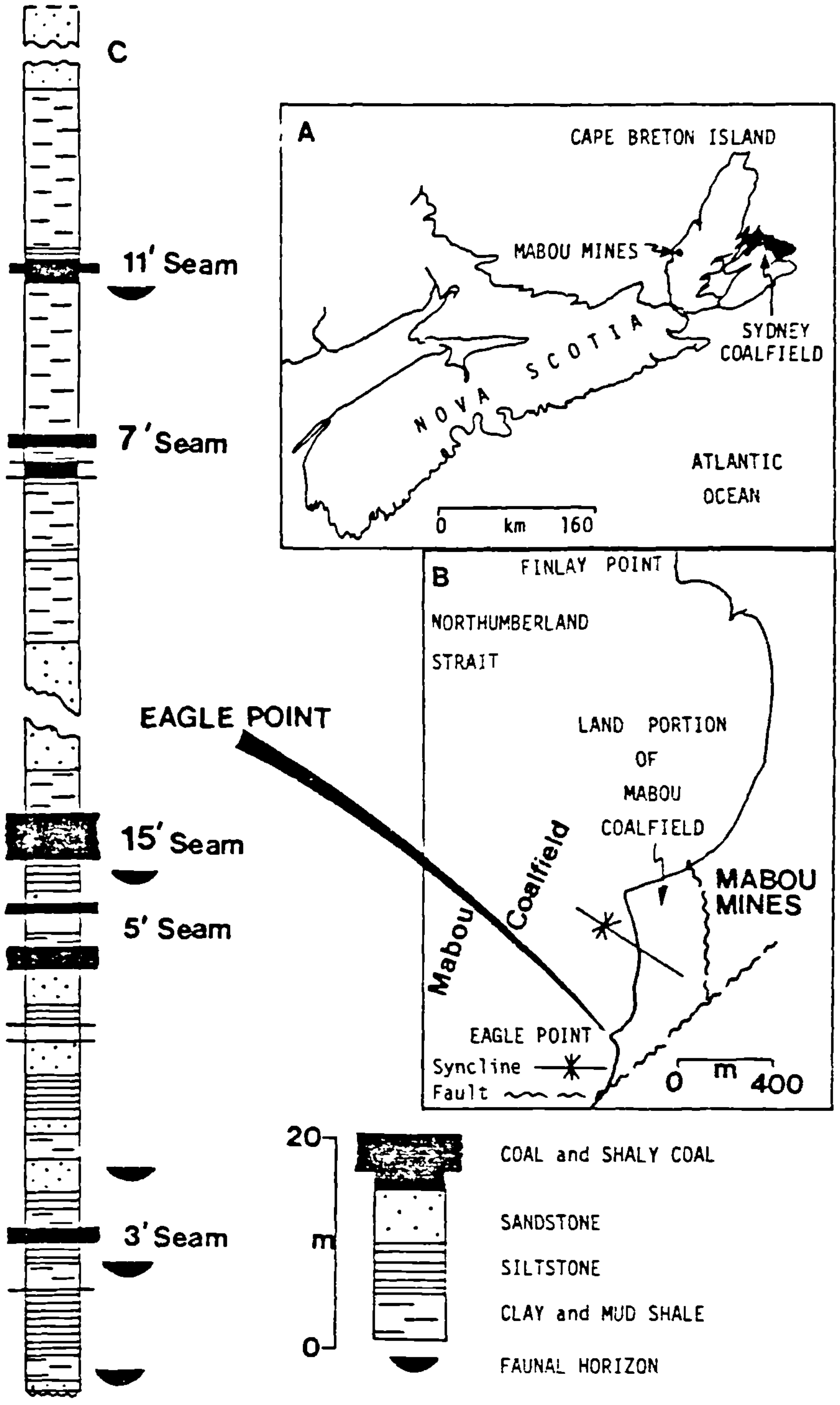


FIGURE 6. 34: The Mabou Mines coastal section showing faunal horizons and seam names. Inset A shows location of this locality in Nova Scotia, Inset B shows the Mabou coalfield. (From Zodrow & Vasey, in prep.).

The bivalve fauna comprises solely *Anthraconauta phillipsii*, though some postero-ventrally attenuated forms possibly referable to *A.* sp. cf. *A. tenuis*, do occur rarely. The report by Dawson (1894) of his *Naiadites carbonarius* could not be confirmed and it would appear that following Rogers (1965, p.673), this genus is not represented in the MMs.

Ostracodes are represented by a diverse assemblage of *Carbonita* spp. including *C. evelinae*, *C. inflata*, *C. bairdiodes*, *C. salteriana*, *C. scalpellus*, *C. pungens* and *C. humilis* (reported as *C. fabulina* by Copeland (1957) - J. E. Pollard, pers. commun., 1981)). In addition, some rare large punctate ostracodes possibly referable to *Gutschickia bretonensis* were recorded.

Spirorbis sp. is locally abundant and attached to the posterior ends of bivalve shells in what may be a commensal position (cf. Trueman 1942) and to certain floras.

6.5.2. Correlational aspects of the fauna.

A correlation with the British Phillipsii Chronozone is suggested. Shells which could be unequivocally be assigned to *A. tenuis* *s.s.* are absent as are any shells which could be referred to *Anthraconaia*. The ostracode assemblage differs from that of the stratigraphically younger Sydney faunas in that *Carbonita evelinae* is not the dominant form and also in the occurrence of *Gutschickia bretonensis*, which was previously unreported from the Pictou/Morien Group.

The flora gives a slightly different correlation (Zodrow & Vasey 1983) and a Westphalian C/D transitional age is suggested on this basis (*ibid.*).

6.6. The Pictou coalfield.

A single N. S. Department of Mines & Energy borehole core was examined from this coalfield which is entirely landlocked and occupies an area of about 5 X 16 km in northern Nova Scotia (Figure 6.1). For this reason, only a very general description of the basin is given here.

Strucurally, the Pictou coalfield is confined to a graben bounded by major faults (Figure 6.35). Within this fault block the coal measures lie in a number of open folds and, according to Hacquebard (1980), become progressively younger from east to west. Work by Hacquebard (1980) using fossil spores has dated the coalfield as Westphalian C (*sensu* Bell 1944) which, if Zodrow & McCandlish's (1978) emended floral correlations are accepted, represents the upper Westphalian C and lower Westphalian D.

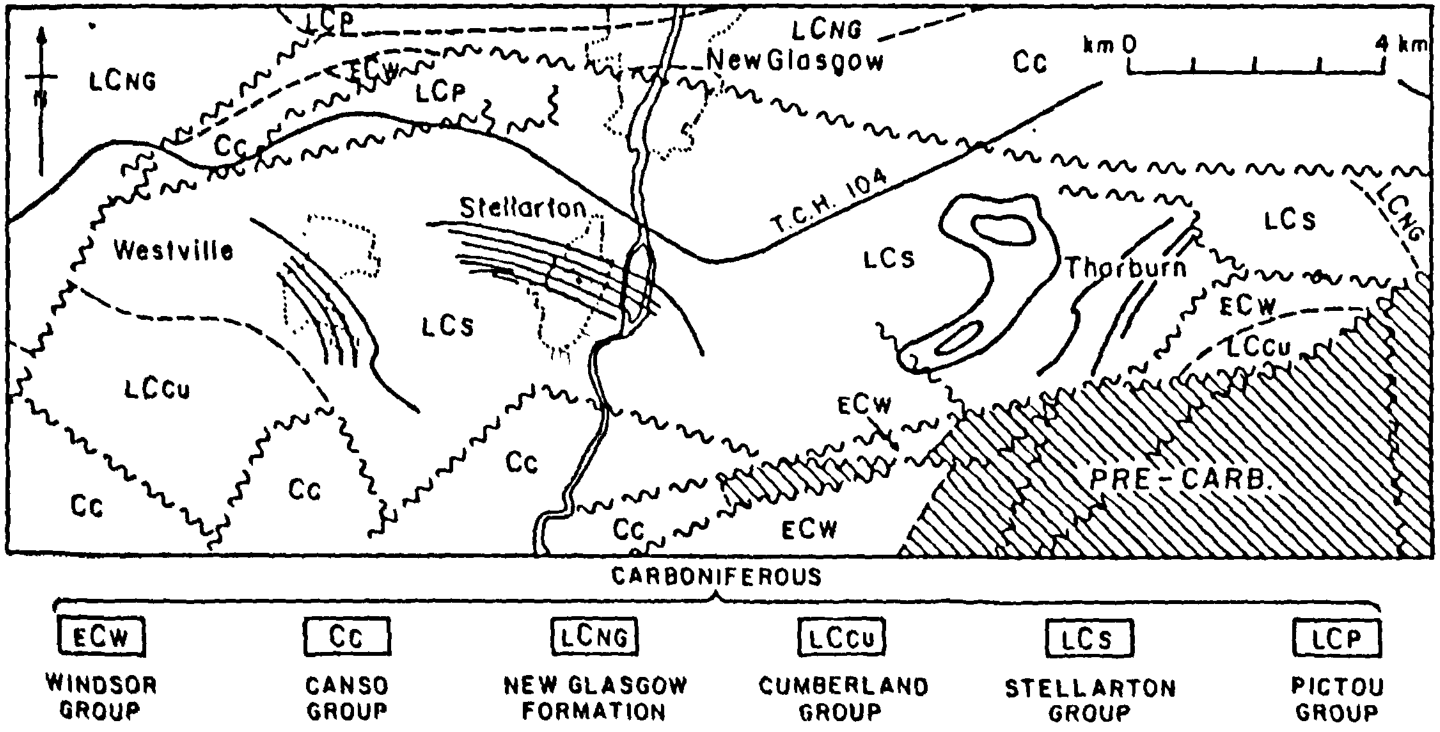
The Pictou coals (45 seams in all) were deposited in a narrow, intermontane lake basin in which finer, organic-rich sediments occupy a central position and are surrounded by coarser sediments on the basin border. Hacquebard & Donaldson (1964) gave an account of the depositional environment which they termed "limnic".

6.6.1. D.D.N.S.P. - 19.

Figure 6.35 shows the location of this hole and Figure 6.36 is a log of the hole which encompasses the Foord - New seam interval.

Only a single fossiliferous horizon was located in the core (other holes were examined also and no faunas located). The horizon lies stratigraphically between the Cage and Foord seams in an organic carbon-rich, dark grey muddy shale.

The fauna comprises abundant ostracodes referable to *Carbonita pungens*, *C. secans*, *C. evelinae* and *C. salteriana*.



• DDNSP 19

FIGURE 6.55: GEOLOGY OF THE PICTOU COALFIELD

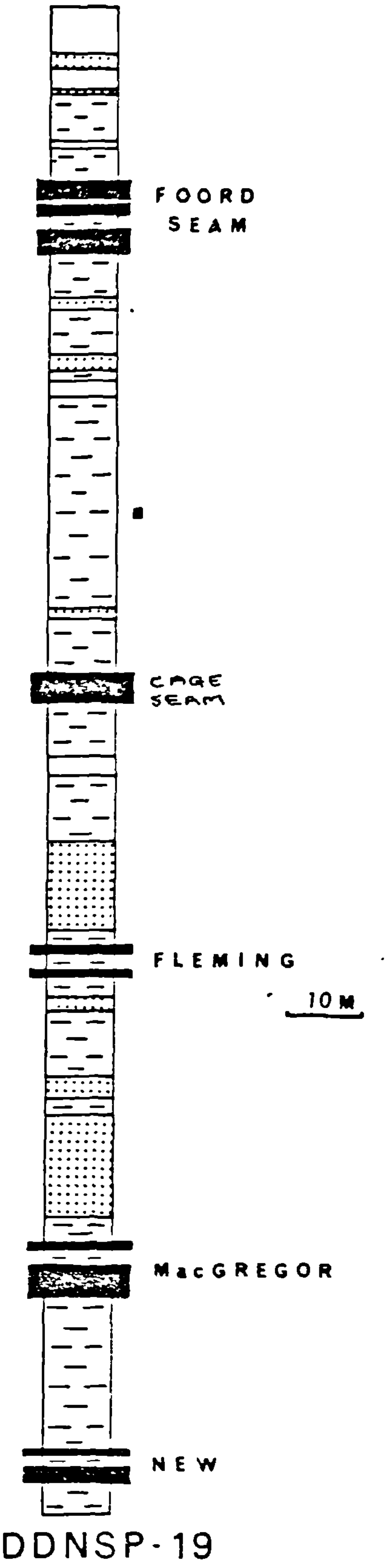


FIGURE 6.36: Log of Hole D.D.N.S.P.-19 (Pictou coalfield), with seam names given. ■ FAUNAL HORIZON.

Occasionally poorly preserved bivalves have been identified as *Anthraconaia arenacea*; rare *Leaia* sp. and *Spirorbis* sp. also occur.

6.6.2. Correlational aspects of the fauna.

The occurrence of *Anthraconaia arenacea* suggests a correlation with the British Tenuis Chronozone (Westphalian D) through comparison with the Sydney faunas (Table 6.1) for this short interval.

CHAPTER 7

PALAEOECOLOGY AND CORRELATION.

Eagar (1978) in summarizing findings regarding shell shape changes of bivalves and their functional significance noted that many of the changes in shape of shell were probably phenotypic. Whilst of use in the study of Upper Carboniferous palaeoenvironments, these findings have a direct stratigraphic significance. Since the systematics of this group of fossils are based largely on external morphological criteria and moreover, their stratigraphic use depends on the recognition of morphological varieties and their relative numerical strengths on any particular horizon, then consideration of environmentally related changes in morphology is of the utmost importance.

The purpose of this chapter is to evaluate the stratigraphical 'anomalies' of the Nova Scotian non-marine bivalve sequence by very detailed consideration of the extent to which different elements of the non-marine fauna are dependent on facies, or are more, or less reliable.

7.1. Shell shape changes and evolution in a paralic area.

Figure 7.1 shows the palaeogeographical features of the paralic British area during the Westphalian. Marine bands are a significant feature of the paralic Coal Measures of Britain and some nineteen widespread marine bands are known along with other local events (Calver 1969). Shell beds first appear in numbers in the Upper Namurian and at that time appear to have been largely confined to the Pennine area, but become increasingly abundant during the early Westphalian.

7.1.1. Invading and established faunas.

Eagar (1977a, 1978) has shown that the evolution of *Carbonicola* from marginally marine stocks of cf. *Sanguinolites* Hind *non* McCoy which took place during the late Namurian - early Westphalian, was marked by certain changes in shell morphology. This event included increased dentition, deepening of the hinge plate, loss of shell ornament and elongation in a postero-ventral direction. Eagar (1977a, 1978) noted that such morphological changes were consistent with increased ease of burrowing and upward escape.

The entry of these early Westphalian invading faunas into low energy, highly eutrophic environments is marked by changes in morphology comparable to those noted in Recent Swedish Unionides (Agrell 1949). Increases in the A/L, H/L and T/L ratios take place to produce more ovate, tumid shells in response to increases in the organic carbon content of the associated sediments. Similar trends were recorded in populations of *Anthraconaia* (Eagar 1973, 1975) from north-eastern USA and in *Anthraconauta* from Britain and Spain (Eagar 1973, in prep. [1983]). For these established faunas, the palaeoecological evidence suggests a shallow embedding, or ploughing position or one in which the bivalve rested on one or other of its valves. The increased bulk of the animal in relation to its surface area resulting from these shape changes would have provided increased power for the foot as well as preventing sinking in the soft bottom muds (Eagar 1978, p.179).

Importantly, morphological changes also occur in established faunas under adverse conditions (such as diminished food supply and increased current activity). The fauna tends towards smaller shells with greater H/L ratios, loss of posterior expansion and often, greater development of the umbones (Eagar 1968, 1973, 1977a, 1978). These changes have been expressed by Eagar (1973)

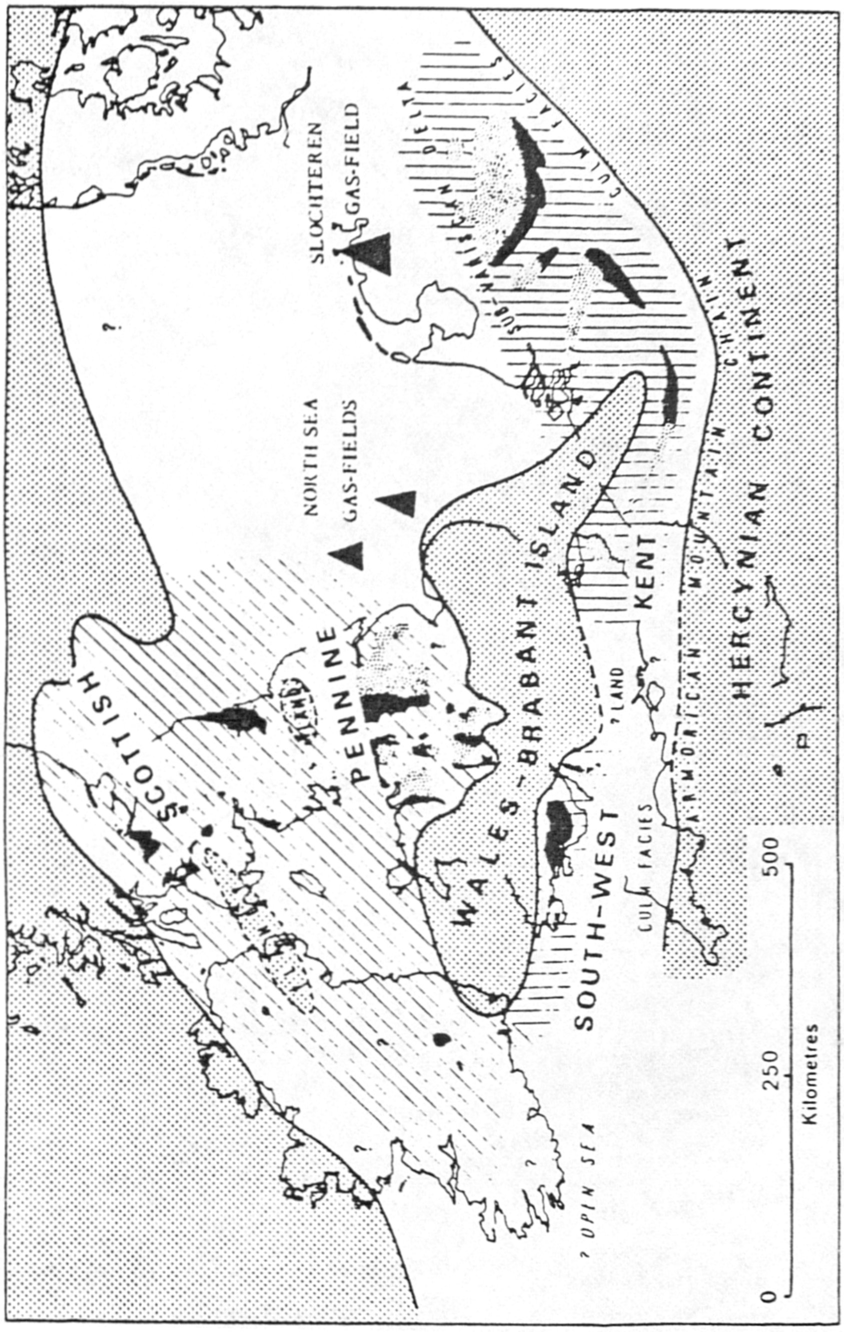


FIGURE 7.1: Westphalian palaeogeography of the British Isles after Calver (1969).

in the form of the two palaeoecological laws given in Chapter 3 (Figure 7.2).

7.1.2. Opportunism and survival.

Upper Carboniferous non-marine bivalves were opportunistic in the sense of Levinton (1970), being controlled primarily by the physical as opposed to the biotic environment; they were also relatively unspecialised (Eagar 1978). Both of these characteristics were strong factors in ensuring their survival in the rapidly changing environments of the Upper Carboniferous. As opportunists, these faunas rapidly invaded new environments temporarily rich in food and at first, devoid of competing forms of animal life (ibid.) but as populations, they were unstable disappearing with rapidity under certain conditions. Previously identified causes for their disappearance were marine transgression (Trueman & Weir 1946, Calver 1968a, 1969, Eagar 1961, 1973, 1977a), high sedimentation rates (Eagar 1952, 1961, Broadhurst 1964) and oxygen deficiency (Eagar 1961). Evidence from Nova Scotia suggests that competition may have been an additional and important factor (section 7.3.2.4.).

As many workers have emphasised populations of Upper Carboniferous, non-marine bivalves characteristically display a wide range of morphological variation. Similarly, within the population habitat, conditions probably varied over short distances, particularly in terms of current activities. Eagar (1974, 1978) observed a similar pattern of variation in populations of the Recent non-marine bivalve *Margaritifera margaritifera*, and concluded that this wide ranging variation constituted a "functional insurance" for their survival. Thus, within the rapidly changing environments of the Upper Carboniferous, the combination of a low degree of specialization and a high degree of opportunism probably ensured the survival of these bivalves. In addition, it is considered here that within a

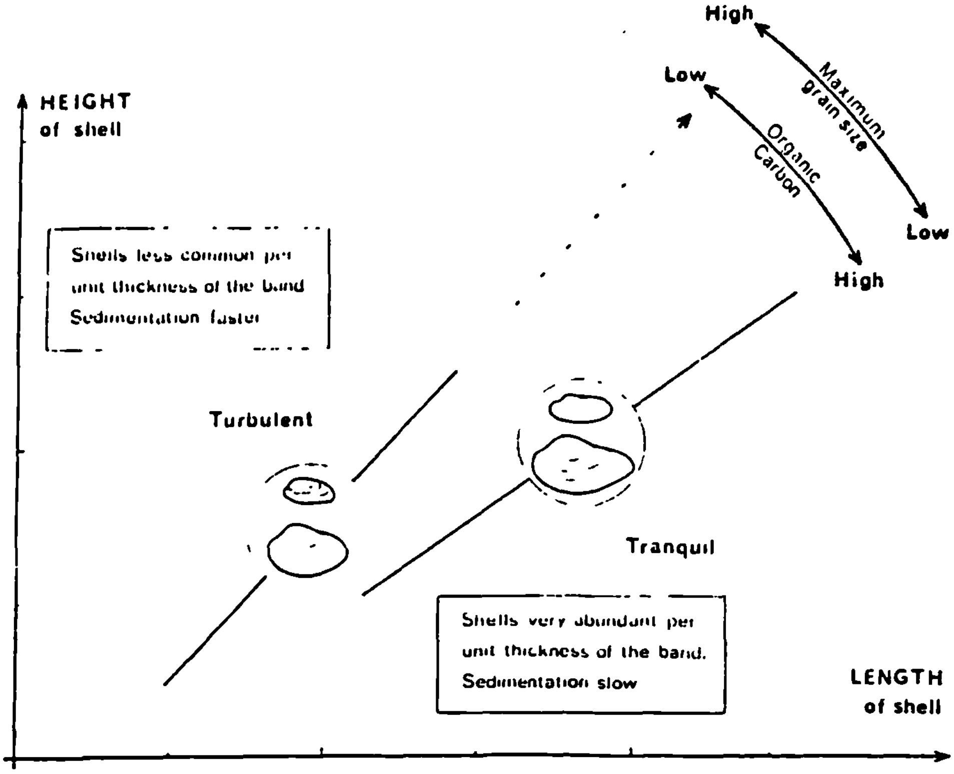


FIGURE 7.2: Diagrammatic representation of Eagar's two palaeoecological laws (from Eagar 1978).

continually but progressively changing environment, this combination of factors would have acted as an evolutionary 'driving force'.

7.1.3. The effect of marine transgression.

Trueman & Weir (1946, pp. xxiv-xxv) regarded periods of peat formation and marine incursion as major factors influencing the overall faunal changes observed in the British Coal Measures and pointed out that some of the most important zonal boundaries are placed at coal seams or marine bands. Eagar (1973, pp.409-411) noted that zonal discrimination was easier in parts of the British succession where coal seams and marine bands occur most frequently. Table 7.1 shows the ranges of the genera of non-marine bivalves of the British Westphalian and the important marine bands. It should be noted that both Anthracosia and Anthracosphaerium disappear from the record at the level of the A. hindi marine band in middle Similis-Pulchra Chronozone times and Naiadites did not apparently survive for long above the A. cambriense marine band in Britain. In addition, Curvirimula disappears in the upper Lower Coal Measures with the lessening of marine influence (Calver 1968a) only to reappear in association with later marine events.

Evolution requires isolation of stocks which have penetrated new environments (Eagar 1973, p.409). In the paralic British-NW European area faunas could penetrate long distances into the pro-deltaic environments (ibid.). Phenotypic changes in response to environmental factors and the wide range of variation in a population resulted in faunas with slightly different ranges and modes (ibid.) which on marine transgression, were nearly all wiped out. More locally, faunas were wiped out by silting and other environmental factors mentioned earlier. On regression of the sea, a suite of new and unoccupied environments once more became available which the surviving, previously isolated, faunas were

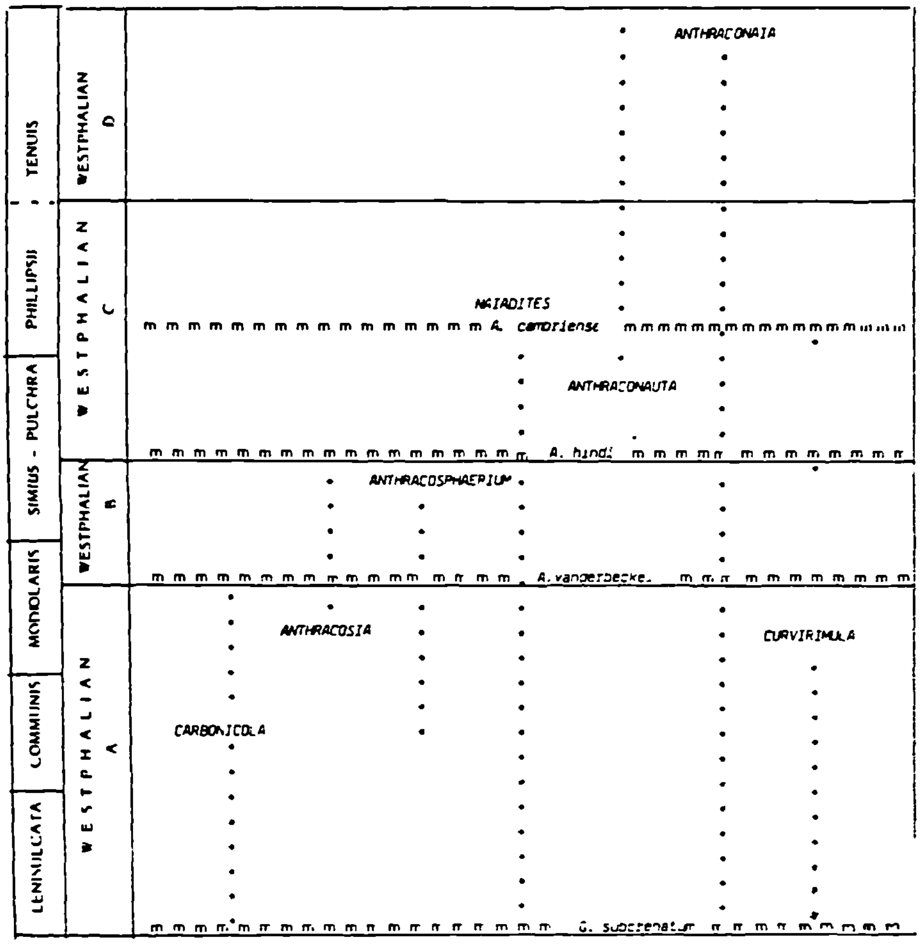


TABLE 7.1: Ranges of the genera of non-marine bivalves in Britain (after Calver 1956, 1963, 1968a, Ramsbottom <u>et</u>. <u>al</u>. 1978, George, 1974 and Cleal 1984).

able to rapidly invade and colonise (Figure 7.3). Thus, through the catastrophic removal of large numbers of forms at a single horizon and the rapid introduction of a series of new forms above it, the stratigraphic use of these bivalves becomes possible (cf. Eagar 1973, pp.409-411).

7.1.4. Progressive environmental change.

The Westphalian of the British-NW European paralic area is characterised by a series of environmental changes. The earliest Westphalian strata was deposited in an area subject to marine incursion and is punctuated by a series of up to ten marine horizons. Coals are thin and faunas and floras relatively sparse (Calver 1969). The measures straddling the Westphalian A/B boundary however, reflect more continental, non-marine conditions. Coal seams are thicker and non-marine faunas common. A second series of marine bands terminating with the *A. cambriense* marine band associated with thin coals and diminished faunas reflects a second period of marine influence during late Westphalian B - early Westphalian C times (Calver 1969, Bless *et. al*. 1977, Ramsbottom *et. al*. 1978). The laterpart of the British Westphalian is marked by a retreat of the Westphalian marine influence and the beginnings of a more arid, continental environment.

Within this context, certain changes in the fauna are apparent, several have already been mentioned but the progressive change towards a continental regime in upper Middle and Upper Coal Measures times resulted in the disappearance of *Naiadites* and the introduction of *Anthraconauta*. In addition, trends towards elongation in both *Anthraconauta* and in the later representatives of *Anthraconaia* occur (Trueman & Weir 1946, Weir 1968, Eagar 1973, in press [1979], in prep. [1983]) during this period. These changes were attributed by Eagar (1973, p. 409) to "slow specialisation under uniform or near uniform conditions".

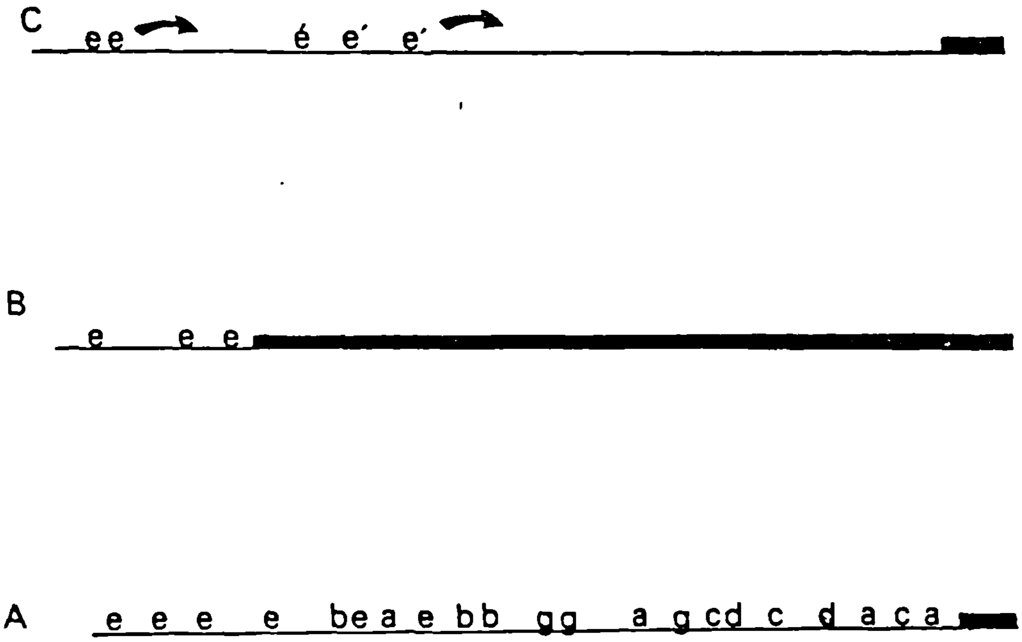


FIGURE 7. 3: The effect of marine incursions on a non-marine bivalve fauna. A - Sea at some distance, many morphological varieties with overlapping environmental ranges inhabit the lowland area.

B - Marine incursion, many of the morphological varieties are drowned. Morphological variety e, which had worked its way farther up the deltaic environment survives.

C - Marine regression, Previously isolated form e invades the new and unoccupied environments.

Trends towards elongation in the Upper Coal Measures faunas have a stratigraphical significance, at least in Anthraconauta where the elongate A. tenuis is used to discriminate the Westphalian D Tenuis Chronozone (Eagar 1973, Ramsbottom et. al. 1978, and see Cleal 1984). Eagar (1973) biometrically analysed assemblages of Anthraconauta from both the Phillipsii and Tenuis Chronozones, concluding that shells from organic carbon-poor, coarser sediments were a little smaller and appreciably more elongate. Furthermore, specimens from the organic carbon-poor lithologies were "more strongly represented" in the Tenuis Chronozone, a factor which Eagar attributed to changing conditions in the British Upper Coal Measures (Eagar 1973, p. 402). Thus, the trend towards more elongate forms may have been related to a pervasive change in the overall environments of the later Westphalian in Britain.

7.1.5. Evidence from the Appalachians and NW Spain.

Eagar (1970, 1973, 1975, in press [1979], in prep. [1983] and Eagar & Weir 1971) studied the non-marine faunas of the Appalachian and Spanish coalfields. Members of the family Anthracosiidae are absent from both areas and faunas comprise entirely myalinid genera, although Naiadites may be absent from the Appalachians (Eagar 1973). Table 7.2 shows Eagar's correlation of the Upper Carboniferous and 'Autunian' strata of Britain, USA and NW Spain.

7.1.5.1. The Appalachian area.

During Allegheny and lower Pottsville times, shell beds are often closely associated with marine faunas: indeed marine influenced sediments form a greater part of the Appalachian succession than in Britain (Eagar 1970). In lower Pottsville strata, Curvirimula often occurs on the same bedding planes as Myalina and Lingula and thus, occupies a similar facies to that

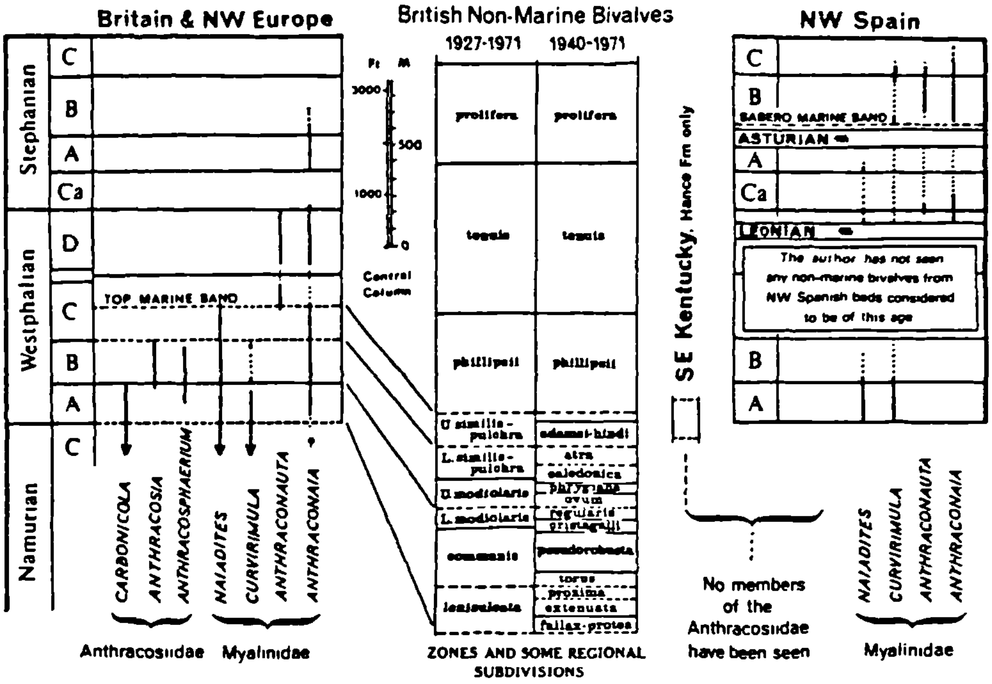


TABLE 7.2: Eagar'S (1973) correlation of Britain, NW Europe, NE USA and NW Spain.

which it occupied in Britain. Anthraconautiform Anthraconaia occur in the middle part of the Pottsville and display similar changes in shape of shell in organic carbon-rich and poor facies as do British anthracosiid and Anthraconauta faunas (Eagar 1973). In the uppermost part of the Pottsville and in the Allegheny Groups, Anthraconauta tenuis and A. phillipsii occur.

In later measures, marine bands continue up to the middle of The Conemaugh Group of West Virginia and marine influence was observed as high as the lower part of the Dunkard Group (Eagar 1975, in press [1979]). In these measures, two distinct groups of Anthraconaia occur, larger elongate forms and a smaller group of high H/L shells (Eagar 1975). Non-marine faunas, mainly sporadic invading faunas of Anthraconaia, are present in younger strata.

Eagar (in press [1979]) concluded that the non-marine bivalves of the Appalachian region, possibly because of their close association with marine faunas, display striking similarities in their succession with parts of the non-marine faunal sequence of NW Europe. By close comparison of shells from the Stephanian and younger strata of both areas, Eagar (ibid.) was able to demonstrate that similarities were greatest between faunas collected from similar facies.

7.1.5.2. Faunas of NW Spain.

Conditions of deposition were broadly comparable to those of the Appalachians when compared with those of the paralic NW European area. In both NW Spain and in the Appalachians, non-marine faunal phases were of shorter duration. Eagar (in prep. [1983]) concluded that in the Spanish coalfields, the limited extent of non-marine life and frequency of incomplete marine incursions allowed little space for isolation of non-marine stocks. Local evolutionary changes do occur but were probably related to local isolation.

The faunas have little value in trans-European correlation but show similarities with the Appalachian faunas, particularly in the younger communities of Anthraconaia of the Stephanian B (ibid.).

7.1.6. Summary.

Progressive environmental change appears to have been an influence in the evolution of the non-marine bivalves of the British and to a lesser extent, NW European area, where there was a more or less progressive diminution of marine influence. The faunal succession is of greater stratigraphical use than in those areas where conditions remained largely unchanged. Thus, in the intermontane basins of NW Spain and nearshore Appalachians the non-marine faunas seem to be of limited stratigraphical value.

Catastrophic events such as marine transgression apparently caused the rapid evolutionary changes necessary for stratigraphically useful faunas and this is particularly the case where such events were of short duration. The lower and middle Westphalian measures of Britain demonstrate this particularly well, whereas in Spain and the Appalachians the marine phase was prolonged (Eagar in prep.[1983]). However, the stratigraphical distribution of the myalinid genera in all three areas is related to marine influence (Table 7.2) accounting for the survival of these genera in the Spanish coalfields.

Local environmental changes resulted in morphological changes which were apparently largely reversible (Eagar 1978). The importance of this situation has been demonstrated in an area where environmental changes were pervasive so that certain morphological changes became highly suited to the later environments (e.g. elongation in upper Westphalian faunas of Britain).
With this in mind, it would seem reasonable to argue that the Nova

Scotian non-marine bivalve faunas would produce little of stratigraphic use since the Nova Scotian environments of the Upper Carboniferous were intracontinental, lacked marine influence of any sort and were not subject to any obvious progressive environmental changes.

7.2. Shell shape differences with palaeoenvironment of some Nova Scotian faunas.

Much work has been done regarding shell shape changes with palaeoenvironment particularly in the anthracosiids (Eagar 1948, 1978). Several Nova Scotian assemblages were analysed using the PCA method described in Chapter 3, including some Naiadites and Curvirimula faunas (Two genera not previously subjected to variation studies of this kind).

7.2.1. Carbonicola.

Carbonicola is considered to be a semi-infaunal/infaunal burrowing bivalve on the basis of several studies (Eagar 1971, 1973, 1975, 1977a,b). Its shape of shell and mode of life appear to have been mainly governed by three interrelated factors, sedimentation rates, food supply and current activity.

The earliest British record of Carbonicola s.s. comes from the upper Namurian of the Pennine area (Eagar 1977a, Eagar et. al. 1983). Most documented earlier forms have now been referred to the genus Paracarbonicola Eagar, which ranged from the Viséan and Pendleian of Britain and did not survive the Arnsbergian (E2) stage of the Namurian (Eagar 1977a).

Apart from C. bradorica, all the records of Carbonicola in Nova Scotia come from the Canso Group (Rogers 1965) and from

Riversdale strata, the latest record being at Boss Point. C. bradorica, after examination of Rogers' (1965) plates, figures and description should probably be referred to Paracarbonicola Eagar (see systematic section). This new, though tentative, reference accords well with the age of its type locality at Baddeck, which may be late Viséan in age (Rogers 1965).

7.2.1. Invading and established faunas of Carbonicola in Nova Scotia.

Shells of the Carbonicola? angulata group at Parrsboro occur in pale, coarse sediments which display evidence of comparatively rapid deposition. The shells are elongate, having low H/L and A/L ratios. Such characteristics are typical of an invading fauna (Eagar 1977a, p.537) and, although direct evidence to suggest a steeply inclined or steep-burrowing mode of life was not found, this seems likely from its morphology.

In direct contrast, shells of the C?. eagari sp. nov. group at Boss Point occur in a fine-grained, organic carbon-rich lithology and are of a more subovate shape with high H/L ratios and longer anterior ends. Their preservation as articulated shells lying subparallel to the bedding suggest a shallow burrowing or ploughing living position for this established fauna (Eagar 1978).

The two sampled populations show little intraspecific variation (Figures 4.6 & 4.10) and evidence from Boss Point (section 4.1.2.) suggests that the C?. eagari fauna died out suddenly on resumption of heavy sedimentation rates (cf. Broadhurst 1964).

7.2.2. *Naiadites*.

In Britain, *Naiadites* is first recorded in the Scottish Calciferous Sandstone Series (Leitch 1942, Bennison 1961) and becomes increasingly important as coal measure facies develop through the Westphalian A. *Naiadites* disappears from the record at a level just above the *A. cambriense* marine band of the middle Westphalian C. In Nova Scotia, *Naiadites* makes a somewhat later appearance and is unrecorded from Canso Group or older strata (Rogers 1965, Table 8). In the Boss Point - Joggins section, *Naiadites* was first recorded from Logan's Coal Division 44 (Logan 1845), well within the Cumberland Group, as defined by Bell (1944), but probably partly of Westphalian A age - see later. Elsewhere, *Naiadites* is recorded in the Riversdale Group throughout the coal-bearing member. Thus, it would seem that *Naiadites* first enters the Nova Scotian succession in the late Westphalian A. Its upper limit in Nova Scotia is not known, although it does not occur in the mid Westphalian C - Lower Permian Pictou/Morien Group.

Naiadites possessed a wide degree of tolerance in the British Coal Measures (Calver 1968a), occurring interleaved with marine fossils on some horizons, and as shown by Eagar (1961, p. 146), it takes the place of *Curvirimula* at the base of the typical faunal profile of the shell beds of the upper part of the lower Coal Measures and in the middle Coal Measures. *Naiadites* often occurs as the only bivalve on a horizon in both Britain (Calver 1968a) and in Nova Scotia. Trueman & Weir (1955, pp. 208-9) discussed the mode of life of *Naiadites* concluding that most *Naiadites* were epifaunal, byssally attached forms with a tendency to rest on one valve when inequivalved, other equivalved forms occupying an upright position. They tentatively suggested that certain elongate forms may have abandoned byssal attachment in favour of a semi-infaunal burrowing position. Calver (1968a) suggested that *Naiadites* was epifaunal living free of the bottom muds and may have been pseudo-planktonic, attached to floating plant debris (see also Eagar 1961, p. 144).

7.2.2.1. The Port Hood faunas.

PCA and correlation analysis was performed on twenty-three measured shells collected from the Cape Linzee section. Care was taken to ensure that the shells and whole single valves were collected from positions inferred to be life or near-life positions. Both the grain size and the colour of the lithologies from which the shells were collected display a high degree of interdependence; coarse lithologies tend to be paler in colour. Grain size was chosen as the environmental indicator as it displays greater correlations with the measured shell dimensions than the N values of the grey tones.

From the correlation chart (Table 7.3), it can be seen that the A/L, D/L and HH/L ratios increase with coarsening of sediment and that the PE/L ratio decreases. The PCA plot (Figure 7.4) shows these shell shape trends against grain size variation. 78% of the sampled variation was explained on the first three principal components. Furthermore, essentially the same relationships between shell shape and increasing grainsize are indicated, although the H/L ratio decreases. The decrease in H/L is probably due to the high positive correlation observed in this sampled assemblage between the H/L and PE/L ratios.

These shell shape changes are summarized in the pictographic representation of the PCA results (Figure 7.4). Shells tend to be smaller, of lower obliquity with longer anterior ends and diminished posterior expansion in the coarser lithologies. It should also be noted that these shells tend to possess larger and rather better developed umbones.

TABLE 7.3 : PORT HOOD *NAIADITES*, CORRELATION CHART AND PCA RESULTS.

	A/L	DM/L	D/L	HH/L	U/L	PE/L	G. SIZE
H/L	-0.27	0.49	-0.18	-0.08	0.02	0.71	-0.08
A/L		0.12	0.48	0.45	-0.25	-0.46	0.43
DM/L			0.14	0.33	0.02	0.35	0.18
D/L				0.37	0.10	-0.63	0.77
HH/L					-0.22	-0.02	0.32
U/L						-0.22	0.03
PE/L							-0.49

PCA RESULTS:

EIGENVALUES: 3.02, 1.93, 1.28, 0.66, 0.48, 0.34, 0.22, 0.07

% variance : 37.7, 61.8, 77.9, 86.4, 92.1, 96.4, 99.1, 100

EIGENVECTORS:

1: 0.42A/L, 0.49D/L, -0.47PE/L, 0.45 G. SIZE
2: 0.48H/L, 0.61DM/L, 0.40HH/L, 0.37PE/L
3: -0.31A/L, 0.76U/L

TABLE 7.4: CHIMNEY CORNER *NAIADITES*, CORRELATION CHART AND PCA RESULTS.

	A/L	DM/L	D/L	HH/L	U/L	COLOUR	G.SIZE
H/L	0.54	0.43	0.06	-0.24	0.23	-0.01	-0.19
A/L		0.35	-0.14	0.15	0.31	0.25	-0.27
DM/L			-0.02	0.14	-0.02	-0.10	0.01
D/L				-0.27	0.29	-0.28	0.01
HH/L					-0.19	0.21	0.07
U/L						0.23	-0.25
COLOUR							-0.19

PCA RESULTS:

EIGENVALUES: 2.13, 1.73, 1.46, 0.83, 0.72, 0.45, 0.39, 0.29

% variance : 26.5, 48.2, 66.5, 76.8, 85.8, 91.5, 96.3, 100

EIGENVECTORS:

1: 0.52H/L, 0.59A/L, 0.32DM/L, 0.32U/L, -0.34G. SIZE
2: 0.34DM/L, -0.57D/L, 0.52HH/L, -0.46U/L
3: -0.37H/L, -0.50DM/L, 0.31U/L, 0.6COLOUR

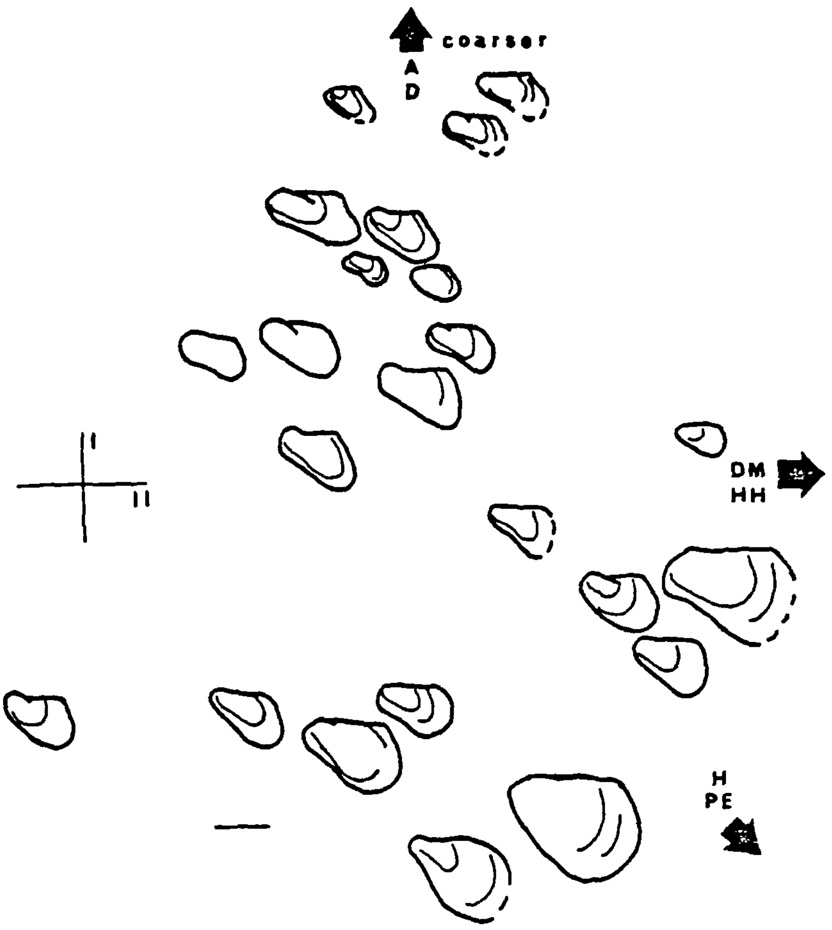


FIGURE 7.4: Morphological changes with palaeoenvironmental change in *Naiadites* spp. from Port Hood. PCA1 v PCA2. Scale bar - 1 cm.

7.2.2.2. The Chimney Corner faunas.

A similar analysis was performed using thirty-three measured shells from the Chimney Corner coastal section. Unfortunately, the shells were mainly collected from silty shales of varying hues withthe result that there is little correlation between colour and grain size. Furthermore there are few correlations between either the colour of the sediment or grain size and the measured shell dimensions (Table 7.4).

7.2.2.3. The Parrsboro faunas.

Analysis of twenty three measured shells from the Parrsboro Formation using both colour and grain size as environmental indicators, displays some shell shape trends. The correlation chart (Table 7.5) reveals that the H/L, U/L and PE/L ratios decrease and the DM/L ratio increases with increasing organic carbon-content. The PCA plot (Figure 7.5) displays essentially the same trends. However the D/L ratio increases with increasing organic carbon-content, a feature of its high negative correlation with the PE/L ratio in this sample (Table 7.5). The overall shell shape trend is towards shells of lower obliquity and diminished posterior expansion with greater turbulence, sedimentation rate and lower food supply in their environment.

7.2.2.4. The River Hebert faunas.

Analysis of sixteen measured shells from the River Hebert cores using both grain size and colour as environmental indicators reveals certain comparable but limited results, shells being mainly collected from medium to pale grey muddy and silty shales. Table 7.6 shows the correlations between the measured shell dimensions and the environmental indicators from which it may be observed that shells tend to have increased H/L, A/L,HH/L and DM/L ratios

TABLE 7.6: CORRELATION CHART AND PCA RESULTS, RIVER HEBERT NAIADITES.

	A/L	DM/L	D/L	HH/L	U/L	PE/L	COLOUR	GRAIN SIZE
H/L	0.19	0.35	-0.09	0.52	-0.48	0.14	-0.39	0.36
A/L		-0.32	-0.07	0.09	0.02	-0.14	0.17	0.24
DM/L			-0.10	0.25	-0.31	0.19	-0.37	-0.01
D/L				0.14	-0.09	-0.94	0.07	0.06
HH/L					-0.55	-0.16	-0.27	0.44
U/L						0.12	-0.16	-0.44
PE/L							-0.18	-0.14
COLOUR								-0.08

PCA RESULTS:

EIGENVALUES: 2.65: 2.17: 1.03: 0.64: 0.47: 0.39: 0.18: 0.02

Cum. Var.% : 29.5: 53.6: 69.6: 81.1: 88.2: 93.4: 97.8· 100.0

EIGENVECTORS:

I :0.49H/L, 0.06A/L, 0.29DM/L, 0.06D/L, 0.51HH/L, -0.46U/L, -0.05PE/L, -0.22COL., 0.34G. size.

II :-0.15H/L, 0.17A/L, -0.29DM/L, 0.58D/L, 0.08HH/L, -0.10U/L, -0.64PE/L, 0.28COL., 0.14G. size

III:0.1H/L, 0.63A/L, -0.43DM/L, -0.39D/L, -0.06E/L, 0.22PE/L, 0.28COL., 0.30G. size.

TABLE 7.5: CORRELATION CHART AND PCA RESULTS PARRSBORO NAIADITES.

	A/L	DM/L	D/L	HH/L	U/L	PE/L	COLOUR	G. SIZE
H/L	0.25	0.01	-0.45	-0.14	0.48	0.66	-0.40	0.14
A/L		0.52	0.15	-0.09	0.07	0.17	-0.03	-0.01
DM/L			0.19	0.09	-0.22	0.19	0.33	-0.01
D/L				-0.28	-0.09	-0.74	0.06	0.11
HH/L					-0.55	0.32	0.12	-0.28
U/L						0.00	-0.26	0.00
PE/L							-0.22	0.08
COLOUR								0.25

PCA RESULTS:

EIGENVALUES: 2.50, 1.97, 1.66, 1.19, 0.69, 0.40, 0.34, 0.17, 0.09

% variance : 27.8, 49.7, 68.1, 81.3, 88.9, 93.8, 97.1, 99.3, 100

EIGENVECTORS:

1: 0.55H/L, -0.41D/L, 0.53PE/L, -0.32COLOUR

2: 0.6HH/L, -0.53U/L, 0.31PE/L,

3: 0.64A/L, 0.63DM/L

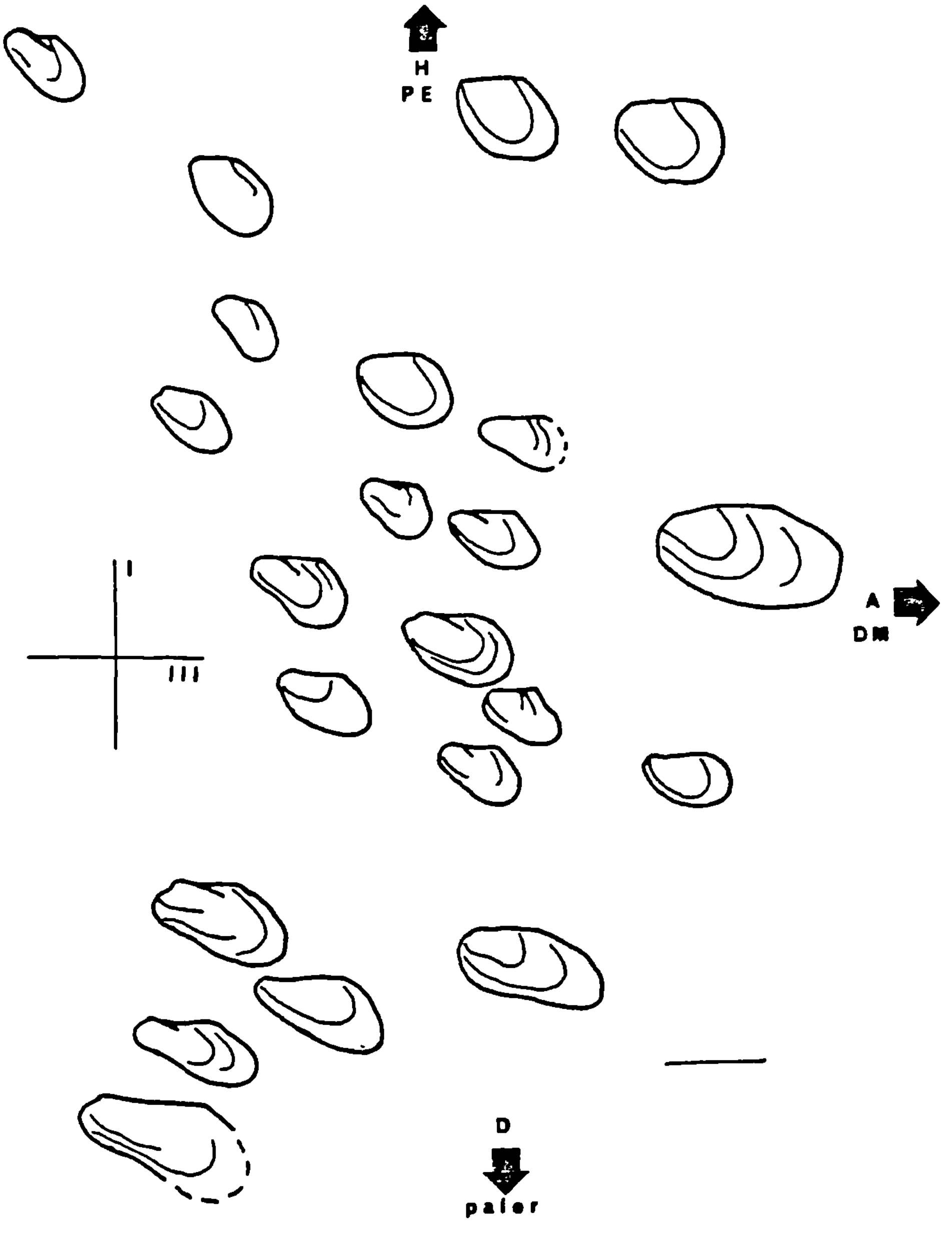


FIGURE 7.5: Morphological changes with palaeoenvironmental change in Naiadites spp. from Parrsboro (Parrsboro Fm.). PCA1 v PCA3. Scale bar - 1 cm.

and decreased U/L ratios in paler, coarser lithologies. Thus, shells with well developed umbones, diminished posterior expansion and longer anterior ends (Figure 7.6) tend to characterize paler and coarser sediments.

7.2.2.5. Summary and discussion.

The results of these analyses strongly suggest that the shape of shell of Naiadites in Nova Scotia displays some degree of correlation with their palaeoenvironment as reflected by grain size and colour (primarily organic carbon-content) of sediment. It can be reasonably inferred that these environmental indicators reflect turbulence, sedimentation rates and food supply of the habitat, factors which in turn affect the substrate condition and oxygen content of the bottom waters.

The shell shape changes indicated in these analyses are summarised in Figure 7.7. With increased turbulence and sedimentation rates, Naiadites trends towards smaller shells of lower obliquity which possess longer anterior ends and display diminished posterior expansion. These major morphological changes are often accompanied by greater development of the umbones and reduced shell width such that there is a degree of parallelism between the ventral and upper posterior margins.

It is of stratigraphic interest to note that the result of these morphological changes is to produce shells referable to N. subtruncatus s.l. in turbulent environments and to produce shells referable to N. triangularis s.l. and N. quadratus s.l. in highly eutrophic and tranquil environments. N. carbonarius and variants appear to be the modal form of Naiadites in Nova Scotia as well as being the modal form in the pictographic representation of these analyses.

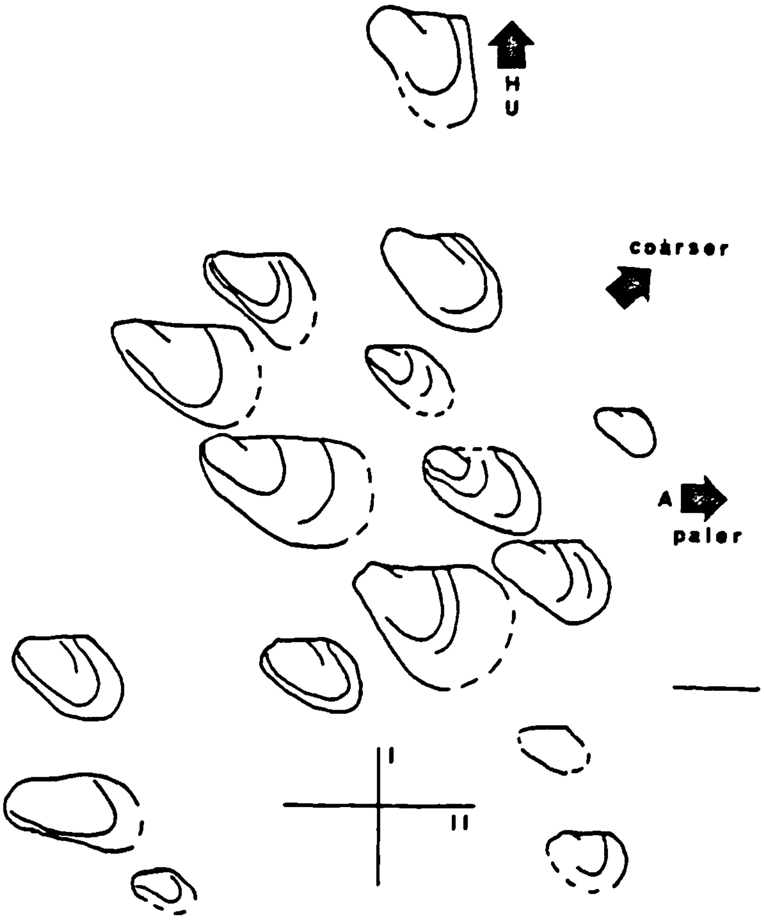
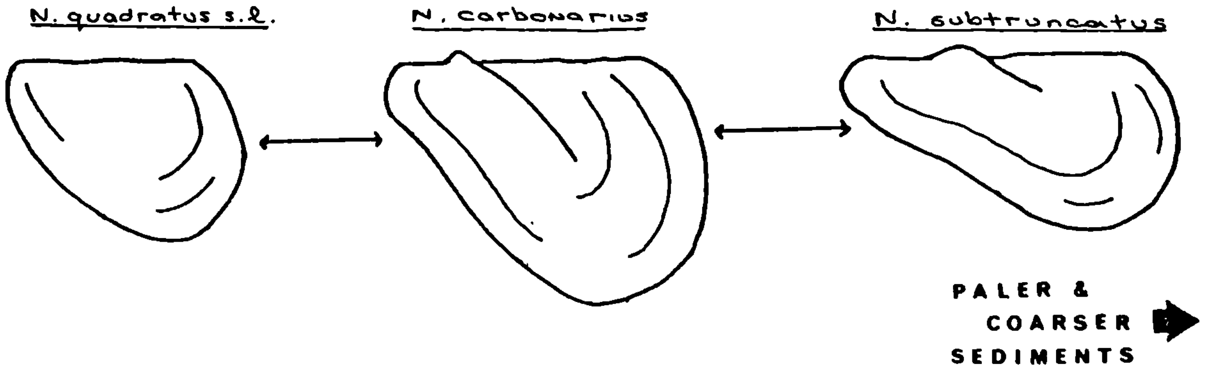


FIGURE 7.6: Morphological changes with palaeoenvironmental change in Naiadites spp. from River Hebert. PCA1 v PCA2. Scale bar - 1 cm.

FIGURE 7.7: Diagrammatic summary of morphological changes observed in Naiadites spp. with increasing turbulence and grainsize.



7.2.3. Curvirimula.

In Britain, Curvirimula is first recorded in the Lower Carboniferous of the Pennines and is widespread in the lower and middle parts of the Lower Coal Measures (Weir 1960, Calver 1968a). The genus disappears from the stratigraphic record at the top of the Communis Chronozone reappearing only in measures associated with marine bands. Its last recorded appearance in Britain is in the upper part of the A. cambriense marine band (Weir 1960, p. 299, Woodland & Evans 1964, p. 163). In the Appalachians, Curvirimula was recorded by Eagar (1970, p. 687) from the Hance Formation and in Spain, the genus ranges throughout the Westphalian and into the Stephanian C (Eagar 1973, in prep. [1983]).

Little has been said regarding the mode of life of this bivalve except that it seems to have been tolerant of, if not favoured, a brackish environment (Weir 1960, Eagar 1947, 1961, Calver 1968a). Curvirimula is found immediately above and below marine bands (Eagar 1961, 1970) often accompanying Lingula, Myalina and foraminifera. This is also true for the genus in Spain, though here it appears to have moved into fresher water environments in late Stephanian times displacing Anthraconauta (Eagar, in prep. [1979]).

The genus occurs sometimes attached to plant debris (ibid.) and may possess a well developed byssal sinus even when there is no evidence of attachment.

7.2.3.1. The Chimney Corner faunas.

Two analyses were performed. The first analysis utilised shells from the C. corvosa horizon and the second used fifty-seven measured shells collected from both the C. corvosa (see Figure 4.32) and adjacent horizons.

The C. corvosa horizon.

Both colour and grainsize measures were used as environmental indicators owing to their low interdependency. Table 7.7 shows no significant correlations between the measured shell dimensions and the environmental indicators occurred, a result possibly due to the relative uniformity of the colour and lithology of the C. corvosa bed.

Combined analysis.

As before, no significant correlations were observed and it is possible that the large number of shells included in this analysis from the C. corvosa bed which, as has been stressed, is lithologically fairly uniform, 'overweighed any sampled variation. However, the shells of the C. corvosa bed do display quite a wide range of morphological variation (Figure 4.30) and it could be argued, in view of this, that this variation is not the result of the sampled environmental changes. This would be the expected result should Curvirimula be a pseudoplanktonic bivalve.

7.2.3.2. The Port Hood faunas.

Sixteen measured shells were subjected to a similar analysis in which both colour and grain size were used as environmental indicators. However, it should be noted that the range of colour values is low (N3-4). From the correlation chart (Table 7.8 - using a rather limited number of specimens), it may be seen that the U/L and W/L ratios tend to decrease and the H/L ratio increases with increasing grain size. PCA plots further confirm this trend (Figure 7.8). Shells in the finer sediments therefore, tend to be elongated in a postero-ventral direction with subparallel ventral and upper posterior margins.

TABLE 7.8: CORRELATION CHART AND PCA RESULTS, PORT HOOD *CURVIRIMULA*.

	A/L	DM/L	W/L	HH/L	U/L	COLOUR	GRAINSIZE
H/L	-0.13	-0.09	0.44	-0.01	0.21	0.08	0.27
A/L		0.33	0.19	0.34	-0.08	0.26	0.11
DM/L			0.70	0.76	-0.23	0.30	-0.21
W/L				0.59	0.07	0.43	-0.28
HH/L					-0.54	0.25	0.10
U/L						0.23	-0.31
COLOUR							0.08

EIGENVALUES: 2.81: 1.66: 1.35: 1.07: 0.64: 0.27: 0.14: 0.06

Cum. Var. %: 35.2: 55.9: 72.8: 86.1: 94.1: 97.5: 99.3: 100.0

EIGENVECTORS:(values over 0.3 used)

I :0.05H/L, 0.29A/L, 0.53DM/L, 0.49W/L, 0.52HH/L, -0.17U/L, 0.3COL., -0.04G.SIZE.

II :0.4H/L, -0.14A/L, -0.03DM/L, 0.36W/L, -0.25HH/L, 0.66U/L, 0.3COL., -0.31G.SIZE.

III:0.62H/L, 0.02A/L, -0.21DM/L, 0.03W/L, 0.05HH/L, -0.1U/L, 0.15COL., 0.73 G.SIZE.

TABLE 7.7: CORRELATION CHART AND PCA RESULTS, CHIMNEY CORNER CURVIRIMULA.

	A/L	DM/L	W/L	HH/L	U/L	COLOUR	GRAINSIZE
H/L	0.24	-0.38	0.48	0.41	-0.35	0.05	-0.21
A L		0.09	0.44	0.26	0.17	-0.12	-0.04
DM/L			0.44	-0.25	0.56	0.04	0.19
W/L				-0.34	0.40	0.08	-0.08
HH/L					-0.49	0.06	-0.03
U/L						0.17	-0.03
COL.							-0.32

PCA RESULTS:

EIGENVALUES: 2.31: 1.95: 1.36: 0.82: 0.74: 0.48: 0.26: 0.09

CUM. VAR.% : 28.9: 53.3: 70.3: 80.4: 89.7: 95.7: 98.9: 100.0

EIGENVECTORS:

I :0.36H/L, -0.04A/L, -0.53DM/L, -0.24W/L, 0.43HH/L, -0.57 U/L, -0.05COL, -0.10G.SIZE -

II :0.49H/L, 0.49A/L, 0.10DM/L, 0.6W/L, 0.24HH/L, 0.13U/L, 0.14COL, -0.22G.SIZE

III:0.00H/L, -0.32A/L, -0.13DM/L, -0.07W/L, -0.14HH/L, 0.13U/L, 0.67COL, -0.62G.SIZE

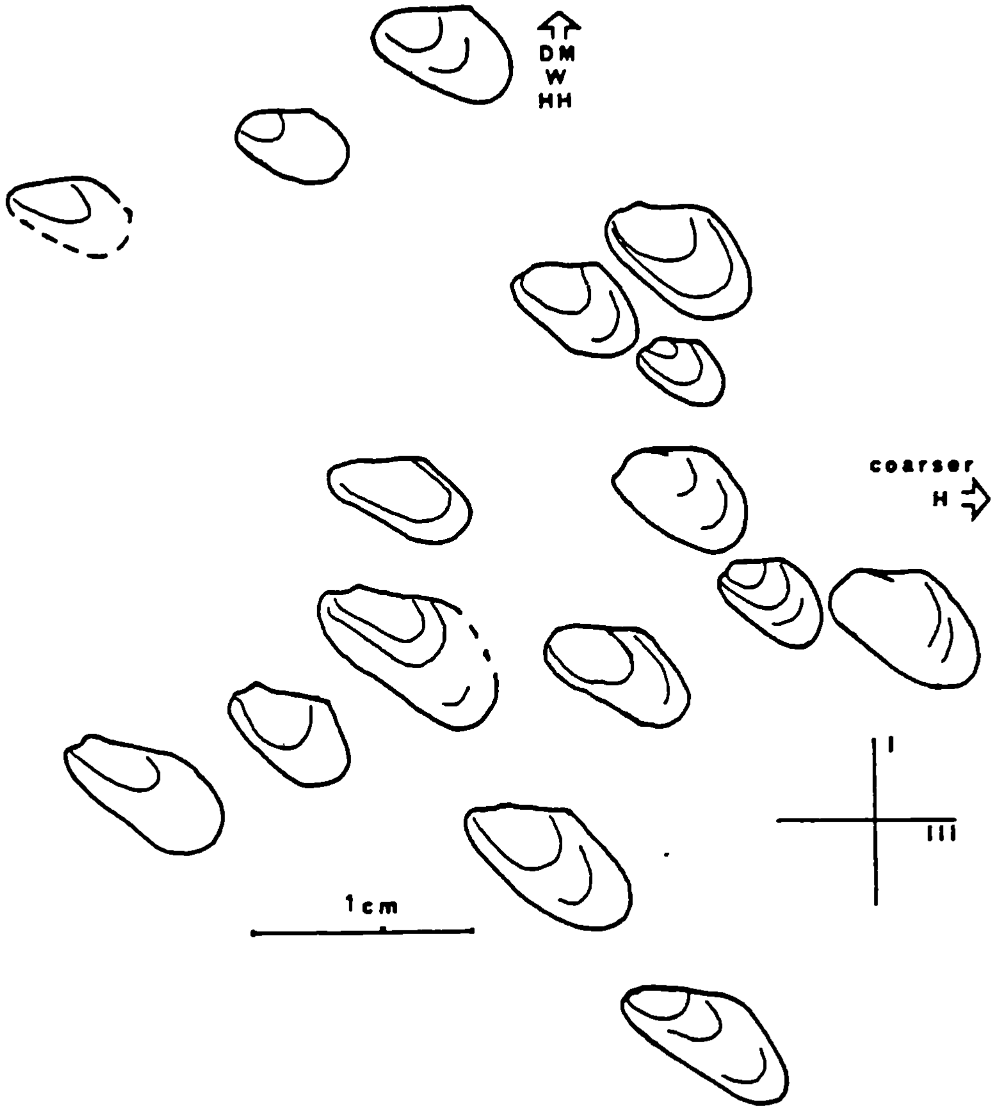


FIGURE 7.8: Morphological variation with palaeoenvironmental changes in Curvirimula spp. from Port Hood. PCA1 v PCA3. Scale bar is 1 cm.

7.2.3.3. Summary and discussion.

The results of these two analyses are ambiguous. The Joggins faunas were not analysed due to their tendency to occur in calcareous lithologies (and the $CaCO_3$ content could not be easily quantified). However, the results imply two possibilities;

1. The external morphology of Curvirimula is unrelated to the environmental factors considered. In this respect, the smaller number of specimens used in the Port Hood analysis and that fact that some of these shells occur in an unusually coarse lithology for Curvirimula, should be taken into consideration.

or 2. Some degree of environmental influence may occur in the Chimney Corner analysis. A correlation was perhaps masked through the lithological uniformity of the C. corvosa bed.

7. 2. 4. Anthraconauta.

Anthraconauta is typical of the Upper Coal Measures in Britain ranging through the upper Westphalian C and D. In the Appalachians, Eagar (1970) recorded Anthraconauta in strata of a presumed similar age and in NW Spain, the genus ranges from mid-Cantabrian to lower Stephanian C strata (Eagar 1973, in prep. [1983]).

The mode of life of Anthraconauta was discussed by Calver (1968a) who believed it to occupy a fresh to brackish salinity range on the basis of commonly associated fauna. Weir (1960, p.274) regarded the lack of a well developed byssal sinus in Anthraconauta as evidence to suggest an epifaunal, mud-dwelling habit, though elongate varieties such as A. tenuis may have been burrowers (see Eagar 1973, fig.12E)

7.2.4.1. Shell shape changes in the Tenuis and Phillipsii Chronozones of Britain.

Eagar (1973, pp. 400-404) studied shell shape variation in Anthraconauta with palaeoenvironment from both the Tenuis and Phillipsii Chronozones of Britain. Shells were measured using the w and m measurements of Eagar (1973), where w is the greatest width of the shell measured at right angles to m, and m is the distance measured from the umbo along the line of maximum growth to the postero-ventral extremity. Shells were grouped into two broad catagories, those occurring in organic-rich facies where the colour of the sediment was greater then N3 on the Rock-color chart, and those occurring in a grey-sediment facies.

Figure 7.9 shows the resultant fitted regression lines for collections of shells from both these facies in the two Chronozones. In each Chronozone there is a trend towards smaller and more elongate shells in the paler grey sediments. Eagar (ibid.) concluded that in both the Phillipsii and Tenuis Chronozones there is some degree of correlation between shape of shell, as measured by his w/m ratio, and the proportion of organic carbon in the associated sediment, although grain size was virtually always uniform (Eagar, pers. comm.).

7.2.4.2. Shell shape changes in the Stephanian of Spain.

Eagar (in prep. [1983]) performed similar analyses using collections of Anthraconauta from the Stephanian of the Cinera-Matallana and El Bierzo coalfields of Spain. In the Cinera-Matallana coalfield where sediment was of clay grade,similar results to those previously observed in Britain (Eagar 1973). Shells displayed trends towards lower A/L, w/m and H/L ratios and increased D/L ratios with decreasing organic

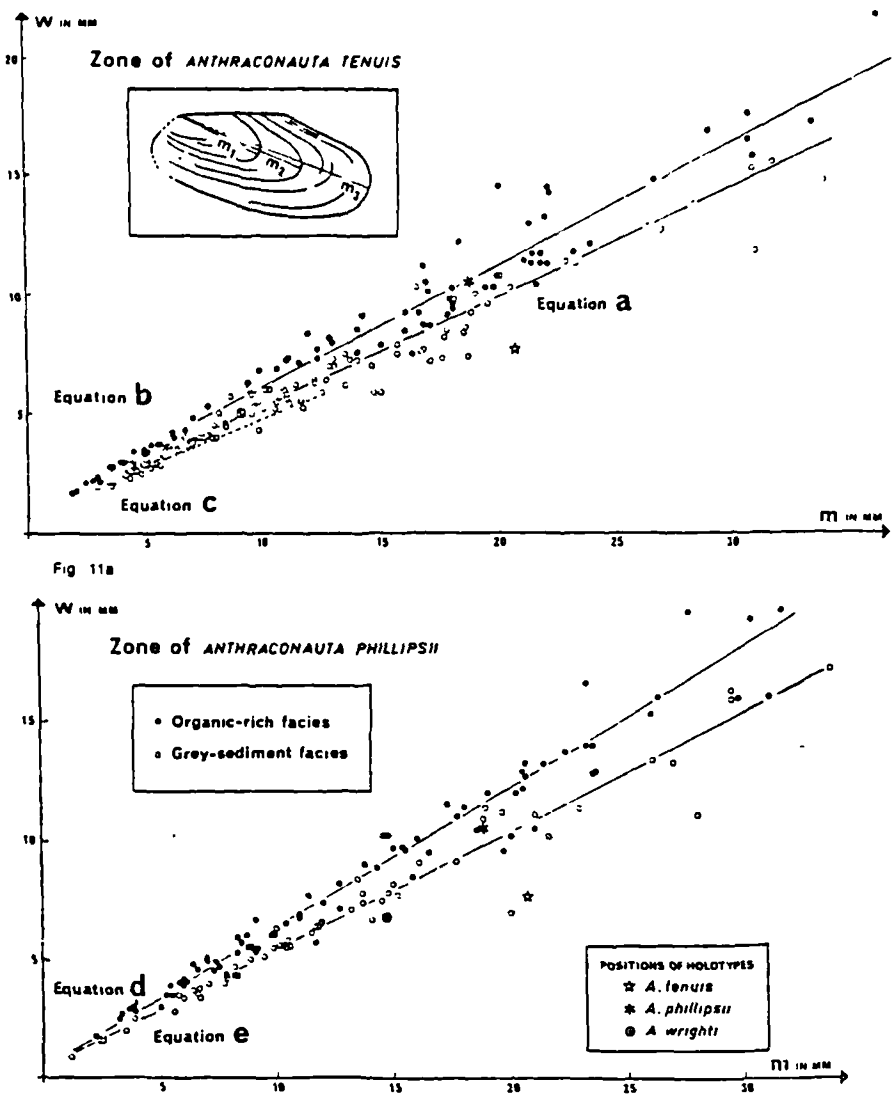


FIGURE 7.9: Eagar's fitted regression lines (Eagar 1973). Equation a - w=.457m + 0.71, equation b - w=.514m + 0.99, equation c - w=0.404m + 0. 77, equation d - w=0.6m + 0.23, equation e - w=0.499m + 0.39.

carbon-content of the enclosing sediment. However, in the El Bierzo coalfield, shells collected from a coarsening-upward sequence revealed a striking morphological change. A highly variable fauna in organic carbon-rich, fine-grained shales trended towards more broadly oval, less oblique forms through an increase in the anterior length of the shells, w/m, H/L and DM/L ratios, a decrease in the D/L ratios and greater development of the umbones (a trend also reported in Anthraconauta in the Sydney coalfield, see Vasey in prep. [1983], see also below).

7.2.4.3. Lingan faunas.

Figure 7.10 shows a coarsening-upward sequence of dark and pale grey silty shales and sandstones (N3-4.5) at Lingan in the Sydney coalfield (between the Harbour and Hub seams). The fauna occurs in the basal 1 m or so of the sequence which grades up into cross-bedded sands and is interpreted as a lake delta deposit. The basal 50 cm are dark grey, fine-grained silts with Anthraconauta spp. preserved as crushed shells lying parallel to bedding. Spat, juvenile shells and a few shelly fragments also occur. The dark grey silts grade up into pale grey, silty sandstones with thin bands of 'Estheria', ironstone and thin, cross-laminated sands. Preservation is as before but at least 30% of the shells were found with their anterior ends down into the sediment and their commisural planes subvertical. Two collections of shells were made from each of the lithologies.

Prior to analysis, a reduced major axis regression line was fitted to an H-L scatter of the two collections (cf. Eagar 1973). Figure 7. 11 shows the two lines and their respective equations. Shells in the paler-grey sediments tending to be smaller perhaps suggesting either stunting due to generalised environmental stress or, that the shells died sooner than usual.

Colour measurements were used as an environmental indicator

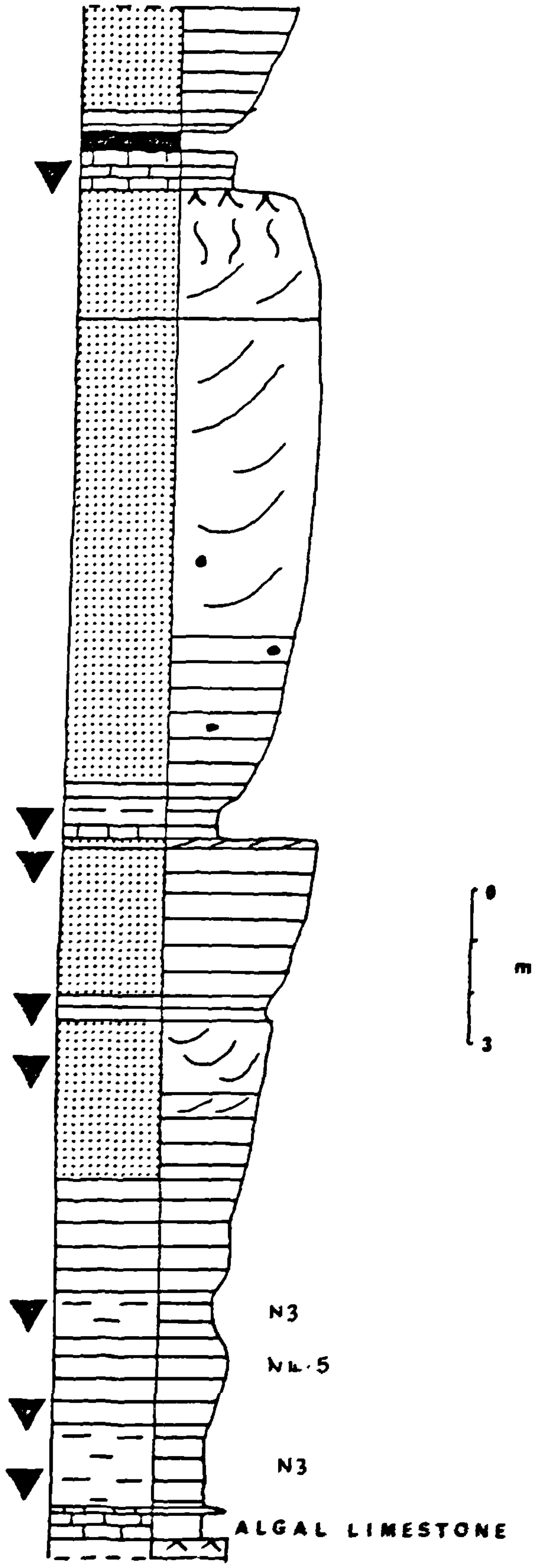
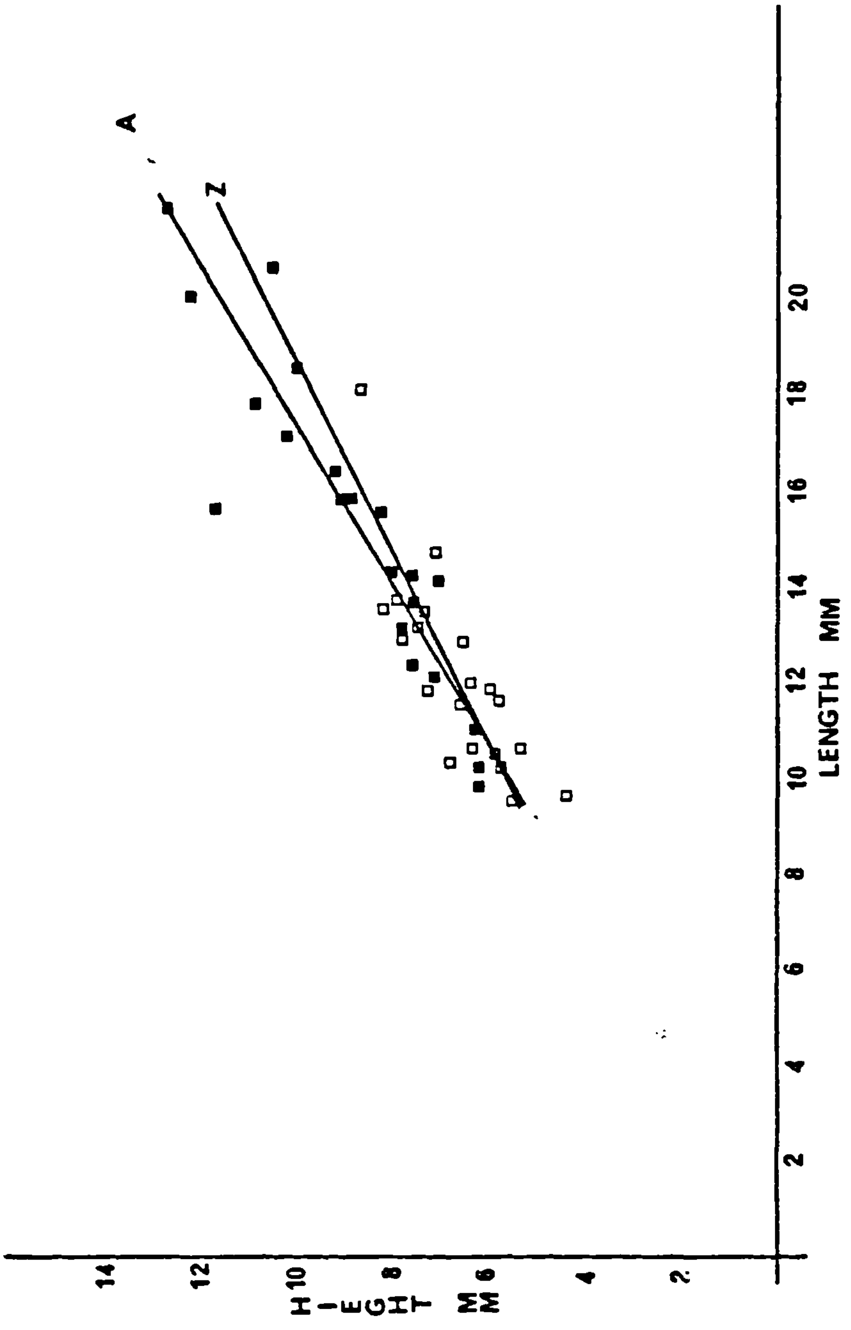


FIGURE 7.10: The Lingan section.

FIGURE 7.11: Regression lines fitted to two populations of *Anthraconauta* from Lingan. □ - shells from pale-grey sediments, ■ - shells from dark-grey sediments. Equation A - H=0.59L - 0.14, Equation Z (fitted to scatter of shells from the pale-grey lithologies) - H=0.49L + 0.76. R(A) = 0.92, R(Z) = 0.83.



as both the colour and the grain size of the sediments correlate highly (Table 7.9). Examination of the correlation chart shows that with increasing organic carbon-content, the A/L, DM/L, D/L, W/L and to some extent the H/L ratios all decrease. A PCA plot (Figure 7.12) shows that with increasing grain size and decreasing organic carbon-content, Anthraconauta becomes smaller, has a longer anterior end, diminished posterior end, a slightly greater H/L ratio, a shortened, straightened ventral margin and greater development of the umbones.

7.2.4.4. Faunas from above the Phalen seam.

Sixty-four measured shells collected from over 1 m of coarsening-upward muddy and silty shales were subjected to analysis. Colour values were again used as an environmental indicator. Unfortunately, the correlation between the measured shell dimensions and colour are quite low, though the H/L, DM/L, W/L and D/L ratios do display a relationship (Table 7.10) and all decrease with increased organic carbon-content.

PCA analysis, where 78.6% of the sampled variation was explained on the first three principal components, shows essentially the same trends (Figure 7.13), though they are not as definite as at Lingan. Thus, in paler grey lithologies shells tend to be smaller, with a longer anterior end, diminished posterior end, greater umbonal development with subparallel ventral and upper posterior margins. However, a wider range of morphological variation is observed in both the pale grey and dark grey sediments than at Lingan.

7.2.4.5. Summary and Discussion.

Figure 7.14 summarises the shell shape changes associated with palaeoenvironmental changes in the two Nova Scotian examples. The Lingan analysis provides field evidence to suggest

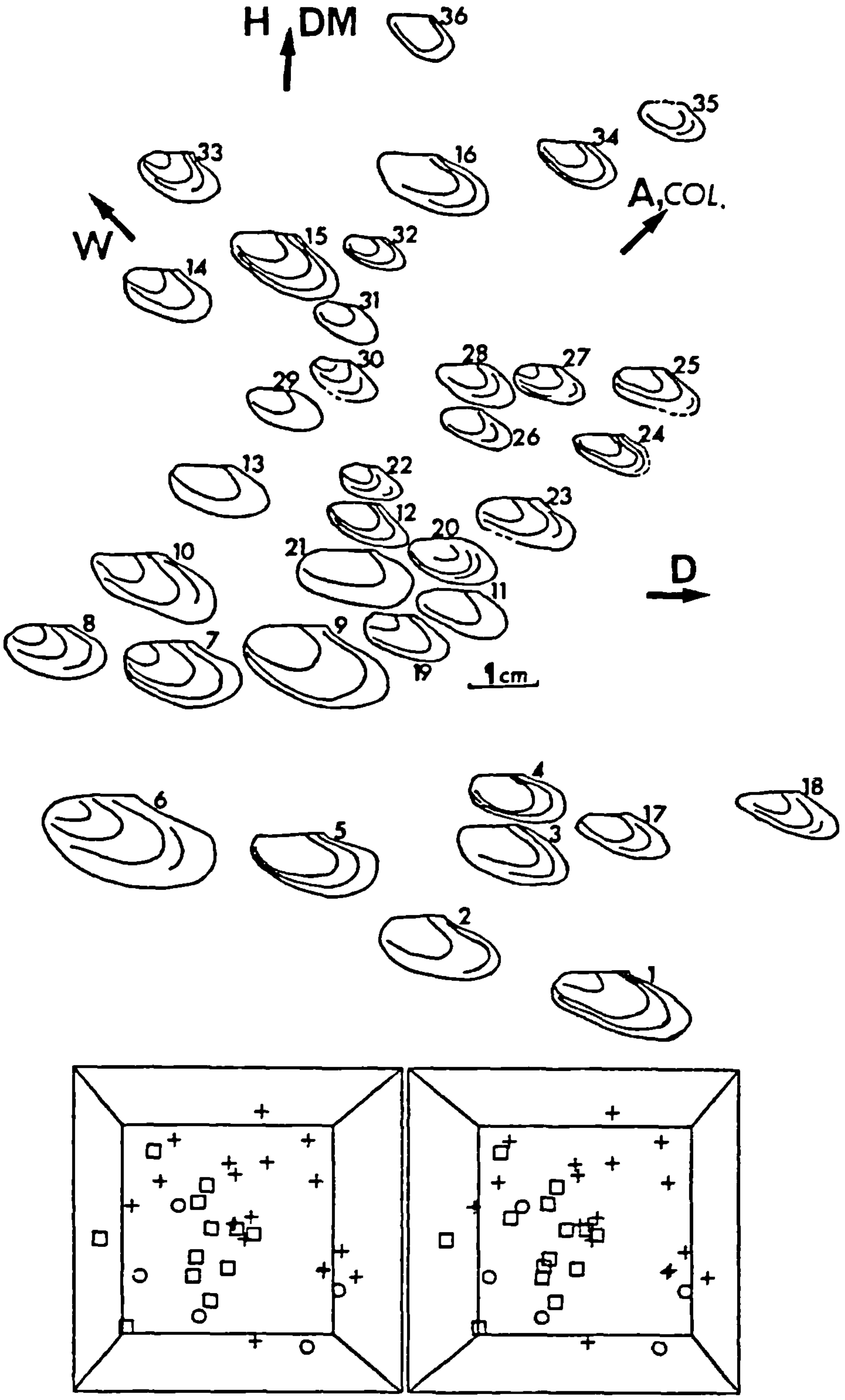


FIGURE 7.12: Morphological variation with changing colour of sediment in Anthraconauta spp. from Lingan. Stereo PCA plot of the same data.

TABLE 7.9: CORRELATION CHART AND PCA RESULTS, HARBOUR-HUB SEAM *ANTHRACONAUTA*.

	A/L	DM/L	D/L	W/L	COLOUR
H/L	0.24	0.36	0.04	0.54	0.15
A/L		0.35	0.18	0.12	0.43
DM/L			0.05	0.63	0.41
D/L				-0.28	0.15
W/L					0.17

PCA Results:

EIGENVALUES: 2.39: 1.40: 0.85: 0.63: 0.51: 0.22

Cum. Var. %: 39.9: 63,2: 77.3: 87.8: 96.3: 100.0

EIGENVECTORS:(Values greater than 0.3 used).

I :0.43H/L, 0.38A/L, 0.54DM/L, 0.03D/L, 0.48W/L, 0.38COL.

II :-0.18H/L, 0.43A/L, -0.04DM/L, 0.64D/L, -0.47W/L, 0.38COL.

III:-0.58H/L, 0.19A/L, 0.07DM/L, -0.62D/L, -0.56W/L, 0.48COL.

TABLE 7.10: CORRELATION CHART FOR THE PHALEN SEAM *ANTHRACONAUTA*.

	H/L	A/L	DM/L	D/L	W/L	COLOUR
H/L	-	0.47	0.31	0.26	0.76	-0.18
A/L	0.47	-	0.48	0.02	0.47	-0.04
DM/L	0.31	0.48	-	0.54	0.63	-0.26
D/L	0.26	0.02	0.54	-	0.05	-0.13
W/L	0.76	0.47	0.63	0.05	-	-0.20
COL.	-0.18	-0.04	-0.26	-0.13	-0.20	-

PCA results:

EIGENVALUES: 2.68: 1.09: 0.94: 0.65: 0.52: 0.12

Cum. Var. %: 44.7: 62.9: 78.6: 89.3: 98.0: 100.0

EIGENVECTORS: (Values greater than 0.3 used)

I : 0.5H/L, 0.43A/L, 0.46DM/L, 0.13D/L, 0.54W/L, -0.21COL.

II : 0.11H/L, -0.32A/L, -0.14DM/L, 0.77D/L, -0.11W/L, -0.51col.

III: 0.31H/L, 0.18A/L, -.31DM/L, 0.47D/L, 0.00W/L, 0.75COL.

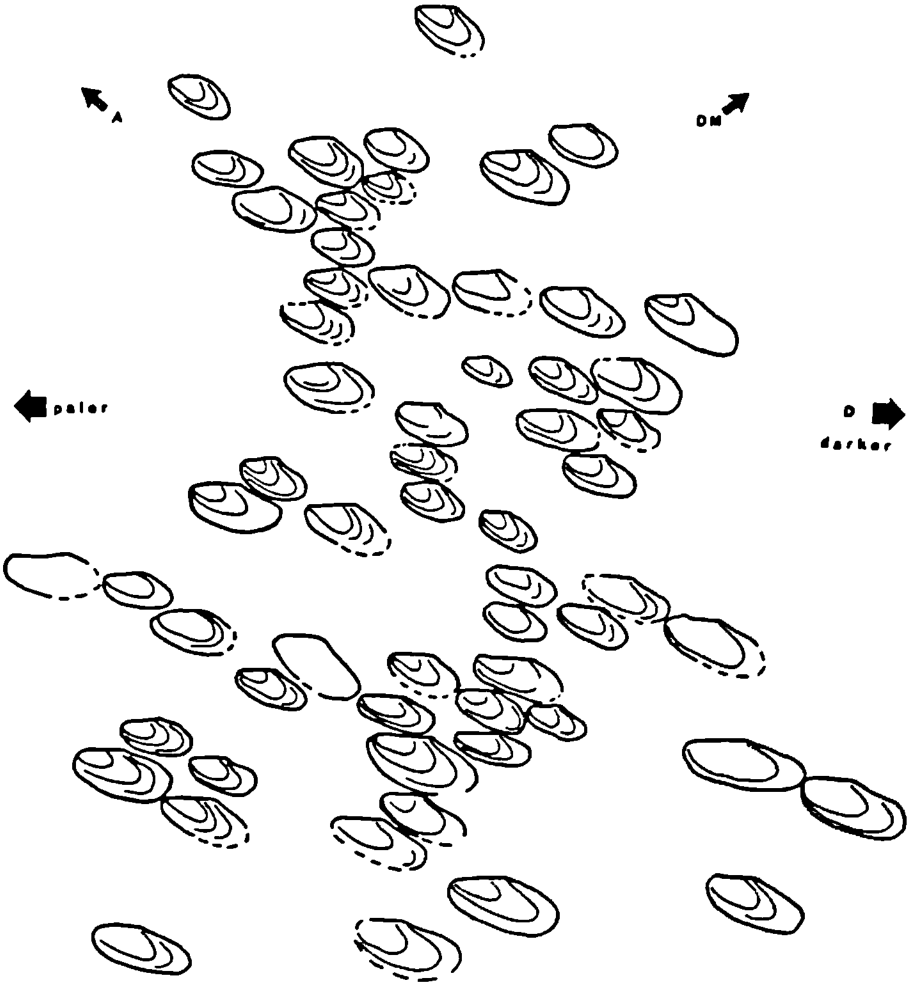
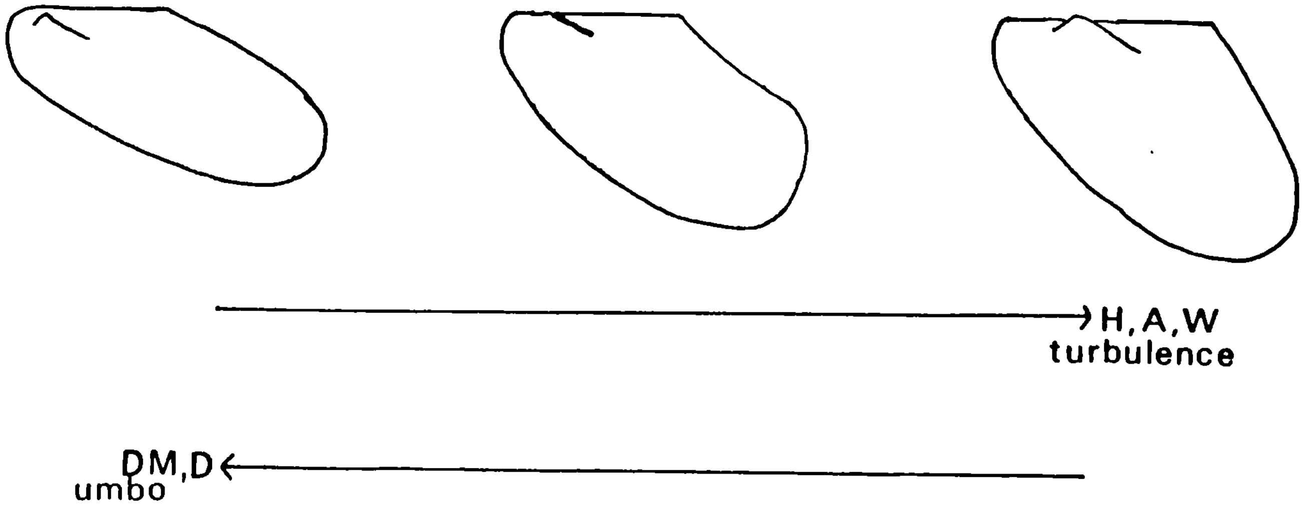


FIGURE 7.13: Morphological variation with changing colour of sediment in Anthraconauta spp. from above the Phalen seam.

FIGURE 7.14: Summary of morphological changes with changing environments in *Anthraconauta*.



that these morphological changes were accompanied by a change in living position such that an epifaunal, mud-dwelling mode of life under eutrophic conditions was abandoned in favour of a semi-infaunal, anterior end down position under turbulence. The results of this work also contrast with that of Eagar (1973) and in part, with that of Eagar (in prep. [1983]) in that Anthraconauta trended towards more elongate shapes (lower H/L ratios) in Eagars' pale grey sediment facies (although Eagar's work did not deal with grain size. However, the behaviour of these Nova Scotian shells closely parallels that of those from the El Bierzo coalfield in Spain.

Of potential stratigraphic value is the tendency for both the modification of living position and of shell shape under more turbulent conditions to result in shells of the A. calveri group, more subovate variants of the A. phillipsii group and occasionally, A. sp. cf. A. wrighti (see also Eagar in prep. [1983]). Elongate shells such as A. tenuis and variants occur in lithologies indicative of more eutrophic conditions.

Eagar (1973) also showed that the morphological changes observed in both the Phillipsii and Tenuis Chronozones of Britain in both the pale-grey and dark-grey sediment facies were essentially the same and commented that this may help in explaining the difficulties experienced by stratigraphers in determining the Phillipsii/Tenuis Chronozone boundary (see also Cleal 1984).

7.2.5. Anthraconaia.

The genus Anthraconaia as defined by Weir (1966), contains several distinct morphological groups which may ultimately be separated out and assigned to new genera. Indeed, recently Eagar (in press [1979]) suggested that if more were known about the hinge of certain Stephanian shells, it might be possible to assign them to a new genus.

The adamsii/modiolaris deep-bodied forms of the British upper Westphalian A to lower C tend to occur occasionally separately (and are absent in Nova Scotia). The elongate shells characteristic of the later Westphalian of Britain and the Stephanian of the Appalachians, Spain, Germany (Eagar 1975, in press [1979], in prep. [1983] and Eagar et. al. 1983), tend to be associated with escape shafts and near-marine faunas. These shells were probably invaders in a similar way to the early cf. Sanguinolites and Carbonicola faunas (Eagar 1977a, in prep. [1983]). Thirdly, a group of small, anthracosiid-like shells also occur, often associated with the elongate group in the late Silesian strata of the Appalachians, Spain and Germany (Eagar 1975, in press [1979], in prep. [1983]).

In Nova Scotia, two groups of Anthraconaia of contrasting external (and internal?) morphology occur. The elongate Anthraconaia arenacea group occur in Westphalian D strata of both the Sydney and Pictou coalfields, whilst the small-shell group are recorded from several horizons in the Westphalian D - Cantabrian? of the Sydney coalfield.

7.2.5.1. Shell shape variation in some American faunas.

Eagar (1973, pp. 394-8) used the fitted regression line technique to analyse collections of shells provisionally assigned to Anthraconaia from the Hance Formation of the Appalachians. Essentially the same results were obtained in these analyses as with the British Anthraconauta (see below, Eagar 1973, pp. 399-404). Shells proved to have a greater w/m ratio in the organic carbon-rich facies. Similar results were obtained in analyses of Stephanian and 'Autunian' assemblages of Anthraconaia from the same area (Eagar 1975).

7.2.5.2. Faunas from the above the Backpit seam of the Sydney coalfield.

This single analysis of Anthraconaia in Nova Scotia using forty one measured shells from above the Backpit seam revealed some well-defined shell shape trends. A colour measure was used as an environmental indicator, as grain size and colour of the sediment correlated at 0.92 (Table 7.11). From this correlation chart, it may be seen that these shells display increases in the H/L, HMA/L, A/L and Z /L ratios and a decrease in the HH/L ratio with increasing organic carbon-content of the enclosing sediments. A PCA analysis, where 80% of the sampled variation was explained on the first three principal components, reveals essentially the same trends (Figure 7.15). Thus, with increasing grain size and decreasing organic carbon-content, shells tend to be more elongate with shorter and lower anterior ends.

7.2.5.3. Summary and discussion.

Further analyses were not run as there was little or no measurable variation in lithology.

A. arenacea group faunas are limited to coarse-grained, pale grey lithologies and analysis of the faunas above the Backpit seam shows these shells approach A. arenacea and variants in such coarser lithologies. By contrast, the small often anthracosiid-like shells, tend to occur in the finer, darker grey horizons. It should also be said that these small-shell varieties also tend to occur in fine-grained carbonate sediments.

The elongate shells typical of coarse-grained, pale grey lithologies may be termed invading faunas, characterising the upper parts of lake delta sequences. Some of the more subovate faunas characteristic of dark grey, fine-grained lithologies such as those of Glace Bay, may be termed established faunas.

TABLE 7.11: CORRELATION CHART AND PCA RESULTS, BACKPIT-BOUTHILLIER INTERVAL *ANTHRACONAIA*.

	A/L	HMA/L	HH/L	Z/L	COLOUR
H/L	0.59	0.72	-0.15	-0.02	-0.43
A/L		0.47	-0.28	-0.20	-0.41
HMA/L			-0.11	-0.20	-0.30
HH/L				0.08	0.23
Z/L					-0.21

PCA RESULTS:

EIGENVALUES: 2.59: 1.19: 0.99: 0.55: 0.45: 0.23

Cum. Var. %: 43.1: 62.9: 79.4: 88.6: 96.3: 100.0

EIGENVECTORS: (greater than 0.3 used).

I : o.54H/L, 0.5A/L, 0.49HMA/L, 0.23HH/L, -0.09Z/L, -0.39COL.

II : 0.04H/L, -0.10A/L, -0.18HMA/L, -0.02HH/L, 0.84Z/L, -0.51COL.

III: 0.28H/L, -0.10A/L, 0.33HMA/L, 0.88HH/L, 0.13Z/L, 0.10COL.

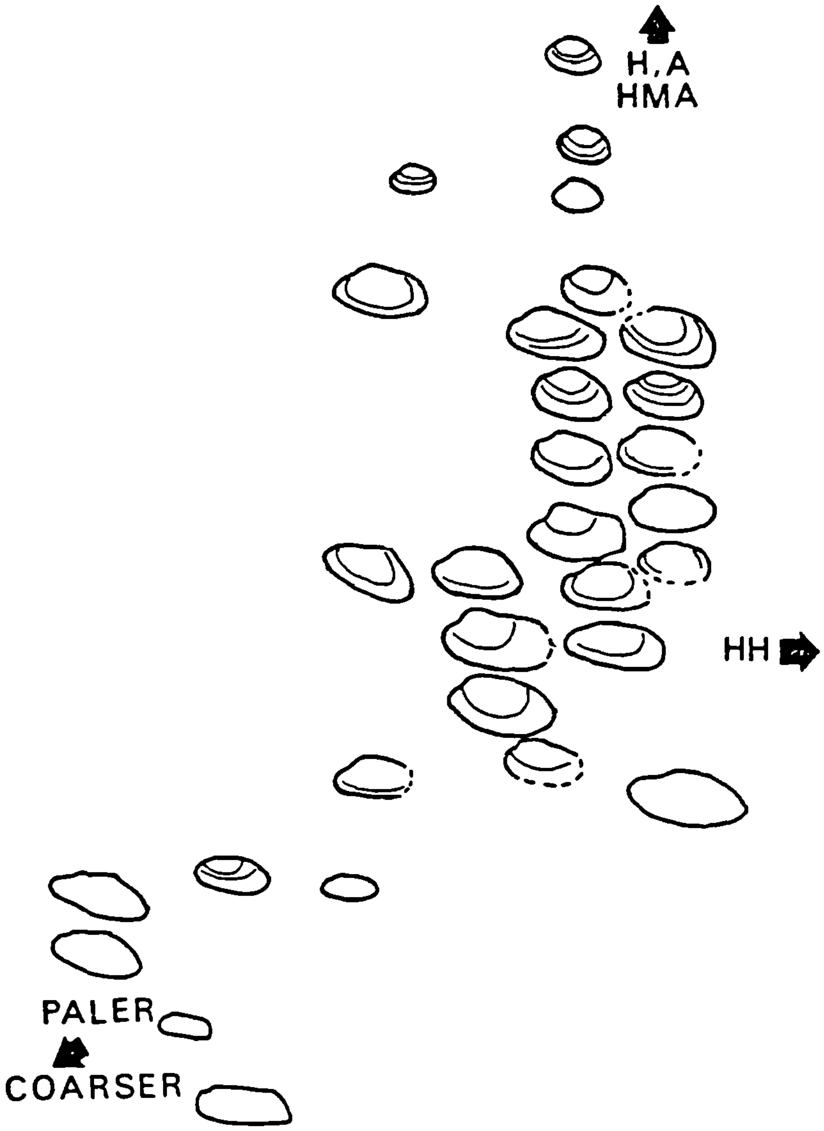


FIGURE 7.15: Morphological variation in Anthraconaia spp. from between the Backpit and Bouthillier seams with changes in colour and grainsize of the sediment.

7.2.6. Shell shape and function.

The shell shape changes observed in established faunas of Anthraconauta, Naiadites and the small-shell group of Anthraconaia can be explained functionally in terms of increased specific gravity. As pointed out by Eagar (1977b), the soft parts of a bivalve weigh very little more than water and the specific gravity of a bivalve is governed almost wholly by the weight of the shell. Under conditions of increasing turbulence, the shells may have tended to change their mode of life from an epifaunal living position to an anterior-end down, semi-infaunal position. This supposed change of living position is accompanied by increased length of the anterior end, diminished posterior length and expansion, shortening and straightening of the ventral margin and greater development of the umbones. Thus, both the external morphological changes and the required change in living position are compatible with greater stability through increased specific gravity and a shift of the centre of gravity towards the antero-umbonal region (Figure 7.16). In addition the substrate is used as an anchor in the semi-infaunal living position.

In contrast, the broadly subovate shell shape characteristic of low energy, highly eutrophic environments offers advantages in terms of a greater obesity to prevent sinking in the soft substrate. The small size of shells in a turbulent environment may also be related to decreased food supply and generalised environmental stress or a shorter life span.

Such changes in shell morphology may be a function of spat selection such that the lighter spat are washed away under conditions of more turbulence (Eagar 1978, p. 190). However observations by both Grier & Mueller (1926) and by Baker (1928) suggest that changes in shell shape of some river anodontid species is phenotypic (see Eagar 1978, p.191). It is highly probable that both of these factors were active in the

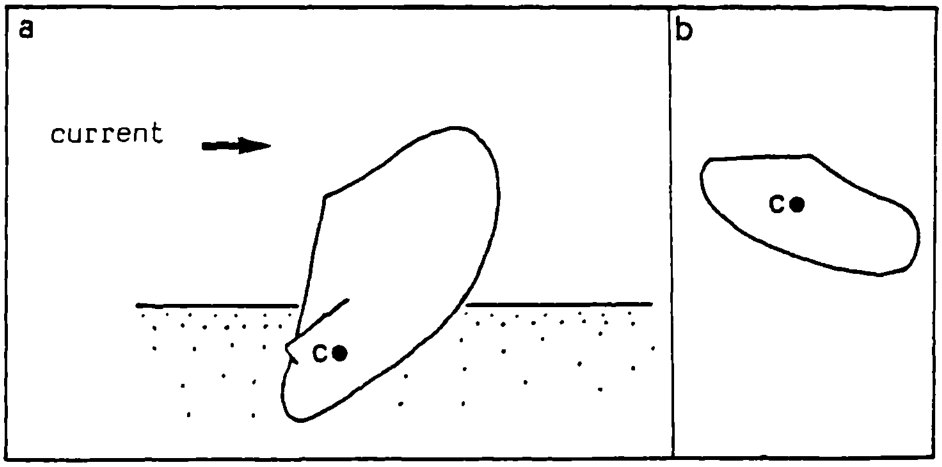


FIGURE 7.16: Diagrammatic representation of supposed mode of life and shape of Anthraconauta under turbulent conditions (a). Shell shape changes and the generally heavier shell provide greater stability for a semi-infaunal mode of life. C - Approximate centre of gravity of the shell.
(b) An Anthraconauta from a more eutrophic, calmer environment. Note the longer posterior part, shorter anterior end, low umbones and lower H/L ratio. In these more eutrophic conditions the shell may have lived on one valve on the muddy substrate or may have employed a ploughing mode of life. The centre of gravity in this shell shape would be more subcentral.

Westphalian; phenotypic changes are certainly suggested through the existance of obvious changes of growth direction observed in some shells.

7.3. Generic changes with palaeoenvironment.

The tendency for a shell band to yield only one genus is well known (e.g. Eagar 1947, Broadhurst 1959, Calver 1968a). In these cases it may be inferred that some limiting factors operative in the palaeoenvironment restricted the faunas. Typically invading faunas occur without associated fauna and in this case, turbulence and high sedimentation rates restricted the fauna to bivalves which by virtue of their morphology, were functionally adapted to steep, rapid burrowing and upward escape. When bivalves occur with associated ostracodes then some information can be obtained about the palaeoenvironment. Thus Curvirimula which in Britain is often associated with near-marine bivalves and ostracodes, can be inferred to have tolerated greater salinity than the other genera.

In the intracontinental coal-forming environment of Nova Scotia, marine influence is unrecorded, though the abundance of pyrite in some dark shales and some coals suggests that there was a sulphate source to be reduced. The underlying marine Windsor Group often contains evaporitic sequences and these may have been a possible sulphate source either through erosion of a Windsor Group hinterland (cf. Masson & Rust 1983) or through circulating leaching groundwaters. Of these two possibilities the latter seems to be the most likely as diagenetic dolomites quite frequently occur in the limestones of the Morien Group whereas evaporite minerals or their pseudomorphs that might be expected to form during evaporational episodes, are entirely absent from the Westphalian lake sediments (Vasey & Zodrow 1983). However, if circulating groundwaters were occasionally slightly saline then a small degree of salinity as a limiting factor acting on the non-marine faunas cannot be entirely ruled out. The only reported occurrence of the brackish ostracode Geisina sp. in association with Curvirimula at Port Hood tends to support this argument.

The range of morphological variation and hence the number of reported morphological varieties in Nova Scotia is quite small. Typically, Naiadites faunas are dominated by the N. carbonarius-productus group and the limited variation towards N. subtruncatus and N. sp. aff. N. triangularis may be explained in terms of local environmental influence.

Information regarding the limiting factors acting on Nova Scotian non-marine bivalve faunas can be obtained through a study of the faunal constituents of various shell beds and their respective lithologies. Certain genera appear to display a relationship in terms of their relative abundance and the lithology of the shell bed in which they occur.

7.3.1. Limiting factors and possible mode of life of Naiadites and Curvirimula.

The shell beds of the Riversdale and Cumberland Groups predominantly contain representatives of both these genera. However, in these beds a distinct relationship is observed between the genera such that one or other of them predominates in a particular faunal phase. Two good examples of this occur in the Cape Linzee section of Port Hood. In horizon PHa, three distinct faunal phases are observed, Naiadites dominating the fauna in the coarser and paler upper and lower parts of the bed (Figure 7.17). Curvirimula dominates the calcareous, darker muddy middle phase (see also Eagar 1974, p.236). In horizon PHe, two phases occur where in the basal pale grey silty shales Naiadites is dominant and in the upper, finer-grained, darker phase Curvirmula is the dominant form.

A similar relationship was observed in the Joggins section

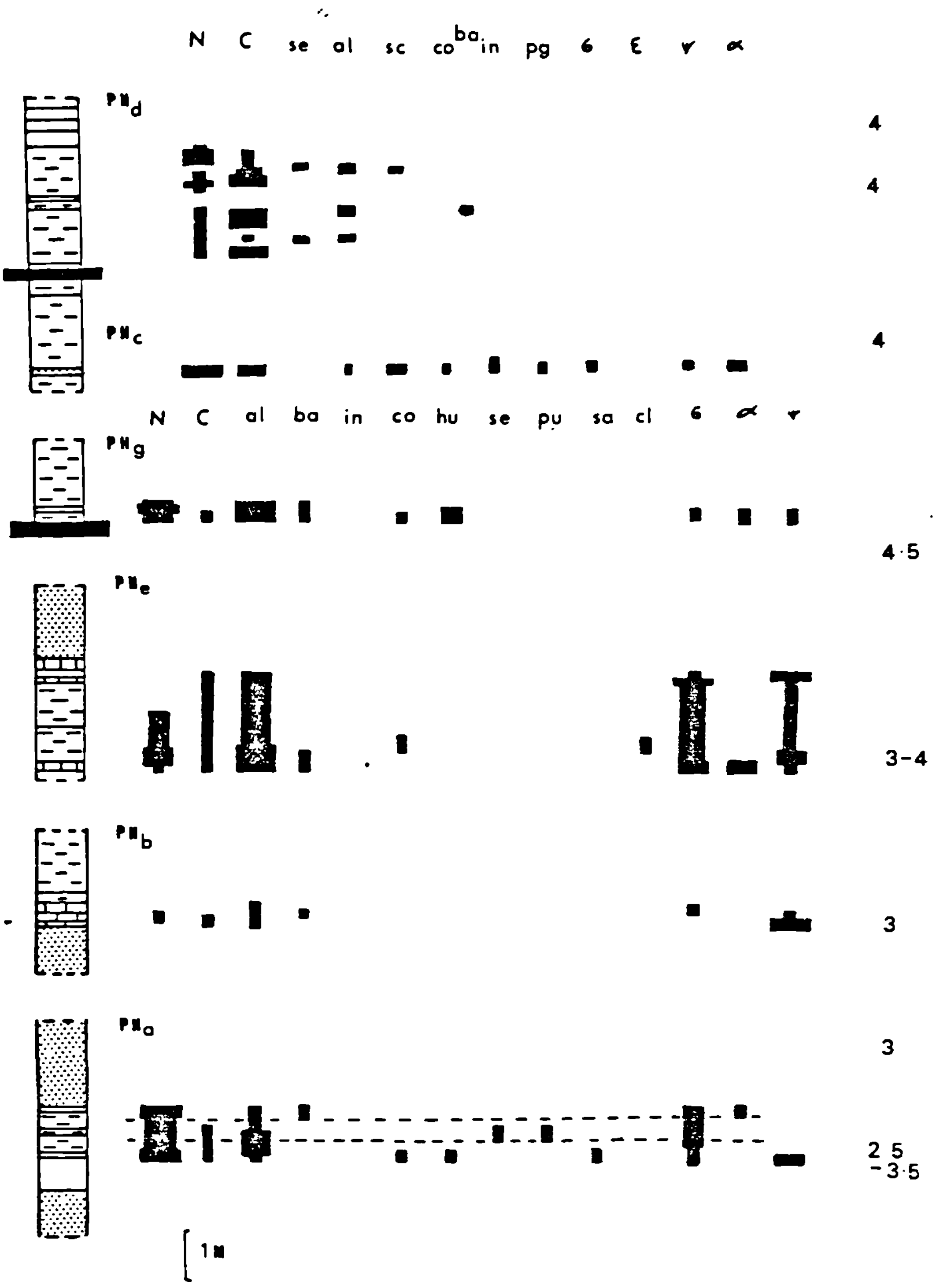


FIGURE 7.17: Curvirimula-Naiadites faunal phases at Port Hood.

where Curvirmula enters a shell bed directly above the coal in calcareous fine-grained mudrocks. Naiadites enters the shell bed later and gradually increases in abundance at the expense of Curvirimula as the lithology coarsens and becomes carbonate-poor.

Certain differences in the associated faunas are also observed in these two phases such that apart from the occurrence of the ubiquitous Carbonita altilis, thin-shelled forms dominate the Curvirimula phase and thick-shelled forms dominate the Naiadites phase.

Naiadites occurs as the sole non-marine bivalve genus in paler grey and coarser lithologies often without associated fauna, though Spirorbis sp. often occurs both attached to the substrate and to the posterior lobes of the bivalves. Turbulence and thus, oxygenation is indicated by many of the shell beds through both disarticulation and fragmentation of the shells, and the predominance of juveniles over adults.

At Parrsboro, the abundance of trace fossils such as Planolites montanus Richter (Pollard, pers. comm., 1984), a group of small, backfilled feeding burrows possibly made by a small arthropod, rain pits and desiccation marks occur indicating somewhat shallow and ephemeral non-marine conditions existed (Calver 1968a).

The Riversdale Group Naiadites shell beds are marked by their occurrence in the floodplain facies bearing no direct relationship to coal seams. However, in the higher parts of the Cumberland Group, Naiadites faunas occur both in close association with coal seams and in the darker, finer-grained lithologies indicating perhaps that Curvirimula had been displaced by Naiadites or had died out.

Curvirimula occurs only rarely as the sole bivalve in shell beds of the Riversdale Group. Such horizons are characterised by dark grey, organic carbon-rich, fine-grained lithologies. Plant material and pyrite both occur and pyrite replaces shell material in these beds. Pyrite occurring as finely disseminated material is common. The associated faunas comprise Gutschickia sp., Carbonita spp. including C. altilis, thin-shelled forms, estheriids and in the Curvirimula corvosa horizon, Pygocephalus sp. Above the six-foot seam of Port Hood, Geisina sp. also occurs.

7.3.1.1. Naiadites.

These and the earlier observations strongly suggest that Naiadites was a byssally attached epifaunal or shallow-burrowing form. A preference for shallow, well oxygenated bottom waters and firm substrates is indicated. Certain inequivalved forms (notably the broader, more subovate varieties) were probably epifaunal and may have rested on one valve (see earlier) whilst equivalve forms such as Naiadites subtruncatus, probably had a semi-infaunal mode of life. There is no unequivocal evidence for Naiadites having had a pseudoplanktonic mode of life (e.g. see Calver 1968a, Bless & Pollard 1973) as the shape of the shell of Naiadites appears to be governed by local palaeoenvironmental factors. The genus was freshwater.

7.3.1.2. Curvirimula.

Curvirimula seems to have tolerated oxygen deficiency of the bottom waters. This is indicated through the nature of the dark grey and also carbonate-rich litholcgies in which it often occurs. In such an environment low current activities and sedimentation rates are indicated. The thin shell and elongate morphology characteristic of Nova Scotian Curvirimula would be admirably suited to both a pseudoplanktonic or to an epifaunal mode of life, providing a degree of buoyancy. The occurrence of *Curvirimula* as the sole bivalve in shell beds where oxygen deficiency of the bottom waters may be inferred, tends to support the possibility that this genus had a pseudoplanktonic mode of life. *Curvirimula* probably floated through byssal attachment to plant debris (cf. Eagar in prep., [1983]). Associated faunas tend to support this hypothesis comprising several forms for which a planktonic mode of life could also be suggested.

In an environment where the bottom waters were anoxic, fauna would be limited to death assemblages of pseudoplanktonic and planktonic organisms. However, if *Curvirimula* were a 'floater', a wider distribution might be expected. That this is not so may be related to the thin and delicate nature of the shell such that dead *Curvirimula* falling into a turbulent substrate would be rapidly destroyed. In addition, depth would prove to be a further factor governing the distribution of *Curvirimula* such that shells would not be preserved in shallow and turbulent water environments.

The occurrence of *Curvirimula* associated with *Geisina* and estheriids (Calver 1968a) suggests that *Curvirimula* was tolerant of some salinity: A hypothesis supported by the presence of pyrite in the lithologies of several *Curvirimula*-bearing horizons. The occurrence of slightly brackish water was possible in Nova Scotia for the reasons given above. However, in agreement with Eagar (1970), I consider *Curvirimula* in Nova Scotia probably occupied a fresher water environment than it did in Britain and in the USA.

7.3.1.3. Summary.

The distribution of both *Naiadites* and *Curvirimula* can be explained in terms of their mode of life and their limiting palaeoecological factors. Naiadites inhabited shallow, ephemeral floodplain lakes subject to turbulence and periods of heavy sedimentation. Occasionally, Naiadites moved into the deeper lakes which followed peat-formation. Curvirimula was probably a pseudoplanktonic form tolerant of a wide range of conditions though limited in terms of its distribution by preservational factors.

In shell beds where both genera occur, Curvirimula enters first as Naiadites, a benthonic form, was unable to tolerate oxygen deficiency and/or the soft fine-grained substrates which probably clogged its siphons. These initial phases of lake formation were suited to the preservation of floating Curvirimula. In a subtropical climate, evaporational episodes associated with the initial lake forming phase may also have led to some salinity, an additional limiting factor acting on Naiadites. The increased abundance of Naiadites reflects both increasing turbulence and oxygenation of the bottom waters and in later stages, perhaps shallowing. Under these conditions, the thin-shelled Curvirimula were possibly more liable to destruction.

7.3.2. Limiting factors and possible mode of life of Anthraconauta and Anthraconaia.

Two distinct groups of Anthraconaia were recorded from the Pictou/Morien Group and these two groups are recognisable in terms of both their external morphology and their relative distribution. The elongate Anthraconaia arenacea group occurs in pale grey, coarser lithologies and may occasionally occur with Anthraconauta. By contrast, the small-shell group are limited to thin, discrete fine-grained beds and appears to be mutually exclusive with Anthraconauta. Anthraconauta more usually occurs as the only non-marine bivalve in a bed and characterises coarsening-upward lacustrine sequences.

In both the Sydney and Mabou coalfields, Anthraconauta is the dominant bivalve and exhibits a wide range of variation in shell shape, part of which has already been explained functionally. Anthraconauta also occurs in a wide range of lithologies from silty cannels to pale grey, fine-grained sandstones. It never occurs in muddy cannels, organic carbon-rich, pyritiferous mudstones or in micrites. At the extreme ends of its range, increased turbulence and heavy sedimentation evidently caused it to disappear.

Typically, Anthraconauta occurs abundantly in the basal finer-grained and darker parts of a coarsening-upward sequence. Here the associated fauna includes a range of ostracodes dominated by Carbonita evelinae, Spirorbis sp. attached to the posterior parts of shells, and occasionally estheriids. Anthraconauta is usually represented by A. phillipsii, attenuated variants and A. tenuis. As the lithology coarsens, the organic carbon content of the lithologies decreases and the abundance of the fauna decreases. The bivalves tend towards shell shapes which can be inferred to have been more stable such as A. calveri sp. nov. and forms referable to A. wrighti s.l. The associated fauna usually comprises sparse ostracodes and occasional Leaia spp. At the coarsest end of its range, Anthraconauta may be joined by invading faunas of Anthraconaia arenacea.

The small-shell group of Anthraconaia tend to occur in two distinct lithlogies here referred to as the Anthraconaia facies A and B. Facies A comprises carbonate-rich lithologies where clastic sedimentation and current activity were low such that the bottom waters may have been prone to oxygen deficiency. Facies A may be recognised whether or not the bivalves are present (e.g. the Algal Limestone of Lingan and cf. also Eagar 1975, fig. 9, which shows similar facies in the Dunkard Group of the Appalachians).

Facies B comprises dark grey (N2-3) mud and clay shales. Pyrite is common in these beds replacing both shell material and as finely disseminated material.

Certain differences consistently occur in the associated ostracode faunas of both these facies, and between these facies and the *Anthraconauta* facies. In facies A the dominant ostracode is usually *Carbonita bairdiodes* with subordinate *C. evelinae*, *C. humilis* and *C. inflata*. The ostracode fauna of facies B usually comprises *Carbonita evelinae*, *C. pungaens* and *C. secans* (Figures 6.19 and 6.22)

7.3.2.1. *Anthraconauta*.

Anthraconauta was able to tolerate a wide variety of substrate types and a wide range of conditions by virtue of morphological adaptability. The genus was however limited at one end of its range by too much turbulence and at the other end of its range by oxygen deficiency and extremely fine-grained substrates. It was probably epifaunal possessing a simple mud dwelling habitat. Too fine-grained substrates probably clogged up it siphons. Increased turbulence led to a change in living position in which the anterior end lay in a burrowing position with relatively increased weight also to the anterior. The increased weight was probably related to spat selection such that smaller but proportionally heavier spat were favoured.

7.3.2.2. The *Anthraconaia arenacea* group.

A. arenacea can be inferred to have had a steep-burrowing living position (cf. Eagar 1977a, 1978) and invaded relatively turbulent environments and firm substrates. There is evidence to suggest that competition may have been a factor governing its distribution as in the Pictou coalfield where *Anthraconauta* is rare. Anthraconaia arenacea occupied organic carbon-rich, finer-grained environments (see also section 7.3.2.4. below).

7.3.2.3. The small-shell group of Anthraconaia.

The small-shell group occupied peripheral and probably ephemeral lacustrine environments that can be inferred to have been both local in extent and of low energy. Such environments were prone to oxygen deficiency and possessed very soft substrates. The small size and the general shell shape of this group of probably quite tumid bivalves reduced the possibility of sinking into the soft substrate. Increased sedimentation rates and turbulence led to their replacement by Anthraconauta.

7.3.2.4. Summary and discussion.

In the Morien/Pictou Group, communities of Anthraconauta, capable of colonizing a wide range of environments within a lacustrine setting were probably the major biotic factor limiting on communities of Anthraconaia. Thus competition is considered as being of great importance. Anthraconaia was inferentially only able to enter and flourish in an environment in which Anthraconauta could not survive. Such environments included lake deltas were turbulence was too great and sedimentation too heavy, and low energy environments. It is interesting to note that each of the two groups of Anthraconaia appear suited in terms of their external morphology for their respective environments.

7.4. Biostratigraphy and correlation.

Tentative correlations based on homotaxy have already been given for the various localities examined. However, several of these give conflicting ages when the correlation is based on more than one genus. Secondly some of these correlations are in marked disagreement with the results of the floral and microfloral work. This apparent paradox can now be explained in the light of the preceding sections of this Chapter.

7.4.1. Evolution in a continental setting.

The Late Namurian - early Stephanian of Nova Scotia is marked by the conspicuous absence of marine incursions and also by a lack of progressive environmental change, two factors which are considered here to be of much importance in influencing the evolution of these bivalves in Britain and elsewhere.

In Nova Scotia, a third factor, that of local environmental influences, appears to be the only operative factor. Local and apparently short-lived changes in the Nova Scotian faunas are considered to occur in response to such environmental changes. Variation in *Naiadites*, *Carbonicola*, *Curvirimula* and *Anthraconauta* is quite limited especially when compared to that observed in their British equivalents (see Trueman & Weir 1946).

7.4.1.1. *Carbonicola*.

Carbonicola is very rare in Nova Scotia as compared with its great diversity and abundance in Britain. Furthermore, *Carbonicola* is unreported from both the Appalachians and also from Spain (Eagar 1970, 1973, 1975, in press [1979], in prep. [1983], Eagar & Weir 1971). Other anthracosiid genera are presently unrecorded outside of the North European area.

Nova Scotian *Carbonicola* are comparatively much smaller than the British forms, suggesting perhaps that conditions in Nova Scotia were not entirely suited to it. Exactly why this should be is difficult to assess with any certainty as records of

Carbonicola in Nova Scotia are rare and the assemblages mainly poorly preserved. However, it would seem from the sparse records of this genus in the Canso Group (Rogers 1965), that elongate and often anthraconaiaoid stocks of Carbonicola invaded Nova Scotia in upper Namurian to Lenisulcata Chronozone times (i.e. very soon after its evolution in the prograding deltas of the Pennine area of Britain - Eagar 1977a). Weir (1969) suspected that Britain and the Pennines in particular, was the centre of dispersal of the Anthracosiidae, a suspicion that Eagar (1977a, in prep. [1983]) has been largely able to confirm. However, although the 'invasion' of Nova Scotia is certainly comparable to that of the Pennines (Eagar 1977a), two points require consideration:-

a. There is no evidence either documented elsewhere, or brought to light by this study of actual invasion (i.e. upward escape shafts etc.).

b. There is no marine or near-marine ancestral form (such as cf. Sanguinolites in the Pennines) from which the Nova Scotian Carbonicola could have evolved.

It is considered more likely that the invasion of the Pennine area by marginally marine stocks which evolved into Carbonicola, extended into the less favourable Nova Scotian environments.

The first invading stocks were later able to occupy lower energy, eutrophic environments in Nova Scotia as such established faunas as C. sculponeata Rogers and the younger C?. eagari sp. nov. suggest. Conditions were however, never quite right (perhaps due to the absence of marine incursions and the generally lower salinities in Nova Scotia) for the continued evolution and dispersal of Carbonicola and it was unable to dominate the Nova Scotian faunas as it did those of Britain. Interestingly, this hypothesis suggests that there was a geographical 'link' between Nova Scotia and NW Europe in the late Namurian - early Westphalian, but not between Nova Scotia and the Appalachians (see

Chapter 8).

The evolution of *Anthracosphaerium* in Britain probably occurred more than once, through isolation of stocks and clines of *Carbonicola* during marine incursions (Eagar 1973) in mid-Communis Chronozone times (Calver 1968a,b). Later, populations of established faunas of *Carbonicola* with incipient *Anthracosia* (cf. with the *C?. eagari* fauna) developed and Eagar (1973, p.410) tentatively suggested that the *Carbonicola* faunas were drowned during transgression wheras *Anthracosia*, which was smaller and more adaptable, had probably worked its way sufficiently far up the delta to avoid a similar fate.

Without the catastrophic effects of marine incursions in Nova Scotia, *Anthracosphaerium* failed to evolve. However, the *C?. eagari* sp. nov. fauna of Boss Point contains certain variants with forwardly tilted umbonal growth lines suggestive of *Anthracosia* (see systematic part of this Thesis), and it is possible that, as in Britain, stocks of *Carbonicola* with incipient *Anthracosia* were beginning to evolve in Nova Scotian established faunas in the early part of the Modiolaris Chronozone. The absence of marine incursions probably resulted in both the termination of this trend and in the eventual disappearance of *Carbonicola* altogether.

Stratigraphically, the invading faunas of the elongate *C?. angulata* group are homotaxially correlative with similar forms in the British uppermost Namurian and Lenisulcata Chronozones. The *C?. eagari* sp. nov. faunas are, as already established, closely comparable to basal Modiolaris Chronozone forms of Britain. The apparent trend towards *Anthracosia*-like shells in this population tends to lend support to this correlation.

7.4.1.2. *Naiadites*.

Naiadites was probably derived from a near-marine or euryhaline myalinid such as *Myalina* in Britain, and Trueman & Weir (1955, p.215) suggested that this may have occurred more than once (cf. also Eagar in prep. [1983). Newell (1942) examined the type specimens of both *Naiadites* and *Myalina* and concluded that, although they were closely similar, there were consistent differences between them. The early British forms *Naiadites crassus* and *Naiadites obesus* appear to have occupied a more saline habitat than the later representatives of this genus (Bennison 1961, Calver 1968a) perhaps indicating that these earlier forms were the brackish intermediates between *Myalina* and *Naiadites* or, that they represent a different genus altogether.

Naiadites is first recorded in Nova Scotia in the upper Westphalian A (upper miospore Zone (e) of Barss, in Hacquebard (1972)). Since this genus is unreported from the Appalachians (Eagar 1973) and there are no known ancestors in Nova Scotia, it may be presumed to have been able to have invade from Britain at about this time.

Throughout its occurrence in the Westphalian A and Westphalian B of Nova Scotia, *Naiadites* faunas are dominated by *N. carbonarius* which is considered here to have been its modal form. Where there is evidence of locally increased turbulence, variants with a longer anterior end, well developed umbones and carina, and diminished posterior expansion become common. Where there is evidence of relative tranquility, very broad forms possessing short acute anterior ends become important (see for example horizons PHc-d (Figure 4.18). However, such changes were usually both temporary and local with the result that *N. carbonarius* again dominated. The development of a posterior 'ear' does not occur in Nova Scotia and even inflection of the upper posterior margin is rare.

The younger faunas of the River Hebert area and at the top of the fossiliferous part of the Joggins section are again dominated by *N. carbonarius* and similar shell shape changes with environment occur. The latest record of Naiadites in Nova Scotia is in the upper part of the lower Westphalian B (middle of miospore Zone (f) of Barss, ibid.). Although younger strata was not collected from in this study and there is no reason to suggest that Naiadites did not continue.

The uniformity of the Naiadites faunas throughout the Riversdale and Cumberland Groups is probably again related to the lack of marine incursions and/or progressive environmental change. It should be pointed out that because of this uniformity, Naiadites is of relatively little use stratigraphically.

7.4.1.3. Curvirimula.

The origins, affinities and evolution of Curvirimula are unknown (Weir 1960, p.301) and in Britain and Spain its distribution seems to be associated with periods of marine influence. The earliest record in Nova Scotia of this genus is presently that of Rogers (in press [1979]) from near the base of the Boss Point Formation. Assuming that Curvirimula did not evolve independently in Nova Scotia, the genus could have reached the area from either the Appalachians and/or Britain.

Curvirimula reached its acme in late Westphalian A - early Westphalian B times in Nova Scotia and disappeared shortly afterwards (at the horizon of Logan's coal division #19). This extended continuous range is perhaps not surprising when it is considered the genus sporadically reappeared in the British-NW European area in association with marine bands until mid-Westphalian C times. In Spain, Curvirimula continued through to the Stephanian C (Eagar in prep. [1983]).

The genus displays quite a wide range of variation in Nova Scotia including most of the British forms. However, their distribution does not seem to have any stratigraphic value. Two morphological varieties which show elongation-attenuation in a postero-ventral direction (C. corvosa and C. attenuata sp. nov.) are limited in their distribution to Nova Scotia and are probably local adaptions as may have been C. linguiformis Eagar MS in the late Stephanian of Spain (Eagar in prep. [1983]).

7.4.1.4. Anthraconauta.

Anthraconauta may have evolved from populations of anthraconautiform Naiadites in the Upper Similis-Pulchra Chronozone of Britain (see Trueman & Weir 1955, p.255). In Nova Scotia, the first recorded appearance of this genus is from 2000' below the Emery seam in the Sydney coalfield. At Mabou Mines, A. phillipsii and some naiaditiform variants occur in strata of late Westphalian C age.

The anthraconautiform trend amongst shells referred to Naiadites (particularly in N. daviesi s.l.) also occurs in Nova Scotia, typically in strata indicative of shallow and relatively turbulent conditions. Whether Anthraconauta evolved independently in Nova Scotia however, is impossible to say but the naiaditiform trend amongst Anthraconauta at Mabou Mines (which may have confused Dawson (1894) into recording Naiadites from this locality) adds further weight to this line of enquiry.

Except for the rather cryptic A. calciferus, all the British forms are represented in Nova Scotia and the appearance of common A. tenuis in the Tracy - Emery seam interval of the Sydney coalfield appears to correspond with the Westphalian C/D boundary as defined florally (see Zodrow 1982 and also Cleal 1984). In addition, a local facies form, A. calveri occurs in the Sydney coalfield. As previously maintained in section 7.2, the morphological variation in Anthraconauta can be explained in terms of local environmental change and functional morphology. The genus ranges upward into possible Cantabrian strata in Nova

Scotia.

7.4.1.5. *Anthraconaia*.

The deep-bodied forms so characteristic of the British upper Lower Coal Measures and lower Middle Coal Measures which have proved to be of stratigraphic use, are absent in Nova Scotia. No explanation can presently be offered for this.

The first occurrence of *Anthraconaia arenacea* in Nova Scotia is above the Backpit seam of the Sydney coalfield (Westphalian D) where there are small numbers of the elongate *A. arenacea* group. These early invading faunas compare quite well with those of the early Westphalian D - early Cantabrian of Spain reported by Eagar (in prep. [1983]). However, no marine ancestor can be provided to suggest that their evolution took place in Nova Scotia. In the Spanish example, these elongate invading faunas later split into several biospecies, *A. prolifera s.l.* splitting into a small-shell group with large H/L ratios and a larger group with decreasing H/L ratios (*ibid*.). The similarity between the Spanish event and that of Nova Scotia, where at the level of the Phalen seam, small shell *Anthraconaia* occur, is striking.

Furthermore, although marine incursions and progressive environmental changes do not occur in the Morien Group, *Anthraconaia* displays increasing diversity with younging (see earlier) and appears of potential stratigraphic use. It is proposed that *Anthraconauta* was the dominant bivalve and occupied most of the lacustrine microenvironments available. *Anthraconaia*, in order to compete for food and space, presumably had rapidly to adapt in order to colonise environments which were unsuited to *Anthraconauta*. Thus, *Anthraconaia* occupied ecological niches at both ends of the range of *Anthraconauta*. As previously remarked upon, both the *A. arenacea* and small-shell groups are morphologically and functionally well adapted to their respective environments. Competition therefore, seems to have provided the evolutionary momentum in this genus required for sufficient changes to take place in the faunas as to make them stratigraphically useful.

7.4.2. The stratigraphic use of the faunas.

The Nova Scotian faunas have been shown to be of limited stratigraphic use. However, certain faunas do invite comparison with those of Britain and the Appalachians so that certain points of correlation can be reasonably postulated. Furthermore, the stratigraphic overlap of such genera as Naiadites and Curvirimula can provide some approximate correlations.

Work by Barss and others (Barss & Hacquebard 1967, Barss, in Hacquebard 1972) using miospores has allowed the zonation of the Pennsylvanian strata of Nova Scotia. These miospore zones are used here as stratigraphic reference points.

7.4.2.1. The Canso-Cumberland Groups.

Table 7.12 shows the miospore zones of Barss (ibid.) and his correlations with the Westphalian stages. Hacquebard (1972) has given general sections for each of the coal basins in which both the miospore zones and the lithostratigraphic units are indicated. In an attempt to test these correlations based on the miospore zones with the non-marine faunas, several points are of importance:-

1. The Curvirimula spp. fauna reported by Rogers (in press [1979]) near the base of the Boss Point Formation (Communis Chronozone - top of miospore Zone (c/b)).

2. The Carbonicola? eagari sp. nov. fauna near the top of the

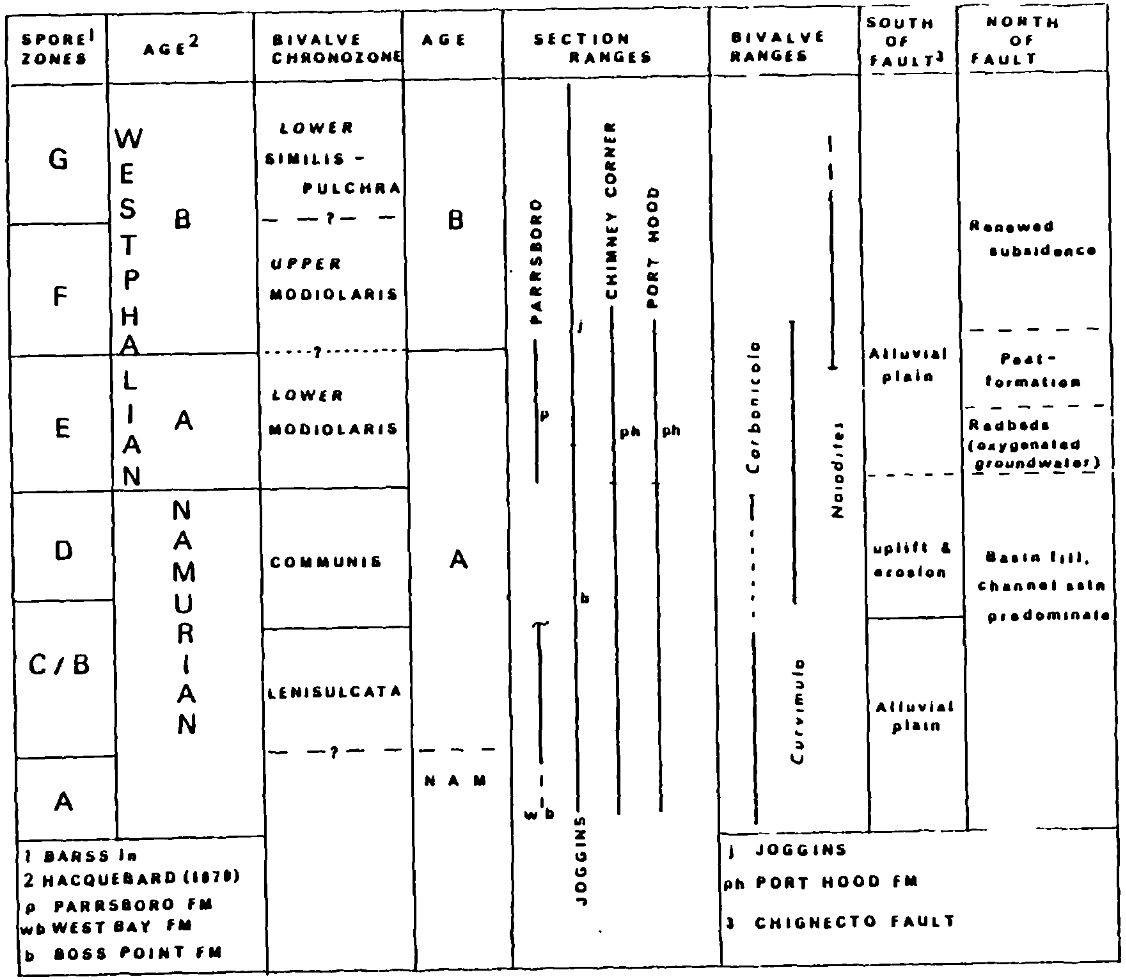

SPORE ZONES 1
AGE 2
BIVALVE CHRONOZONE
AGE
SECTION RANGES
BIVALVE RANGES
SOUTH OF FAULT 3
NORTH OF FAULT
G
F
E
D
C/B
A
WESTPHALIAN
B
A
NAMURIAN
LOWER SIMILIS - PULCHRA
— ? —
UPPER MODIOLARIS
?
LOWER MODIOLARIS
COMMUNIS
LENISULCATA
— ? —
B
A
NAM
PARRSBORO
p
wb
CHIMNEY CORNER
ph
PORT HOOD
ph
JOGGINS
j
b
Carbonicola
Curvimula
Naiadites
Alluvial plain
uplift & erosion
Alluvial plain
Renewed subsidence
Peat-formation
Redbeds (oxygenated groundwater)
Basin fill, channel ssts predominate
1 BARSS in
2 HACQUEBARD (1970)
p PARRSBORO FM
wb WEST BAY FM
b BOSS POINT FM
j JOGGINS
ph PORT HOOD FM
3 CHIGNECTO FAULT

TABLE 7.12

Boss Point Formation (basal Modiolaris Chronozone - basal miospore Zone (e)).

3. The *Carbonicola? angulata* group faunas at the top of the West Bay Formation (uppermost Namurian to Lenisulcata Chronozone - lower miospore Zone (c/b))

4. The *Naiadites* spp. faunas of River Hebert (upper Modiolaris to lower Similis-Pulchra Chronozone - top of miospore Zone (f)).

5. The overlap of the *Curvirimula/Naiadites* spp. faunas throughout the Joggins section (major part of the Modiolaris Chronozone - miospore Zones (e) and basal (f)).

If these points of correlation are accepted then the Westphalian A/Namurian boundary should be lowered to approximately the base of miospore Zone (c/b). This correlation allows space for the Lenisulcata and Communis Chronozones, a consideration that proves difficult in Barss's correlations.

7.4.2.2. The Pictou/Morien Group.

There is some disagreement between the correlations of Zodrow (1982) who used macrofloras and Barss & Hacquebard (1967) who used miospores (Table 7.13). However, as previously pointed out, Barss & Hacquebard (1967) appear to have correlated their miospore zones with Bell's (1938) macrofloral zones. Zodrow & McCandlish (1978) on the basis of new material, lowered the Westphalian C/D boundary. Thus, on this basis the microfloral zones of Barss & Hacquebard should be revised in a similar way.

Non-marine bivalve evidence tends to corroborate Zodrow's correlations (1982) as well as suggesting that the Cantabrian stage is present. Zodrow & Gastaldo (1982) and Zodrow (1982) have

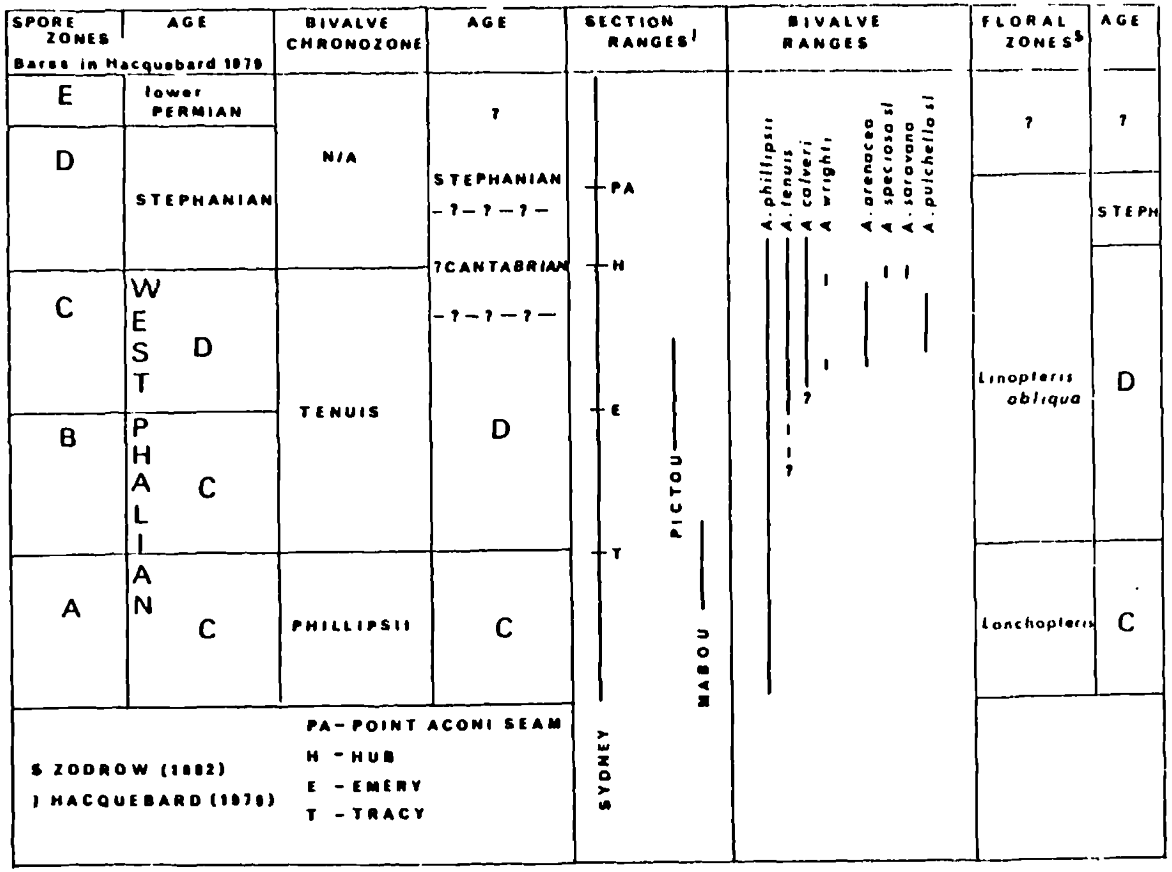

SPORE ZONES
Bars in Hacquebard 1979
AGE
BIVALVE CHRONOZONE
AGE
SECTION RANGES⁾
BIVALVE RANGES
FLORAL ZONES$
AGE
E
lower PERMIAN
D
STEPHANIAN
C
B
A
WESTPHALIAN
D
C
C
N/A
TENUIS
PHILLIPSII
?
STEPHANIAN
-?-?-?-
?CANTABRIAN
-?-?-?-
D
C
PA
H
E
T
SYDNEY
PICTOU
MABOU
A. phillipsii
A. tenuis
A. calveri
A. wrighti
A. arenacea
A. speciosa sl
A. saravana
A. pulchella sl
?
?
?
Linopteris obliqua
Lonchopteris
?
STEPH
D
C
PA- POINT ACONI SEAM
H - HUB
E - EMERY
T - TRACY
$ ZODROW (1982)
⁾ HACQUEBARD (1979)

TABLE 7.13

also recently and independently suggested the presence of a lower Stephanian stage.

By virtue of the Anthraconaia spp. faunas, correlations are mush easier to make in the Morien Group and there are some similarities between these faunas and those of NW Spain and the Appalachians (Eagar in press [1979], in prep. [1983]). Correlations were made as follows:-

1. The Mabou Mines faunas comprise A. phillipsii and variants. Zodrow & Vasey (in prep.) using both macroflora and fauna suggested a correlation with the Westphalian C/D boundary. The fauna indicates an upper Westphalian C age (= miospore Zone (a)). The flora indicates a correlation with the Lonchopteris/lower Linopteris obliqua floral Zones of the Sydney coalfield (= miospore Zones (a) and lower (b)).

2. Shells referreble to A. phillipsii were collected from 800 m below the Emery seam suggesting the presence of the Phillipsii Chronozone (= miospore Zone (a)).

3 A. tenuis and variants occur in the Emery-Hub seam interval of the Sydney coalfield indicating a correlation with the Tenuis Chronozone (=miospore Zone (c)). Faunas below the Emery seam were not recorded.

4. Anthraconaia arenacea occurs above the Backpit seam (to the Harbour seam). These shells are similar to A. pruvosti, considered to be characteristic of the British Westphalian D by Calver (1968a, p.153) (=miospore Zone (c)).

5. Anthraconaia sp. aff. A. speciosa, A. sp. cf. A. saravana and other small-shelled Anthraconaia spp. occur between the Harbour and Hub seams and invite a correlation with faunas documented by Eagar (in press [1979], in prep. [1983]) from the Appalachians and north west Spain. They also occur in

the Cantabrian of NW Spain and with the *A. speciosa* type locality which is probably of lower Stephanian age of the Appalachians. (Cantabrian - lower Stephanian A? = miospore Zone (top of (c)).

6. No faunas were recorded from above the roof shales of the Lloyd Cove seam.

On this basis, miospore Zone (b) and the lower two thirds of Zone (c) are considered to represent the Tenuis Chronozone (Westphalian D) of Britain and the top of miospore Zone (c) is tentatively considered to be Cantabrian in age.

7.4.3. Inter- and intrabasinal correlation.

Definite correlations are difficult to make and this task was attempted in the same way. However, the occurrence of certain distinctive faunas did allow some correlations:-

1. The *Curvirimula corvosa* Bed of Chimney Corner (roof of the #5 seam) is laterally traceable in outcrop and core alike.

2. The occurrence of *Geisina* sp. above the 'Six-foot' seam of Port Hood allowed this horizon to be traced in the core.

3. Distinctive *Anthraconaia* faunas were traceable laterally for several kilometres in outcrop and offshore cores (e.g. above the Phalen seam).

However, these few instances were probably made possible because the particular lakes had a larger than usual areal extent. Usually, faunas are so local as to be of no stratigraphical use.

Interbasinal correlation proves to be almost impossible in the case of particular horizons. The Curvirimula corvosa Bed and the 'Six-foot' seam horizons in the Chimney Corner-St. Rose and Port Hood areas may prove easier to correlate. More usually, the correlation of sections was made using the overlap of the genera and their relative abundance.

7.4.4. Westphalian stage boundaries in Nova Scotia.

With the absence of marine bands, it is impossible to place stage boundaries with any accuracy, though their general position can be assessed.

7.4.4.1. The Namurian-Westphalian A boundary.

This boundary occurs in the basal part of miospore Zone (c/b) on the basis of the preceding evidence. In the sections examined, the boundary would fall in the upper part of the Canso Group at Parrsboro and Joggins but well within the Canso Group at Chimney Corner and Port Hood. The Canso Group - Riversdale boundary therefore does not even approximate a chronostratigraphic division.

7.4.4.2. The Westphalian A/B boundary.

This boundary occurs in either the top of miospore Zone (e) or the base of Zone (f) and, as already stated (Chapter 5), falls somewhere within Logan's Coal Divisions 28- 20 in the Joggins section, Elsewhere, the boundary would be placed near the top of the Riversdale Group.

This particular correlation is interesting from the point of view that the period of coal-formation observed at the top of the Riversdale Group in the Chimney Corner and Port Hood areas would now correlate with that of Joggins (lower Cumberland Group).

7.4.4.3. The Westphalian B/C boundary.

This boundary is impossible to place as no measures of this age were seen.

7.4.4.4. The Westphalian C/D boundary.

Cleale (1984) pointed out that the I.U.G.S. subcommision on Carboniferous stratigraphy had recommended that the base of the Westphalian D is best recognised using plant macrofossils and proceeded to draw it at a horizon somewhat lower than the rather arbitary level chosen by Ramsbottom *et*. *al*. (1978). Cleale (*ibid*.) also showed that the base of the Tenuis Chronozone can be defined in several ways, none of which correspond with the floral boundary (though they approximated to it). On this basis the Westphalian C/D boundary is taken as the roof of the Tracy seam in agreement with Zodrow's floral boundary (Zodrow 1982).

7.4.4.5. The Westphalian -?Cantabrian boundary.

The small-shell *Anthraconaia* faunas between the Harbour and Hub seams tend to indicate a post-Westphalian age. To some extent this corroborates the floral evidence, though Zodrow (1982) provisionally placed the boundary in the roof shales of the Hub seam. It should also be noted that the last occurrence of the Westphalian D, *Anthraconaia arenacea*, occurs at the level of the Harbour seam.

The small-shell *Anthraconaia* fauna occurs at a level some 10 m above the Harbour seam, at a similar horizon to the algal limestone (Vasey & Zodrow 1983). For these reasons it is proposed that provisionally, the boundary be placed at an arbitary level some 10 m above the Harbour seam (=algal limestone). The placement by Zodrow (1982) in the roof of the Hub seam disagrees with the floral evidence and further work is needed to establish this boundary on the basis of both flora and fauna.

CHAPTER 8

SUMMARY, DISCUSSION AND CONCLUSIONS.

8.1. Introduction.

The Westphalian non-marine bivalve faunas of Nova Scotia have been studied in terms of their variation, geographical and stratigraphical distribution and their palaeoecology. They improve our understanding of Nova Scotian Westphalian palaeoenvironments and, although of less stratigraphical use than similar British faunas, they serve as a useful stratigraphical aid when taken in conjunction with published work on the macro- and microfloras.

In addition, numerical methods have been applied to the classification of these faunas and to study their external morphological variation with palaeoenvironmental changes. Cluster analysis combined with PCA serves to produce a phenetic classification which apparently retains sufficient resolution to allow continued stratigraphical work, though this must still be tested in a British context. PCA can be used to study variability with changing palaeoenvironments adding weight to published biometrical work and highlighting consistent trends in shell-shape variation. A functional explanation for these trends may be proposed.

8.2. Nova Scotian faunas: origins, diversity and evolution.

Nova Scotian faunas inhabited lakes of variable depth, lateral extent and duration. As opportunists, the bivalves were well able to invade and adapt to such unstable environments.

There is no evidence to suggest that the Nova Scotian faunas evolved independently, but rather they were probably periodic invaders of the area, possibly from NW Europe.

Carbonicola may have invaded Nova Scotia sometime during the upper Namurian from the British Pennine area. Early Nova Scotian *Carbonicola* faunas comprise mainly elongate invaders similar to the *Carbonicola bellula s.l.* group of the Pennines (cf. Eagar 1977a). Although *Carbonicola* did move into less turbulent, more eutrophic environments, it never monopolised them as much as in Britain. Evolution of *Carbonicola*, which survived until at least late Westphalian A times in Nova Scotia, apparently did not occur and evidently this genus did not reach the Appalachian area.

The low diversity and abundance of *Carbonicola* in Nova Scotia may be related to the fresher water environments there and to the lack of marine incursions, which also inhibited its evolution.

Myalinid genera are quite abundant but of low morphological diversity as compared to NW Europe. The origins of *Curvirimula* even in Europe are unclear and Nova Scotia does not provide any further clues. It is evident from *Curvirimula*'s distribution (NW Europe, Spain, Appalachians, and Nova Scotia) that it was a very widespread form, probably by virtue of its pseudoplanktonic mode of life. It entered Nova Scotian environments in at least mid-Westphalian A times possibly from the British area, and adapted to the fresher water environments of Nova Scotia disappearing from the area in lower Westphalian B times when there was a return to a more dynamic regime.

Naiadites displays a small amount of morphological variability which was related to palaeoenvironmental factors. It entered the Nova Scotian area towards the end of the Westphalian A and evidently did not reach the Appalachian area where it is unrecorded. The Nova Scotian form , *Naiadites carbonarius*, is the modal form throughout its range and as a genus, it has little stratigraphical use in Nova Scotia. Naiadites was able to colonise a wide range of lacustrine environments by virtue of its morphological variability but being a benthonic form, was limited at both ends of its palaeoenvironmental range by turbulence and substrate condition. The disappearance of Naiadites in Nova Scotia was not recorded and therefore cannot be discussed.

Anthraconauta may have evolved independently in Nova Scotia from certain anthraconautiform Naiadites, though this was not directly observed. Like Naiadites, it was a benthonic bivalve and was limited by turbulence and substrate condition, though it displays a wide range of morphological diversity, somewhat wider than in Britain. Anthraconauta ranges into the early Stephanian in Nova Scotia and had access to the Appalachian and Spanish areas.

Anthraconaia is unknown from pre-Westphalian D strata in Nova Scotia and its absence from these measures may be related to the absence of marine influence. Invading faunas of A. arenacea characterise the middle and upper parts of the Nova Scotian Westphalian D and this event is comparable to those in Spain, Germany and the Appalachians. The rapid evolution of Anthraconaia, particularly the small-shell forms, may be useful stratigraphically and probably occurred as a result of competition with Anthraconauta.

The Nova Scotian faunas occupied fresh to brackish waters and their lack of diversity can be related to an absence of marine incursions and progressive environmental change. Local environmental factors were operative however, resulting in only local adaption. This highly local morphological variation is responsible for their diminished stratigraphical value.

8.3. Nova Scotian faunas: palaeoecology.

Consistent trends in external shell morphology are observed amongst the benthonic myalinid genera in Nova Scotia. The major limiting factors were identified as turbulence and substrate condition, factors which affect a range of other environmental parameters (oxygen deficiency, current activity, light, depth and the presence of toxic elements).

Naiadites, Anthraconauta and to some extent, Anthraconaia show similar trends such that under highly eutrophic and calm conditions, their morphology is one of wider, broader shells with a short anterior end, long posterior end and low, small umbones (and carina). Such a shell-shape provides greater bulk in which the centre of gravity of the shell is more centrally placed (Figure 8.1). This prevents sinking in soft bottom muds and the bivalves probably adopted a simple mud-dwelling mode of life resting on one valve. In environments of relatively greater turbulence and where the substrate was fairly coarse, shells become smaller, have longer anterior ends, a diminished posterior end, subparallel ventral and upper posterior margins and well developed, inflated umbones (and carina). Functionally, these morphological changes were probably accompanied by a change in the bivalves living position (Figure 8.2) into an anterior end-down, shallow-burrowing position. Well developed byssal sinuses characterise Naiadites of this type and byssal attachment may have been a consistent feature of this living position. This shell-shape provides greater shell weight, specifically in the antero-umbonal region. Thus the centre of gravity is closer to the antero-umbonal region providing enhanced stability in a semi-infaunal living position. Sucha shift in the centre of gravity may be at least partially related to spat selection and not wholly phenotypic.

At extreme ends of the environmental range, both Naiadites

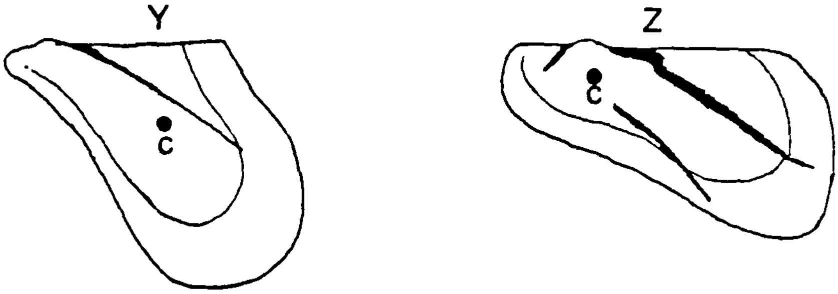


FIGURE 8.1: Shell shape and centre of gravity in Naiadites. Y - Broad, short A/L - form characteristic of fine-grained, dark grey sediments. Z - Elongate form characteristic of coarser, paler sediments.

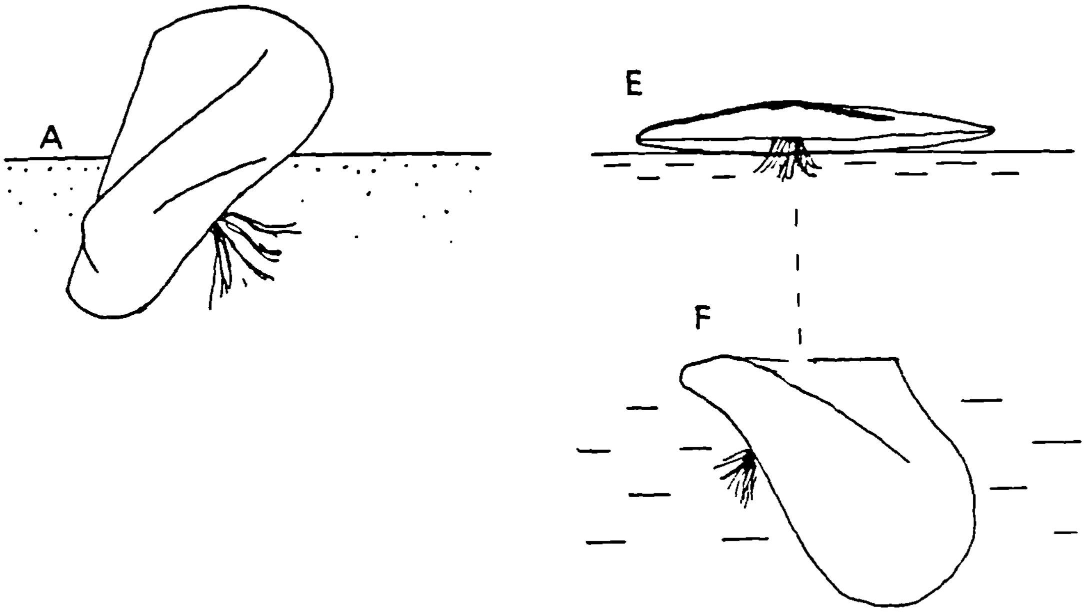


FIGURE 8.2: Suggested mode of life of Naiadites under differing environmental conditions. A - Turbulent, E - calm, eutrophic. F - top view of E to show byssal attachment. In this position inequality of the two valves was probably also a feature of the shells.

and Anthraconauta died out. Too fine-grained a substrate would tend to block the bivalves' feeding apparatus and low turbulence coupled with high proportions of organic matter probably resulted in oxygen deficiency, increases in toxic element concentration and an indistinct sediment/water interface. At the other extreme, high sedimentation rates and turbulence would tend to drown the bivalves which were not active burrowers (i.e. Naiadites and Anthraconauta), and also flip the shells out of their living position.

Depth was also a limiting factor, though evidence suggests that Naiadites was able to tolerate wet and dry periods in the Parrsboro Formation.

Anthraconaia was able to tolerate greater environmental extremes than either Naiadites or Anthraconauta possibly because Anthraconaia was a more active burrower. The elongate A. arenacea was probably capable of upward escape under heavy sedimentation and was thus able to occupy more turbulent environments. The small-shell forms were apparently capable of tolerating oxygen deficiency and very fine-grained substrates.

Curvirimula displays quite a wide range of morphological variation which appears to be unrelated to bottom conditions. It possesses a very thin shell and may have been quite inflated. Curvirimula is thought to have been byssally attached, pseudoplanktonic form (cf. Eagar, in prep. [1983]). Turbulence, depth and preservational factors probably limited its distribution. Shallow waters and/or turbulence would probably also limit its distribution through shell breakage and the thin, delicate shells were unlikely to be preserved in coarse substrates subject to high current activities.

The absence of salinity as a major limiting factor acting on the Nova Scotian faunas has far reaching implications. Most of the genera were capable of some degree of tolerance of varying salinities (eg. *Curvirimula*) however, the distribution of these genera in Britain cannot now be seen simply in terms of salinity. *Curvirimula* which for example, reappears in the Middle Coal Measures of Britain is commonly the only non-marine bivalve intimately associated with near-marine faunas in the early and late stages of marine transgression . As such stages of transgression were characterised by oxygen deficiency of the bottom waters (halocline), this would tend to limit other benthonic genera such as *Naiadites*. *Curvirimula*, as a pseudoplanktonic form would be unaffected by bottom conditions and thus, it would be the only non-marine bivalve occurring in the marine band at this stage. It was thbrefore perhaps not the inability of *Naiadites* to tolerate elevated salinities that limited it (though this may well have been part of the reason), but it was the inability of *Naiadites* to live under oxygen deficient bottom conditions that caused its exclusion. Such a conclusion tends to emphasise the idea of generalised environmental stress as opposed to one single limiting factor.

8.4. Nova Scotian faunas: stratigraphical use.

Without the proximity of a marine area, marine incursions and progressive environmental changes, evolution did not occur at the varietal (or 'specific') level. Local environmental changes even across a few 10's of metres of lake floor, ensured that most faunas are not laterally traceable. For these reasons, correlation is difficult without reference to other palaeontological evidence such as that provided by the macro- and microfloras.

Certain faunas lend themselves to comparison with British faunas and provide points of correlation. The overlap of genera such as *Naiadites* and *Curvirimula* is also useful. Finally the small-shell *Anthraconaia* display recognisable morphological trends with time but unfortunately, they are limited to certain thin and laterally impersistent bands.

Through careful work and with reference to micro- and macroplant zonation schemes, it has proved possible to correlate the Nova Scotian Westphalian with that of Britain. The lithostratigraphic boundaries of Bell (1944) do not reflect chronostratigraphical boundaries and thus, reference is made to the micro- and macroplant zonation schemes.

The bivalve faunas show that the Westphalian A/Namurian boundary should be lowered significantly from where it was placed by Barss & Hacquebard (1972). Furthermore, the Westphalian C/D boundary occurs one miospore Zone lower than placed by Bell (1938) and Hacquebard & Barss (1967). Finally, a Stephanian stage may be recognised in the upper part of the Morien Group.

8.5. Nova Scotian Westphalian environments.

A two-phase history of basin formation is evident in Nova Scotia (Bradley 1982). The early Westphalian basins were narrow rapidly subsiding pull-apart basins bounded by major strike-slip faults. After a period of possible non-deposition, the later Westphalian basins were large, broad basins which subsided due to thermal subsidence.

Within this setting, deposition in the central basin areas was dominated by meandering river channels crossing a muddy floodplain. Rivers tended to migrate into areas of relatively more rapid subsidence producing a series of stacked channel deposits (eg. Boss Point Formation) whilst areas of relatively slower subsidence were dominated by crevasse splay and floodplain deposition (eg. Joggins). Other areas display sequences comprising alternations of channel-dominated and floodplain-dominated sediments.

The relative topographic relief of the river channels allowed plant growth and soil formation. These features have a climatic significance indicating a subtropical climate with alternating wet and dry seasons (cf. Plint & Poll 1982).

Lakes formed mainly on the floodplain through diferential subsidence though larger, very extensive lakes formed during periods of lowered sedimentation rates (see later). The lakes were of variable extent ranging from a few tens of metres upto 100's of kilometres in extent. Similarly, depth and permanency were also variable.

A variety of lake microenvironments have been established on the basis of the distribution of various faunas (FIGURE 8.3). The main body of the lake was usually quite deep with a muddy, eutrophic bottom. Algae commonly occupied the photic zone and provided a source of food. Oxygen deficiency was occasionally a feature of the lakes central and deepest parts limiting fauna to pseudoplanktonic and planktonic organisms. Closer to the lake margins, the intrusion of crevasse splays led to the build up of lake deltas and provided for coarser and former substrates. In the vicinity of lake deltas, the bottom waters were subject to greater turbulence and were well oxygenated.

A host of marginal lake environments occurred and these inluded swampy lake margins colonised by small plants. Interplant areas were subject to stagnation. Other areas were subject to diminished clastic input and carbonate deposition accompanied by stromatolite accumulation was a feature of these areas. Both of these marginal environments were colonised by the small-shell group of *Anthraconaia*.

8.6 Tectonics and palaeogeography.

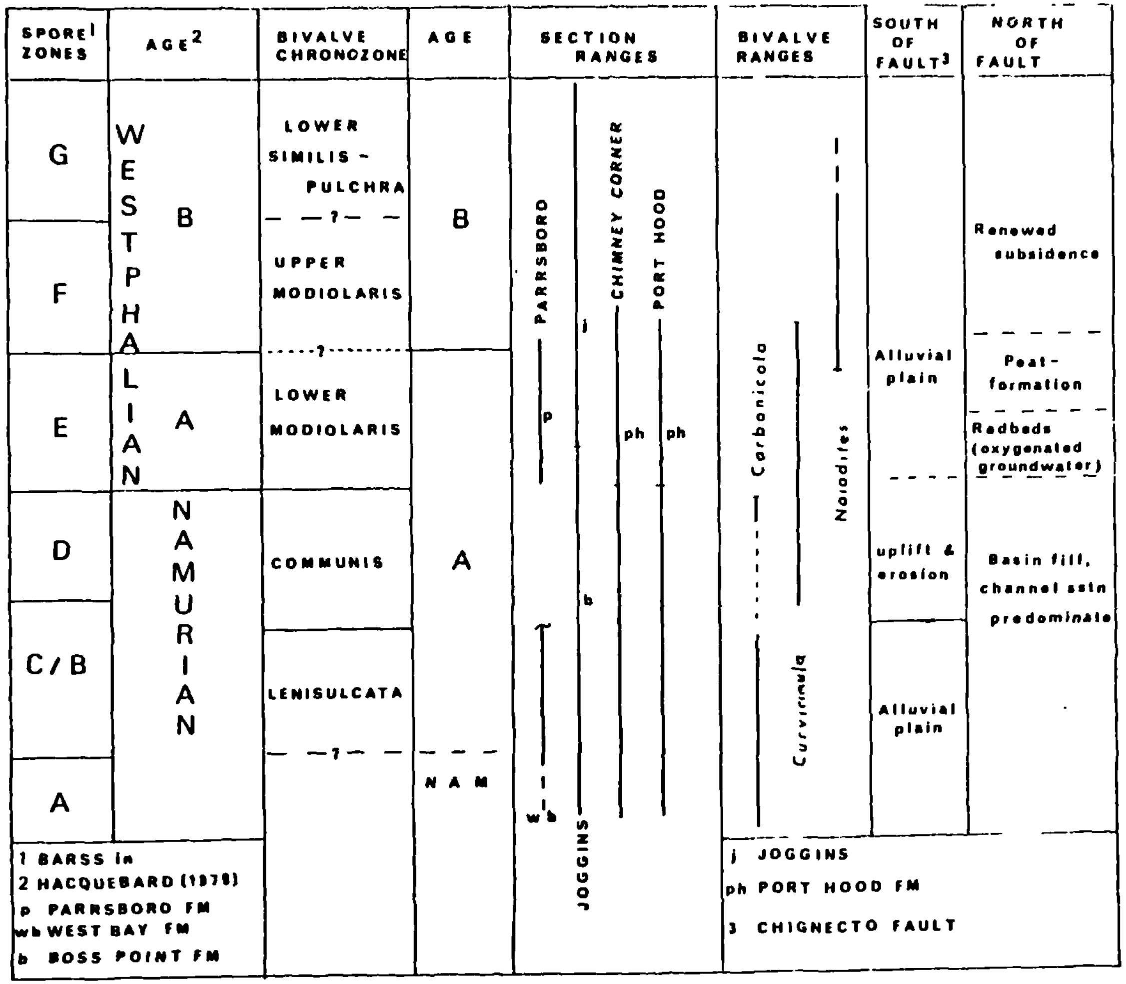
Sedimentation patterns in the Nova Scotian Westphalian were controlled primarily by tectonic factors. Strike-slip boundary faults provided the sediment source areas and controlled subsidence rates.

An example of tectonic control may be seen in the Canso-Cumberland Groups (Table 8.1). The major Chignecto fault controlled sedimentation in the Minas Basin to the SW whilst sedimentation patterns to the NE remained similar. The Minas Basin was dominated by deposition on an alluvial plain in late Namurian-early Westphalian A times. Mid-Westphalian A fault movement resulted in uplift and erosion which was followed by renewed subsidence and basin-fill sedimentation in the late-Westphalian A-early Westphalian B.

To the NE of the fault, all the basins examined display a similar depositional history. Channel-dominated basin-fill sedimentation occurred until the top of the middle Westphalian A indicating that subsidence rates were greater than sedimentation rates. During the lower part of the upper Westphalian A, sequences are characterised by reddened sediments indicating that subsidence had slowed. Groundwaters were oxygenated and subaerial weathering took place. The upper part of the Westphalian A contains the major coals and the most extensive lakes (100's of kilometres in extent). It is suggested that during this period, subsidence slightly outweighed sedimentation, the source areas having been eroded. The early Westphalian B marks a return to renewed subsidence and channel-dominated, basin-fill sedimentation.

The invasion of non-marine bivalve faunas also provides evidence of possible palaeogeographical importance. In late Namurian-early Westphalian times faunas were able to periodically

TABLE 8.1


SPORE¹ ZONES
AGE²
BIVALVE CHRONOZONE
AGE
SECTION RANGES
BIVALVE RANGES
SOUTH OF FAULT³
NORTH OF FAULT
G
F
E
D
C/B
A
WESTPHALIAN
B
A
NAMURIAN
LOWER SIMILIS - PULCHRA
— —?— —
UPPER MODIOLARIS
······?·······
LOWER MODIOLARIS
COMMUNIS
LENISULCATA
— —?— —
B
A
NAM
PARRSBORO
p
wb
JOGGINS
j
b
CHIMNEY CORNER
ph
PORT HOOD
ph
Carbonicola
Curvirimula
Naiadites
Alluvial plain
uplift & erosion
Alluvial plain
Renewed subsidence
Peat-formation
Redbeds (oxygenated groundwater)
Basin fill, channel sstn predominate
1 BARSS in
2 HACQUEBARD (1978)
p PARRSBORO FM
wb WEST BAY FM
b BOSS POINT FM
j JOGGINS
ph PORT HOOD FM
3 CHIGNECTO FAULT

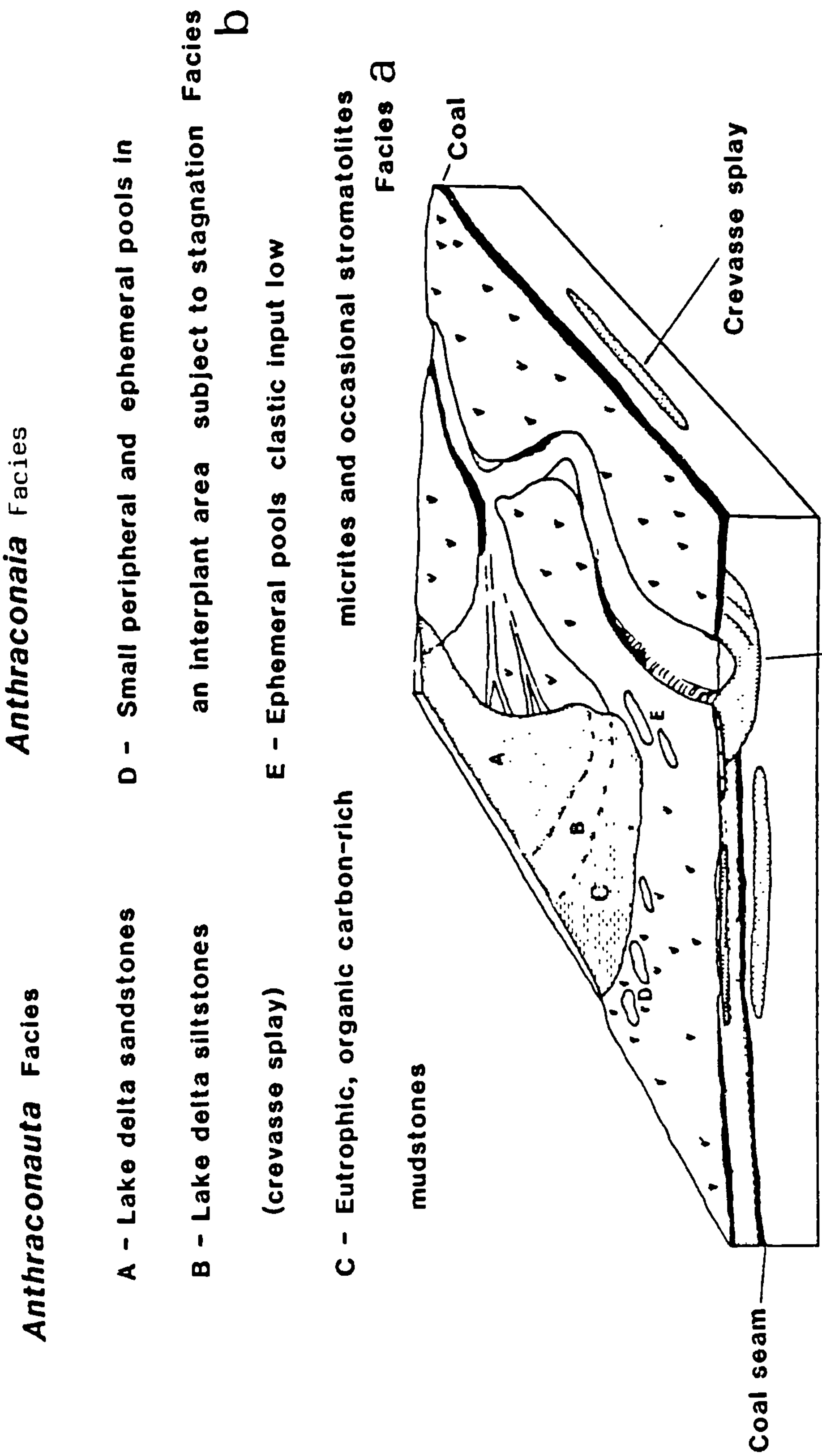


FIGURE 8.3: The Sydney palaeoenvironment and faunal facies as envisaged in this study. General environmental model after Gersig & McCabe (1981).

invade Nova Scotia from the NW European area suggesting that there was a link between the two areas. Bivalves are propagated in the gills of fish so this hypothesis requires a network of interlinked lakes and river systems to have existed between the two areas. Faunas however, did not reach the Appalachian area suggesting that there was a major high between Nova Scotia and the Pennsylvanian basins.

Later Nova Scotian Westphalian faunas compare with those of NW Spain rather than with NW Europe. This suggests that there was a link between the Spanish and Nova Scotian areas in later Westphalian-early Stephanian times (Figure 8.4).

The evidence suggests that Nova Scotia was an intracontinental area. Contemporaneous oceans remained at some distance from the area throughout the Westphalian but Nova Scotia was linked to the paralic coastal areas of NW Europe and later, Spain. A barrier existed between the Nova Scotian area and marine influenced Appalachian area.

8.7. Economic considerations.

The results and conclusions of this thesis show that sedimentation patterns in Nova Scotia were tectonically controlled. Bivalves and other invertebrate faunas are limited to lake sediments which reach their maxima during phases of relative tectonic stability when sedimentation rates were low and subsidence was slightly higher. Two such phases have been identified on the basis of the faunas. These are the late Westphalian A - early Westphalian B and Westphalian D episodes. Coal seams are of their greatest lateral extent and thickness during these two periods.

The non-marine faunas may also prove to be of local stratigraphic use for the correlation of seams. Should the

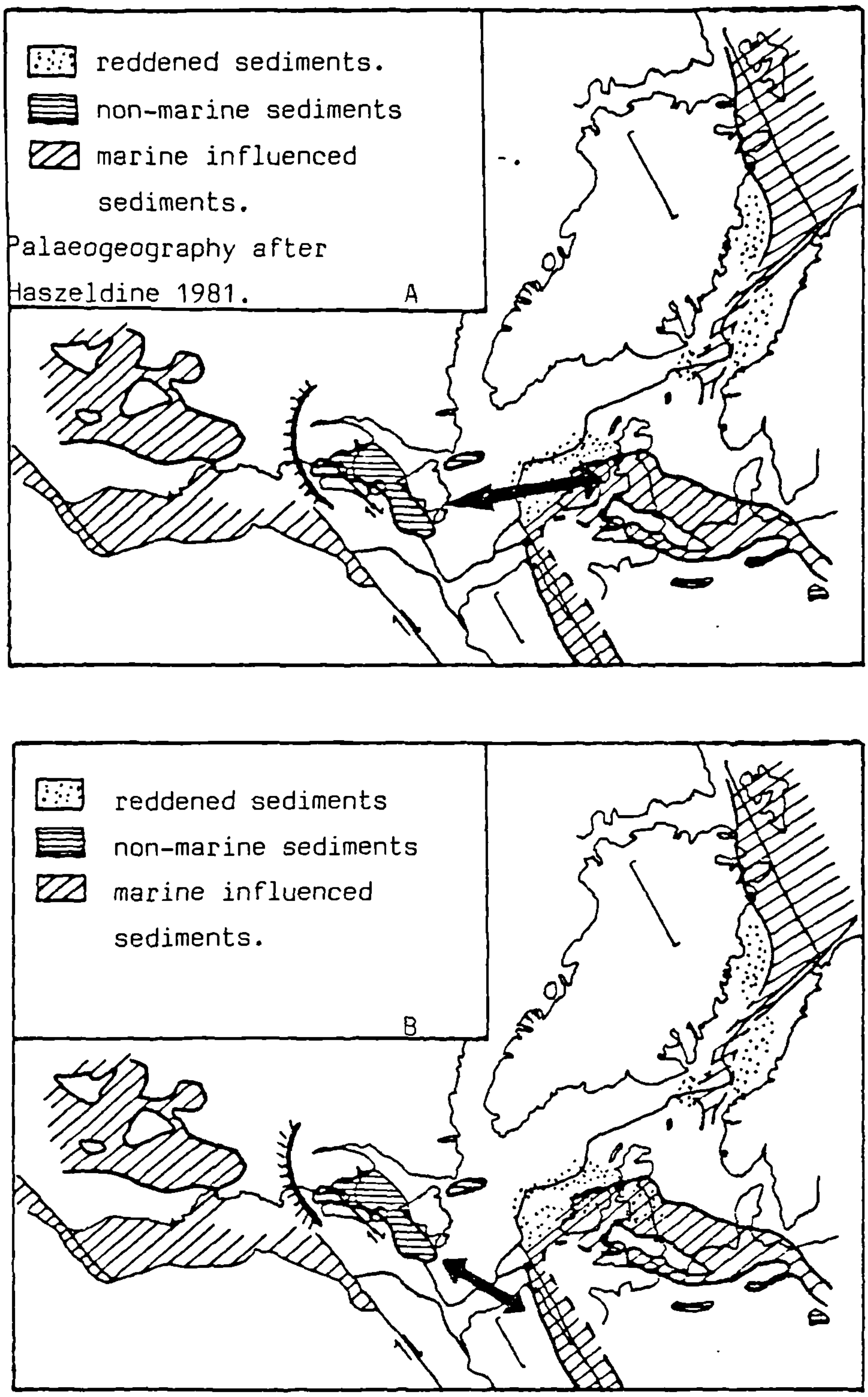


FIGURE 8.4: A - Westphalian A/B: faunas possibly invaded Nova Scotia from the paralic British area. There was a barrier between NE USA and Nova Scotia.

B - Westphalian C/D and younger: British area becoming more continental and less marine influenced and NOva Scotian faunas have more features in common with NW Spanish and Mid European faunas. Barrier between Nova Scotia and the Appalachians probably still intact.

variational trends amongst myalinids in coal seam roof-rocks be recorded, then they might serve usefully to indicate increased risk of the loss of the seam due to washout.

8.8. Concluding remarks.

This study was intended to show the value of Westphalian non-marine bivalve faunas in both stratigraphical and palaeoenvironmental work. Non-marine faunas in the Nova Scotian Westphalian have been neglected for far too long. Stratigraphically, the faunas have proved to be of limited use, though more detailed work on the faunas of a single basin (eg the Sydney Basin) may well be of value in this respect. Palaeoenvironmentally, the faunas are of considerable value and it is unfortunate that they are usually ignored or simply recorded in the form of faunal lists in so many papers of a sedimentological nature.

Of great value in the future would be a series of facies analysis studies of some of the major coal basins using both a detailed sedimentological study combined with a detailed study of the faunas. Secondly, more notice should be taken of the faunas by geologists logging core for the Canadian government and private concerns. This would greatly aid palaeoenvironmental analysis and future workers.

SYSTEMATIC PALAEONTOLOGY.

Introduction.

The following systematic account deals only with the non-marine bivalve faunas. Nova Scotian varieties are fully described. The following abbreviations are made:- R.M. = The Redpath Museum collections, B.M. = The British Museum (Natural History) collections, G.S.C. = The Geological Survey of Canada collections and, the subscript "GMV" = British Geological Survey collection.

Several specimens may have dual numbers (ie. G.S.C. and B.G.S.), these are specimens which because they have been figured or are type material must by law, return to Canada. Other specimens now in the B.G.S. collection may also be return to Canada in the future and given new G.S.C. numbers.

Phyllum MOLLUSCA
Class BIVALVIA
Family ANTHRACOSIIDAE Amalitsky, 1892
emend. Trueman & Weir, 1946
Genus CARBONICOLA McCoy, 1855

CARBONICOLA SCULPONEATA Rogers
Pl. 1, fig. 8.

Carbonicola sculponeata ROGERS, 1965, p. 668, pl. 83, fig. 6.

Measurements and form ratios:-

Pl.	fig.	L(mm)	H(mm)	H/L(%)	A(mm)	A/L(%)
1	8	10.1	5.3	50.2	3.9	37

Remarks:- This morphological variety was named by Rogers (1965) for a small subrectangular and fairly tumid shell housed by the Redpath Museum, Montreal. As defined by Rogers (*ibid*.), it is a Canso Group form and was not seen in this study.

Rogers (*ibid*.) gave the length of the anterior end of the holotype as 2.9 mm or 28.2%. Independent measurement of the shell proves the anterior end to be 3.9 mm in length (or 37%).

Type specimen:- The holotype is R.M. 10011 and came from the Canso Group at Mabou, Cape Breton Island.

Distribution:- The Canso Group of Nova Scotia.

CARBONICOLA? ANGULATA (Dawson)

Pl. 1, figs. 1, 4, 5, 7.

Naiadites angulata DAWSON, 1860, p. 45.
Naiadites angulatus DAWSON, 1868, pp. 204-5, fig. 46.
Carbonicola angulata HIND, 1894, pl. 20, fig. 14.
Carbonicola angulata DAWSON, 1894, p. 167.
Carbonicola? angulata ROGERS, 1965, p. 669, pl. 83, figs. 7-9.
Naiadites angulatus WEIR, 1968, p. 416.
non Cardinia angulata RHYCKHOLT, 1852, p. 104, pl. vi, figs 10-11.
non Carbonicola angulata HIND, 1894, p.75, pl. xi, figs. 3-5.
non Carbonicola angulata WEIR, 1968, p. 415, pl. xlvii, figs 11-12.

Diagnosis:- shell small,lateral outline a subparallelogram. The lowest part of the ventral margin is well towards the posterior end of the shell to produce a slight expansion of the posterior half of the shell relative to the short, straight hinge-line. Umbo low, distinct and slightly prosogyrous. Anterior end high and broadly rounded. Antero-dorsal margin concave. Ventral margin very slightly convex, curving sharply into the posterior margin which is slightly convex and lies at an angle of about 120° to the hinge. A slight convexity runs from the umbo to the poster-ventral extremity.

Type material:- The type specimen of *C?. angulata* is R.M. 3132 and was identified as such by Rogers (1965).

Measurements and form ratios:-

Pl.	fig.	L(mm)	H(mm)	H/L(%)	A(mm)	A/L	HMA(mm)	HMA/L
1	1	13	6	46.2	2.9	22.3	2.0	15.4
1	4	16.8	6.7	40.0	4.3	25.5	1.8	10.6
1	5	16	6.2	38.7	4.3	26.0	1.8	11.3

Remarks:- The type specimen was described by Rogers (1965, p.669) and is a cast of an external impression preserved in black shale of the Canso Group of Mabou.

Due to the limited amount of material available for study and a lack of hinge material, it has proved wiser to retain the generic query added by Rogers (*ibid*.) because of the presence of anthraconaiiform variants occurring at the type locality. The 'species' is also somewhat smaller than comparable British forms.

Trends towards limited posterior expansion also occur at Parrsboro (see Figure 4. 10a, shells 2589, 2588). An additional trend, which includes the two figured shells (Plate 1), occurs towards more elongate shells with shorter anterior ends which recall *Anthraconaia arenacea* of the Pictou/Morien Group. Both *A. arenacea* and *Carbonicola*? *angulata* display variational trends towards very elongate shells (see Figure 4.10a, shells 2593, F1, 2587a,b and 2575 and Figure 6.32) and both occur in similar facies (coarse-grained sediments with evidence of some turbulence). Such morphological similarity under similar palaeoenvironmental conditions reflects a degree of parallel evolution in these two shell groups.

Cardinia angulata Rhyckholt cannot now be recognised and as suggested by Weir (1968), it should be suppressed. Later, Hind used the name Carbonicola angulata for a group of shells from the upper Communis Chronozone of Lancashire, England including Naiadites angulata Dawson in his synonomy. This identification is probably incorrect and Rogers (1965 pp.669-670) suggested reference of these English shells to Carbonicola sp. cf. C. declivis Trueman & Weir until such time as the Lancashire locality could be recollected. In this regard, the present work has little more to offer, however as defined by Rogers (ibid.) and in the authors' own experience, C?. angulata Dawson is a Canso Group form (upper Namurian- Lenisulcata Chronozone). C. angulata Hind would appear to be somewhat younger (Calver 1961, pp. 200-201).

Comparison:- A full comparison with similar but much larger British forms was given by Rogers (1965, p. 670). Anthraconaia arenacea of the Morien/Pictou Group is distinguishable from Carbonicola? angulata s.s. through its smaller H/L ratio, more inclined posterior and dorsal margins and generally greater posterior expansion. There is some degree of overlap in shell shape of the elongate variants in both groups, however Anthraconaia arenacea displays quite a wide range of variation towards more typical anthraconaiiform and even anthraconautiform morphologies. Little or nothing is known of the hinges of these two forms.

Distribution:- The type specimen came from the Canso Group of Mabou. It also occurs in the West Bay Formation of Parrsboro and is indicative of Canso Group strata (see also Rogers 1965).

CARBONICOLA? sp. cf. C. FALLAX Wright

Pl. 1, figs. 2, 3 and 6.

Measurements and form ratios:-

Pl.	fig.	L(mm)	H(mm)	H/L(%)	A	A/L	HMA	HMA/L
1	2	15.6	6.4	41	3.2	20.5	3.0	19.0
1	3	14.8	5.7	38.5	3.9	26.4	2.7	18.2
1	6	11.3	4.8	42.4	2.4	21.1	2.1	18.5
C. fallax Holotype		29.3	14.0	47.8	8.2	28.0	6.4	21.2

Trueman & Weir (1946, Pl. XII, fig. 12).

Remarks:- This group of shells from the West Bay Formation (Canso Group) of Parrsboro probably represent an undescribed member of the *C?. angulata* group. Too few specimens were collected to formally describe it. A similar range of variation to that observed in the *C?. angulata* group occurs (Figure 4.10b) including variants with limited posterior expansion (Figure 4.10b, shell 2594) and elongate varieties (Figure 4. 10b, shells E1 and E2). Several shells are close to *C. fallax* Wright of the British Lenisulcata Chronozone (Figure 4.10b, shells 2599, C1) but are much smaller than this British form.

Comparison:- *Carbonicola fallax* Wright is larger, has a larger H/L ratio, longer anterior end and a less steeply inclined posterior margin. It possesses a strong convexity running from the umbo towards the postero-ventral extremity not seen in the Nova Scotian shells. *C. declivis* Trueman & Weir of the upper Communis Chronozone of Britain has a larger H/L ratio and a more steeply inclined dorsal margin as well as a convexity running from the umbo to the poster-ventral extremity. *C*?. sp. cf. *C*. *fallax* differs from *C*?. *angulata* in its lower and slightly shorter anterior end and in its more steeply inclined posterior margin.

CARBONICOLA?EAGARI sp. nov.
Pl. 1, figs 11,13,14,16.

Diagnosis:- Shell small, subquadrate. Dorsal margin long, straight and steeply inclined rounding with some angulation into the steeply inclined posterior margin. Ventral margin convex but not strongly so, curves into a low anterior end. Antero-umbonal slope concave, long and steep. Umbones broad based, lacking definition and slightly prosogyrous. No internal details known. Juvenile growth lines forwardly tilted.

Type material:- Holotype- GMV 2792, Paratype-GMV2782 both from the Boss Point Formation of Boss Point.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	HMA	HMA/L	D	D/L	HP	HP/L
1 Holotype	13	18.3	10.3	56.3	4.9	26.8	5.4	29.5	10.1	55.2	6.1	33.3
1 paratype	11	14.5	7.6	52.4	3.5	24.1	4.3	29.6	7.9	54.5	4.6	31.2
1	14	17.7	10.9	61.4	5.2	29.5	6.7	38.0	10.0	56.9	7.3	41.2
1	16	13.5	7.3	54.2	2.9	21.1	4.2	30.1	6.9	50.8	4.5	33.6

Remarks:- The type specimens are internal moulds and are preserved in an ostracode-spirorbid-rich, dark grey, calcareous muddy shale.

On external morphological grounds, these shells resemble more closely *Anthracosia* King because of their general shape and due to their forwardly tilted juvenile growth lines. However, preservation is generally poor and no internal, hinge or ligament details have been observed. It is considered that since *Anthracosia* is unrecorded in North America and that without good hinge material, it cannot be convincingly demonstrated that these shells are *Anthracosia*. They are therefore provisionally referred to *Carbonicola*?.

Although undoubtedly laterally flattened to some extent, the shells are quite obese and measurements of thickness result in an average T/L of 20-30%. This figure must represent the minimum actual T/L ratio.

These shells as is common for North American anthracosiids, are much smaller than comparable British forms. This may when their relative rarity is taken into account, suggest that the anthracosiids found the entirely non-marine conditions of N. America difficult to colonise effectively (see Chapter 8).

Variation within the type assemblage occurs towards more quadrate, elongate forms referable to *C*?. sp. cf. *C. sculponeata* (see below). Variation within the *C*?. *eagari* sp. nov. *s.s*. group is somewhat limited and is characterised by increased anterior length, lower anterior and posterior ends and more steeply inclined dorsal and posterior margins (eg. Figure 4. 6b, shells 2787, 2818, 0001). An opposite trend results in shells with a straight dorsal margin subparallel to a ventral margins of less convexity, shorter, higher anterior ends and more inflated umbones (eg. Figure 4. 6b, 0002, 2814 and 2780b).

The occurrence of anthracosiids in the Riversdale Group of Nova Scotia is reported for the first time with this new morphological 'species' significantly extending the known stratigraphical range of this family in N. America.

Comparison:- C?. eagari sp. nov. compares quite closely with the much larger C. venusta of the British Modiolaris Chronozone. C. venusta however has higher, more acute and better developed umbones, a broader, higher anterior end, a more steeply inclined dorsal margin and a more broadly rounded ventral margin. C. venusta also has a slightly higher H/L ratio a longer anterior end and generally lacks the forward tilting of umbonal growth lines seen in C?. eagari sp. nov. C. bipennis (Brown) is a much larger British form having a much larger H/L ratio, a longer, higher and broader anterior end and generally better developed umbones.

Anthracosia regularis (Trueman) is externally similar to C?. eagari sp. nov. but has a larger H/L ratio, longer and broader anterior end, a more broadly rounded ventral margin and it is slightly larger in size.

Carbonicola sculponeata Rogers is the only comparable Nova Scotian form, but it has a smaller H/L ratio and a much longer and broader anterior end. It also lacks the forwardly tilted umbonal growth lines of C?. eagari sp. nov.

Derivation of name:- Named in honour of Dr. R. M. C. Eagar of the Manchester Museum.

Distribution:- C?. eagari sp. nov. is only known from a single horizon high in the Boss Point Formation (Riversdale Group) of Boss Point, Nova Scotia.

CARBONICOLA? sp. cf. C. SCULPONEATA Rogers
Pl. 1, figs 9 & 15.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	HMA	HMA/L	D	D/L	HP	HP/L
1	9	12.8	6.7	52.6	3.0	23.7	3.5	27.3	8.5	66.7	3.1	24.0
1	15	9.8	(5.1)	(51.2)	2.5	25.4	2.3	23.6	(6.5)	(66.2)	2.4	24.5

Remarks:- A very small number of shells collected at the type locality of *C?. eagari* sp. nov. were referred to *C?.* sp. cf. *C. sculponeata*. They are mainly poorly preserved external impressions or internal moulds and are of small size. Generally, the shells are too elongate posteriorally to be referred to *C?. eagari* sp. nov. and should further collecting establish that this group of shells is more abundant at the Boss Point locality, then a new name may be required.

No internal, ligament or hinge details were seen amongst these shells which do not possess forwardly tilted umbonal growth lines, but the shells were referred to *Carbonicola?* for the reasons set out above (see *C?. eagari* sp. nov.).

In terms of external morphology, the shells are most similar to *C. sculponeata* of the Canso Group (cf. Pl. 1, fig. 9 with fig. 8),although they may possess a much shorter and appreciably lower anterior end (see below). The shells are undoubtedly members of the ?. *eagari* sp. nov. s.l. group.

Comparison:- *C?.* sp. cf. *C. sculponeata* differs from *C. sculponeata* mainly in the length and height of the anterior end of the shell which is smaller and much lower in the Boss Point material. The umbones of *C?*. sp. cf. *C. sculponeata* are less well defined and somewhat lower than in Roger's holotype (Pl. 1, fig. 8). *C?. eagari* sp. nov. is less elongate, has a more convex ventral margin, a more steeply inclined dorsal margin, a higher H/L ratio, a shorter and lower anterior end and a longer, lower posterior.

Genus PARACARBONICOLA Eagar 1977a

PARACARBONICOLA? BRADORICA (Dawson)

Pl. 1, figs. 17, 18.

Anthracosia bradorica DAWSON, 1868, p.314, fig. 133b.
Carbonicola bradorica DAWSON, 1894, p.167.
Carbonicola bradorica ROGERS, 1965, pp.667-8, Pl.83, figs. 1-5.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L
1	17	8.6	5.1		2.5	
				59.3		29.1

Remarks:- Eagar (1977a) referred small Viséan and early Namurian *Carbonicola* with relatively small, tumid, evenly swollen shells, characteristically with more strongly marked adductor impressions than those of the late Namurian and Westphalian Anthracosiidae, to the new genus *Paracarbonicola*. *Paracarbonicola* possesses common internal shell features which are unknown in *Carbonicola* McCoy as described by Trueman & Weir (1946, p.2).

Paracarbonicola possesses a sharp-edged, steep-sided escutcheon, which has slightly concave sides and characteristically approaches closure near the termination of the dorsal margin (Eagar 1977a, fig. 3, Pl. 1). Rogers (1965, p.667 and text-fig. 1) described a similar feature in the holotype of *C. bradorica*.

The elongate anterior accessory impression described by Eagar (1977a) is not seen in the type of *C. bradorica*, but this may be due to its incomplete anterior end.

From the descriptions of *C. bradorica*'s internal features, its external morphology and its stratigraphic occurrence, it would appear that reference to *Paracarbonicola*? must be made. This specimen has not been examined personally and until such time as it is, the reference must remain questionable.

Family MYALINIDAE Frech, 1891
emend. Newell, 1942
Genus CURVIRIMULA Weir, 1960

CURVIRIMULA BELGICA (Hind)

Pl. 1, figs. 20-25, Pl. 2, figs 1-2.

Anthracomya belgica HIND, 1912, p.17, Pl.i, fig. 3.
Anthraconauta subovata DEWAR, 1939, p.59, Pl. iv, fig.7.
Anthraconauta subovata var. *candela* DEWAR, 1939, p.60, Pl.iv, fig. 9.
Anthraconauta minima (Hind) DELEERS & PASTIELS, 1947, Pls. A and B.
Curvirimula belgica WEIR, 1960, pp.302-308, Pl.xxxii, figs. 45-56; Pl. XXXIII, figs. 1-17, 31, 33-34, text-fig. 35a-c.

Measurements and form ratios:-

Pl.	fig.	L.	H.	H/L	A	A/L	DM	DM/L	W	W/L	U	U/L
1	20	7.9	5.8		1.1		4.6		5.1		0	
				72.8		13.8		58.1		64.9		0.0
1	21	3.6	3.2		1.1		2.4		2.8		0	
				89.1		30.5		67.9		77.5		0.0
1	22	7.6	4.6		1.2		4.3		4.7		0	
				61.0		16.1		56.8		61.6		0.0
1	23	7.5	6.6		-		5.3		-		-	
				87.5		-		70.0		-		-
1	24	8.0	5.0		1.2		6.0		5.1		0	
				61.9		15.0		75.0		63.1		0.0
1	25	5.9	3.7		1.3		4.0		3.9		0	
				63.2		22.0		68.2		66.1		0.0
2	1	9.9	6.6		1.7		6.3		5.8		0.2	
				66.3		17.4		64.1		64.1		1.8
2	2	6.0	3.7		2.5		4.0		5.0		0	
				61.1		42.5		67.1		82.5		0.0
HOLOTYPE		10.4	8.3		1.8							
Weir (1960,				80.0		17.6						
Pl. XXXII, fig. 45).												

Remarks:- *Curvirimula belgica s.s.* is previously unrecorded from the Westphalian of Nova Scotia,although Rogers (in press [1979]) referred shells low in the Boss Point Formation as *C.* sp. cf. *C. belgica*. *C. belgica s.s.* is a fairly rare form and it is more usual for *C. belgica s.l.* to occur as more transversley subovate shells with a long, straight dorsal margin (see Pl. 1, figs. 24-25 and compare with Weir, 1960, Pl. xxxii, figs 47, 51 and Pl. xxxiii, figs. 4, 5-6).

The curved, radial cracks characteristic of this genus are well seen in many of these specimens (Pl. 1, fig. 21 for example) which are undoubtedly referable to *Curvirimula*.

Range and distribution:- *C. belgica* is recorded for the first time in both the Riversdale and Cumberland Groups of Chimney Corner, Port Hood, Joggins and Boss Point. *C. belgica s.l.* ranges throughout the whole range of this *Curvirimula* in Nova Scotia (upper part of miospore Zone (c/b) or lower? to the base of miospore Zone (f) of Barss in Hacquebard 1972), having an apparent acme in miospore Zone e (= lower Modiolaris Chronozone of Britain).

CURVIRIMULA sp. aff. C. TRAPEZIFORMA (Dewar)

Pl. 2, figs 3-5, 8.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	W	W/L	U	U/L
2	3	13.5	9.1	67.4	1.7	12.6	8.9	65.5	7.3	53.7	0	0.0
2	4	7.5	5.7	76.5	0.9	11.9	5.7	75.4	4.5	59.6	0	0.0
2	8	14.0	11.3	80.7	2.2	15.7	8.5	60.1	8.4	60.2	0	0.0

Remarks:- C. trapeziforma s.s. is a very rare form in Nova Scotia and most shells referable to this 'species' lack the narrow, scalene to subtrapeziodal shape of the holotype being postero-ventrally elongate forms with a rather narrow and sharp anterior end. Trends towards elongation of the dorsal margin combined with inflection of the ventral margin are quite common (see Figure 4.30a, shells 1216c, 1219 and 1097).

Shells referable to C. sp. aff. C. trapeziforma appear to be postero-ventrally attenuated variants of the C. belgica s.l. group, though occasionally they occur as the low W/L and A/L variants in the C. corvosa s.l. group.

Distribution:- In Britain, C. trapeziforma is considered typical of the Communis Chronozone, however in Nova Scotia, C. trapeziforma s.l. occurs in somewhat younger strata ranging through miospore Zone (e) (= lower Modiolaris Chronozone of Britain).

CURVIRIMULA TESSELLATA (Jones)

Estheria tessellata JONES, 1891, p.80.

Curvirimula tessellata WEIR, 1960, pp. 310-314, Pl. xxxiii, figs. 70-75, text-figs. 36, 35e.

Curvirimula tessellata ROGERS, 1965, p. 678, Pl. 84, figs. 27-8.

Remarks:-C. tessellata is a very rare form in Nova Scotia. Rogers (ibid.) referred two laterally flattened valves in the Redpath Museum to C. tessellata. In the present author's experience, C. tessellata-like shells occur as crushed valves in the Joggins section and are usually very poorly preserved. For this reason, C. tessellata could not be figured here.

Distribution:- C. tessellata occurs in the Joggins section (miospore Zone (e)).

CURVIRIMULA CORVOSA Rogers
Pl. 2, figs. 5, 9-10.

Curvirimula? *corvosa* ROGERS, 1965, p. 680, Pl. 84, figs. 29-30.
Curvirimula corvosa VASEY, 1984, Pl. 1, figs, a, b.

Diagnosis:- Shell small, subovate, thin and displaying short, curved radial cracks. Umbo broadly inflated, on a level with the near straight dorsal margin. Anterior end short, curving without angulation into the slightly convex ventral margin. A faint umbonal swelling runs towards the postero-ventral extremity, broadening and fading at about half height.

Type material and locality:- R. M. 21163b was designated the holotype and B. M. 4779510 the paratype by Rogers (1965). The type locality is the *C. corvosa* Bed, roof of the No. 5 seam, Chimney Corner, Nova Scotia (Riversdale Group).

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	W	W/L	U	U/L
2	5	9.7	8.2	84.1	2.0	20.3	7.2	74.6	6.5	67.0	0.0	0.0
2 HOLOTYPE	9	9.3	8.1	87.5	2.0	21.5	7.0	75.4	7.4	79.9	0.0	0.0
2	10	8.1	6.8	84.1	1.9	23.4	6.1	75.4	6.1	75.4	0.0	0.0

Remarks:- The holotype is slightly crushed along the upper ventral margin and also in the lower posterior region. Some growth lines are raised as curved nodes and this presumably represents the beginnings of more general crushing.

Rogers (ibid.) was in some doubt as to whether the 'species' corvosa was referable to the genus Curvirimula Weir, but in all aspects of external form, this species should indeed be referred to that genus.

At the type locality, variation within the C. corvosa s.s. group occurs mainly in terms of the DM/L, U/L and H/L ratios such that C. trapeziforma-like variants having lower DM/L, W/L and A/L ratios and greater H/L and U/L ratios occur at one end of the variation (see Figure 4.30). C. belgica-like variants (see Pl. 2, fig. 10) occur as the other end member and are appreciably more subovate with a longer dorsal margin, anterior end and greater shell width (W/L).

Within the type assemblage, variation around C. corvosa s. s. is simply a function of these two trends (though with greater emphasis) towards C. attenuata sp. nov. and C. sp. aff. C. trapeziforma respectively. Ultimately, C. corvosa may prove to be an intermediate variant between C. belgica and C. attenuata sp. nov.

C. corvosa and variants are the commonest members of this genus in Nova Scotia (modal form?). It is quite a distinctive form and makes up the major part of the fauna in the roof of the No. 5 seam at Chimney Corner which is traceable accross the Chimney Corner area, into the St. Rose area and possibly into the Port Hood coalfield. For this reason, the roof of the No. 5 seam is formally named the C. corvosa Bed.

Comparison:- The distinctive external morphology of C. corvosa makes it an easily distinguishable form. It may be distinguished from C. belgica through its greater H/L ratio, high obliquity, longer anterior end and smaller W/L ratio. C. trapeziforma has a lower H/L ratio, lower obliquity and a straight or slightly concave ventral margin.

Distribution:- At present, C. corvosa is only known from the Riversdale and Cumberland Groups of Nova Scotia where it ranges through miospore Zone (e).

CURVIRIMULA ATTENUATA sp. nov.

Pl. 2, figs. 11-15 ,17

Diagnosis:- Shell small, attenuated postero-ventrally, thin and displays short, curved radial cracks. Umbo raised slightly above the short and slightly convex dorsal margin. Upper posterior margin continuously curved and convex passing into a narrow, low posterior end. Ventral margin near straight or slightly inflected, long and subparallel to the upper posterior margin. Anterior end high, short and narrow. A faint umbonal swelling runs towards the poster-ventral extremity broadening and fading at about half height.

Type material and locality:- GMV1075 is the holotype and GMV1239b the paratype. Both the type specimens come from the C. corvosa Bed of Chimney Corner (Riversdale Group).

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	W	W/L	U	U/L
2	15	8.0	6.3		1.9		4.9		4.6		0.0	
HOLOTYPE				79.3		23.8		61.4		57.9		0.0
2	16	9.0	6.8		1.5		5.3		5.2		0.2	
PARATYPE				75.4		17.0		58.9		57.8		2.0
2	11	7.8	5.9		1.3		5.1		5.3		0.0	
				75.6		16.9		64.6		67.5		0.0
2	12	7.8	6.3		1.6		5.0		4.9		0.4	
				81.1		20.7		64.5		63.0		0.5
2	14	8.6	7.9		1.9		5.4		5.5		0.0	
				92.4		22.3		62.3		63.6		0.0

Remarks:- The holotype is a partially crushed left valve and the paratype is a right valve. Some growth lines are raised as curved nodes similar to those observed in the holotype of C. corvosa Rogers, and generally preservation is good.

This 'species' appears to be a greatly attenuated and often naiaditiform, variant of the C. corvosa group (see Figure 4.30) and is mainly recorded in the C. corvosa Bed of Chimney Corner.

Variation within C. attenuata sp. nov. occurs mainly in terms of the W/L, H/L, A/L and U/L ratios. Shells having short, narrow anterior ends, low W/L ratios, shorter dorsal margins and a strongly sinuate ventral margin (naiaditiform variants - see Figure 4.30, shells 1226, 1058 & 1218) form one end of the variation. Less attenuated, more subovate variants with convex ventral margins (Figure 4.30, shells 1093b, 1229 and 1239b) such as the paratype, occur as the opposite variational end member.

Outside of the C. corvosa Bed, C. attenuata sp. nov. is much more restricted in terms of its distribution and abundance. It usually occurs as an extreme variant of the C. corvosa group of elongate and attenuated Curvirimula.

Notably, the Nova Scotian representatives of this genus are only partially crushed and are rarely found completely flattened (cf. Weir, 1960, p.300 and also Eagar, in prep. [1983]). Most Nova Scotian Curvirimula display some umbonal swelling and may have been quite obese, though perhaps not as obese as the Spanish variety C. linguiformis Eagar MS [1983]. The lower degree of flattening amongst the Nova Scotian shells suggests that the umbonal swelling may be a common feature of Curvirimula which is not seen in comparable British material due to greater flattening. The curved, radial cracks characteristic of this genus are not as well defined in Nova Scotian shells, possibly for the same reason.

Comparison:- *C. attenuata* sp. nov. is easily distinguishable from all other forms due to its subparallel postero-dorsal and antero-ventral margins and its extreme attenuation.

Distribution:- *C. attenuata* sp. nov. most commonly occurs at Chimney Corner, notably in the *C. corvosa* Bed. It also occurs in the Riversdale Group of Port Hood and in the Cumberland Group of Joggins. As such, it is restricted to miospore Zone (e).

CURVIRIMULA MYTILOIDES (Dawson)

Pl. 2, fig.7

Naiadites mytiloides DAWSON, 1894, p. 125, fig. 5.
Naiadites? mytiliodes ROGERS, 1965, p. 675, Pl. 83, figs. 32-33.
Curvirimula mytiloides VASEY, 1984, Pl. 1, figs. c,d.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L
2	7	9.8	7.8		1.6		6.5	
				79.6		16.3		66.4

Remarks:- Dawson (1894) dscribed *Naiadites mytiloides* from Riversdale strata at Chimney Corner. In Rogers (1965) revision of all Dawson's genera and species, the type specimen was relocated, figured and described, but Rogers (*ibid*.) expressed doubt as to its true generic affinities.

Vasey (1984) re-examined the holotypes of *C. corvosa* and *N*?. *mytiloides* referring both to *Curvirimula* Weir on the basis of the presence of curved, radial cracks on the shells of both the types, and that both types occur on the same piece of shale from the *C. corvosa* Bed in which *Naiadites* does not occur (Chapter 4). Vasey (*ibid*.) also suggested that *C. mytiloides* may be a senior synonym of *C. corvosa* but as the type (and only known specimen) of *C*.

mytiloides is so poorly preserved as to make *C. mytiloides* unrecognisable, it is not possible to check this. For this reason it is recommended that the name *mytiloides* be restricted to the holotype.

The holotype is poorly preserved with much of the anterior end, all of the ventral margin and part of the posterior end missing (Pl. 2, fig. 7).

Distribution:- From the *C. corvosa* Bed of Chimney Corner.

CURVIRMULA? OVALIS (Dawson)

Pl. 1, fig. 19.

Naiadites ovalis DAWSON, 1860, p. 45.
Anthracomya ovalis DAWSON, 1894, p. 129, text-fig. 11.
Curvirimula? ovalis ROGERS, 1965, PP. 678-9, Pl. 83, figs, 29-30; Pl. 85, figs. 2-5, 7.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L
1	19	10.5	7.2		2.9		7.9	
				68.6		27.6		75.2

Remarks:- *C*?. *ovalis* was described by Dawson (1860) as *Naiadites ovalis* from Joggins. Although no figure was given, he referred to an earlier figure (1854, p. 39, text-fig. 24, Rogers, 1965, Pl. 85, fig. 1) as representing this 'species'. Rogers (1965) was unable to locate this fossil but chose a shell identified by a drawing of *Anthracomya ovalis* in Dawson (1894, p. 129, text-fig. 11) from Parrsboro. The type specimen selected by Rogers (1965) is R.M. 21170 (Pl. 1, fig. 19). Rogers (*ibid*.) also figured two other shells as *C*?. sp. aff. *C?. ovalis*.

Two points should be made regarding the type specimen which has been examined:-

1. The type is an extremely poorly preserved internal mould of a left valve preserved in a fine-grained sandstone. Although indistinct growth lines can be seen, curved radial cracks appear to be absent or not preserved.

2. Substantial collecting of the Parrsboro locality has produced only Naiadites spp. which are often small and anthraconautiform (Chapter 4). Although Bell (1944) listed 'Anthracomya' from this locality, it is more than possible that he was simply referring to Dawson's (1894) record of Anthracomya ovalis or to the anthraconautiform Naiadites and not to Curvirimula.

Both these points suggest that the holotype of C?. ovalis may be in fact a juvenile Naiadites sp. In any case its true generic status must remain in some doubt.

The two shells figured by Rogers (1965) as C?. sp. aff. C?.ovalis both display the curved radial cracks and may be Referred to Curvirimula sp. On the basis of their external morphology and because of the doubt as to the true generic status of the holotype, these specimens may be better referred to C. sp. cf. C. belgica, at least provisionally. For these reasons, I believe that C?. ovalis (Dawson) is unrecognisable and perhaps should be suppressed.

Genus NAIADITES Dawson, 1860

NAIADITES CARBONARIUS Dawson, 1860

Pl. 3, figs. 2-5, 7-8, 12.

Naiadites carbonarius DAWSON, 1860, p. 43.

Naiadites (Anthracoptera) carbonarius DAWSON, 1868, p. 204, text-fig. 42.

Naiadites carbonarius DAWSON, 1894, p. 122, text-figs. 1-3.

Naiadites carbonarius NEWELL, 1940, p. 292-5, Pl. 2, figs. 4a-c, text-fig. 1b.

Naiadites carbonarius NEWELL, 1942, P. 72-3, Pl. 15, figs. 2a,b.

Naiadites carbonarius TRUEMAN & WEIR, 1955, p. 217-221, text-figs 30a-g.

Naiadites carbonarius ROGERS, 1965, p. 671-3, Pl. 83, figs. 10-19.

Diagnosis:- Shell modioloid. From the umbo the carina, which is well defined proximally but not strongly inflated, arches above the level of the hinge and then broadens and fades, following a straight path to intersect the ventral margin anterior to the most ventral point. The broad anterior end is limited by the carina and has a long straight anterior margin lying at right angles to the hinge. A byssal sinus occurs midway between the anterior end and most ventral point which is well to the posterior of the shell. The upper posterior margin is broadly rounded and rarely arcuate. Dorsal margin long and straight.

Type material:- The lectotype of N. carbonarius Dawson is R. M. 21172a. Topotypes and possible syntypes are R.M 21173, 3124, 313a, 10010 and 10009, and B.M. L14990 and L. 47794.

The lectotype was selected by Trueman & Weir (1955) from material figured by Newell (1940) who redefined N. carbonarius. Rogers (1965) gives a brief history as to the choice of this particular specimen.

Measurements & form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	PE	PE/L
3	2	17.8	13.4	75.2	2.9	13.5	15.9	89.2	13.4	75.3	8.4	47.2
3 HOLOTYPE	3	13.9	10.1	72.5	2.7	19.5	10.8	77.9	9.2	65.9	5.3	37.8
3	4	14.9	12.4	83.1	2.3	15.4	12.5	83.9	10.5	70.5	5.2	34.9
3	5	22.3	14.9	66.6	3.4	15.2	16.7	74.3	14.8	66.2	8.1	36.3
3	7	14.4	9.2	63.9	3.0	20.1	11.9	82.7	11.5	79.5	5.8	40.1
3	8	18.0	13.4	74.6	2.8	15.4	15.4	85.3	12.3	68.1	8.0	44.2
3	12	16.3	14.0	85.9	3.1	18.7	14.0	85.9	12.6	77.3	5.1	31.3

Remarks:- Newell (1942) discussed the internal structure of N. carbonarius fully. Rogers (1965) discussed the history of the selection of the type specimens.

The lectotype has subsequently suffered some damage (compare Rogers 1965, Pl. 83, fig. 12 with Pl.3, fig. 2 herein). When examined, the posterior lobe was found to have broken away. To some extent the shell could be restored (as in Pl.3, fig. 2), however a small piece of the upper postero-dorsal margin has been lost. The distinguishing features may still be seen in the lecctotype which is mounted on a piece of card. Some efforts should now be made to ensure that no further damage occurs.

Several shells were collected which are closely similar to the lectotype (see Plate 3, figs. 4 & 8), although usually shells referable to *N. carbonarius* tend to have a diminished anterior end, a less pronounced umbonal swelling and lower posterior expansion so as to resemble the more clearly the "unproduced" variants of *N. productus* figured by Trueman & Weir (1955, Pl. XXVIII and see Rogers 1965, p. 672). *N. carbonarius* remains a distinct form however due to its broader anterior end and straightness of its anterior margin.

Variation within the *N. carbonarius* group seems to be related to the palaeoenvironment in which it lived (Chapter 7) varying towards broad forms with high PE/L ratios in fine-grained, organic carbon-rich sediments to more elongate forms with longer dorsal margins and diminished posterior expansion in sediments indicative of relatively more turbulent environments.

The carina which is well developed in the lectotype, is of variable definition not only between right and left vales but also from valve to valve (see Pl. 3, fig.4 and fig. 5 for eg.). This feature similarly appears to have been affected by palaeoenvironmental factors to some degree (or spat selection).

Inflection of the upper posterior margin is rarely observed in Nova Scotian *Naiadites* spp. and the development of a posterior 'ear' has not been observed in any specimen. In *N. carbonarius*, posterior inflection is very rare (but see Pl. 3, fig. 8).

Newell's (1942) study of the internal features of *N. carbonarius* agree well with those seen amongst the material collected in this study comprising a grooved ligamental area and three small anterior muscle scars (see Pl. 2, fig. 16).

Comparison:- *N. carbonarius* is a distinct form and may be distingiushed from the unproduced variants of *N. productus* (Brown) through its blunter and deeper anterior end. *N. daviesi* Dix & Trueman was considered by Trueman & Weir (1955, p. 221) to be the closest British form to N. carbonarius. N. carbonarius however has a deeper, blunter anterior end, better developed carina, a byssal sinus and is not elongated.

Distribution:- N. carbonarius is the modal form of Nova Scotian Naiadites and ranges from upper miospore Zone (e) to miospore Zone (g) and possibly higher.

NAIADITES PRODUCTUS (Brown)

Pl. 3, figs 9, 11, 15, 17; Pl. 4, figs. 2, 7, 9.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	PE	PE/L	U	U/L
3	9	15.8	10.5	66.7	1.9	11.9	11.7	63.1	12.1	77.0	5.6	35.3	0.7	4.2
3	11	13.7	9.1	66.5	2.0	14.9	8.9	64.9	10.9	79.7	3.8	27.5	1.0	7.3
3	15	23.4	17.0	72.7	2.8	12.0	18.1	77.3	17.2	73.5	8.2	35.0	1.0	4.4
3	17	17.4	12.2	70.3	2.5	14.5	14.0	80.6	12.1	69.4	8.0	45.9	0.0	0.0
4	2	18.2	10.0	54.9	3.3	18.1	13.3	73.8	12.0	65.9	8.3	45.3	0.3	1.8
4	7	12.1	9.5	78.3	1.5	12.0	8.3	68.9	8.8	72.8	5.5	45.8	0.0	0.0
4	9	17.1	12.8	74.6	2.3	13.2	12.1	70.8	11.9	69.7	6.1	35.7	0.1	0.0
Trueman & Weir 1955, Pl. XXVIII, fig. 3.		27.0	22.0	81.5	2.0	7.4	19.5	72.3	19.1	70.7	7.7	28.5	0.2	0.0

Remarks:- N. productus s.s. is not a common form in Nova Scotia and the nearest figured shell is Pl. 4, fig. 9, though this has an imperfect ventral margin and is laterally flattened. The more usual Nova Scotian form resembles the unproduced variants figured by Trueman & Weir (1955) as *N.* sp. aff. *N. productus* (see Pl. 3, figs. 11, 15 etc). These unproduced variants were considered by Trueman & Weir (*ibid.*, p. 226) to be the commonest of all British *Naiadites* and suggested that they may prove to be the morphic norm of the most variable upper Modiolaris and lower Similis-Pulchra Chronozone assemblages.

N. productus s.l. in Nova Scotia seems to be a variant of the *N. carbonarius* group occurring in lithologies suggestive of slightly more turbulence. Variation within *N. productus* tends to be dominated by increases in the H/L and PE/L ratios coupled with a decrease in the D/L ratio so that more typical *N. productus* occur at the extreme end of this variational trend. Decreases in the H/L and PE/L ratios tend to produce a trend towards *N. subtruncatus*-like variants (see Pl. 4, fig. 2). The trend towards shells with diminished posterior expansion appears to be related to increasing turbulence in the palaeoenvironment

As in *N. carbonarius*, inflection of the upper posterior margin is very rare and definition of the carina seems to be variable, although carinas are more strongly developed in the more typical *N. productus* forms.

Comparison:- *N. productus* has a shorter, narrower anterior end than *N. carbonarius* and often displays a trend towards subparallel ventral and upper posterior margins.

Range and distribution:- *N. productus s.l.* has a similar distribution to that of *N. carbonarius*, though it is less common.

NAIADITES SUBTRUNCATUS (Brown)

Pl. 3, figs. 16, 18; Pl. 4, figs. 1, 3, 5.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	PE	PE/L	U	U/L
3	16	12.1	7.7	63.4	2.5	20.4	10.3	85.3	9.7	80.2	-	-	0	0
3	18	18.5	10.9	59.2	2.2	12.0	14.3	77.4	14.1	76.3	4.8	25.7	0.5	2.9
4	1	22.0	14.3	65.0	2.8	12.7	19.6	89.3	16.1	73.1	5.1	23.1	0	0.0
4	3	11.8	7.1	60.1	2.4	20.3	8.5	72.3	9.0	76.3	3.7	31.3	0	0.0
Brown, 1849, Pl. XXII, fig. 15.		28.2	16.3	58.8	4.0	14.2	22.5	79.8	21.4	75.9	9.3	32.9	0.4	1.4

Remarks:- This elongate, modioloid form is common and even dominates some shell beds (eg. The N. subtruncatus Bed of Port(PH2d) Hood). It is a distinctive form having a long dorsal margin, short, broad anterior end and much reduced posterior expansion. Nova Scotian forms are often characterised by a strong carinal swelling which arches very slightly above the level of the dorsal margin and broadens towards the posterior of the shell, delimiting a rather shallow ventral sinus (see Pl. 3, fig. 18 for eg.).

Trueman & Weir (1955, p. 231) discussed the presence of an inflected upper posterior margin in shells which possess a strongly arched carina and have pronounced postero-ventral elongation. Such a shell is figured in Pl. 3, fig. 18.

Variation within assemblages of N. subtruncatus in Nova Scotia occurs around a modal form which is very close to the type specimen (Figure 4.19, shell 2227). Decreases in the D/L, A/L, H/L and DM/L ratios tend to produce shells with a shorter dorsal margin and subparallel ventral and upper posterior margins which could be referred to *N*. sp. cf. *N. productus*.

N. subtruncatus is the end member in a Nova Scotian *Naiadites* assemblage. This variety may have possessed a semi-infaunal mode of life in an upright position, perhaps explaining Trueman & Weir's (1955) findings that this 'species' tends to be equivalved in contrast to other *Naiadites*.

Comparison:- *N. subtruncatus* has a longer dorsal margin than other Nova Scotian forms which when combined with poster-ventral elongation and diminished posterior expansion, makes this form quite distinct.

Distribution:- *N. subtruncatus* commonly occurs within the Riversdale and Cumberland Groups of Nova Scotia, typically on coarser-grained horizons where it may dominate the assemblage.

NAIADITES sp. aff. N. TRIANGULARIS (J. de C. Sowerby)

Pl. 3, figs 10, 13.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	PE	PE/L	U	U/L
3	10	17.3	13.4		1.8		14.2		11.0		8.3		0.2	
				77.6		10.4		82.1		63.3		48.2		1.4
3	13	32.5	22.9		3.5		23.5		26.6		11.2		0.5	
				70.6		10.7		72.2		82.7		34.5		1.4

Remarks:- *N*. sp. aff. *N. triangularis* is a rare form in Nova Scotia which combines a broad shell, high H/L ratio, very short and acute anterior end and a long dorsal margin. Most of the shells referable to this 'species' possess a shallow byssal sinus and carina of variable definition that does not arch above the level of the hinge.

N. sp. aff. *N. triangularis* is usually an extreme variant in Nova Scotian assemblges of *Naiadites* occurring in fine-grained, organic carbon-rich lithologies suggestive of highly eutrophic conditions. It is possibly a variant of *N. productus s.l*. (see also Trueman & Weir 1955, p. 236).

Comparison:- The combination of a short, acute anterior end, long dorsal margin and broad posterior lobe makes this a distinctive and recognisable form.

Distribution:- *N*. sp. aff. *N. triangularis* occurs at a number of horizons in the Riversdale and Cumberland Groups of Nova Scotia having a similar range to that of *N. carbonarius*. It has not been recorded southwest of the Chignecto fault where conditions where more turbulent.

NAIADITES DAVIESI (Dix & Trueman)

Pl. 3, fig. 6, 14; Pl.4, fig. 6.

Naiadites daviesi DIX & TRUEMAN, 1932, p. 16, Pl. i, fig. 13 *Naiadites daviesi* WEIR & LEITCH, 1936, text-fig 6j. *Naiadites daviesi* TRUEMAN & WEIR, 1955, P. 222-4, Pl. XXVII, figs. 42-46, 50.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	PE	PE/L	U	U/L
3	6	13.5	10.3	76.6	2.5	18.4	10.0	74.1	8.6	63.8	6.0	44.7	0	0.0
3	14	8.5	6.3	73.5	1.2	14.0	6.4	75.8	5.8	68.6	3.3	38.2	0	0.0
4	6	16.9	11.8	69.5	2.6	15.2	13.7	80.1	9.3	55.2	9.0	53.2	0	0.0
TYPE from		19.1	14.0	73.3	3.8	19.9	13.7	71.7	14.8	77.4	7.0	36.6	0	0.0

Trueman & Weir, 1955, Pl. XXVII, fig. 42.

Remarks:- *N. daviesi* is a rare form in Nova Scotia outside of the Parrsboro area where it is quite common. Nova Scotian representatives tend towards anthraconautiform variants (see Figure 4. 14a) through lowering of the H/L, U/L and PE/L ratios. A trend towards *N. carbonarius*-like shells occurs through an increase in the PE/L ratio with a corresponding decrease in the D/L ratio to produce broadly ovate forms (eg. Pl. 3, fig. 6). A variational trend towards *N. productus*-like forms also occurs through increased definition of the carina and subparallel ventral and upper posterior margins.

Comparison:- *N. daviesi* lacks the broad anterior end of *N. carbonarius* as well as having a lower H/L ratio. It differs from *N. productus* in its broad posterior end and lack of carinal arching.

Distribution:- *N. daviesi* occurs mainly in the Parrsboro Formation of Parrsboro but has also been recorded rarely eleswhere in the Riversdale and Cumberland Groups.

NAIADITES LONGUS Dawson

Pl. 3, fig. 1.

Naiadites longus DAWSON, 1894, p. 124-5, text-fig. 4.
Anthracomya longus DAWSON, 1894, p. 126, text-fig. 6.
Naiadites carbonarius HIND, 1894, Pl. 20, fig. 1.
Naiadites longus ROGERS, 1965, p. 673, Pl. 83, figs. 20-25.

Diagnosis:- Shell subtriangular and of low obliquity. Dorsal margin straight and long. Anterior end sharp and narrow. Ventral margin long and nearly straight. Upper posterior margin and posterior margins smoothly curved. Carina curved and sharply delimited by the flat anterior surface.

Type material:- The holotype of N. longus Dawson is R.M.21171. Topotypes are R.M. 21165 and 21166 and B.M. L47801.

Remarks:- Dawson (1894) noted the occasional presence of this form in beds that contained N. carbonarius and that there were no intermediate forms. No shells have been located in this study, however that may be referred to N. longus.

Rogers (1965) gave a detailed account of the holotype and other specimens, one of which is an internal view and is reproduced here (Pl. 3, fig. 1) for comparison with Pl. 2, fig. 16. The anterior musclature visible in this shell from the B.M. compares well with with the results of the study by Newell (1940).

Little can be added to Rogers (1965) description of this form except that it is very rare and may prove to be an extreme variant of N. carbonarius should further collecting be undertaken.

Comparison:- N. longus is morphologically distinct from any other Nova Scotian Naiadites due to its low obliquity and sharp anterior end.

Distribution:- The specimens discussed by Rogers (1965) came from the Cumberland Group of Joggins.

NAIADITES sp. cf. N. QUADRATUS (J. de C. Sowerby)

Pl. 4, figs. 4, 8.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	PE	PE/L	U	U/L
4	4	15.1	-		2.6		13.0		-		-		-	
4	8	18.5	17.2		3.4		15.2		11.7		9.2		0	
				93.0		18.0		82.3		63.4		49.4		0.0

Remarks:- A very rare form in Nova Scotia, this U-shaped 'species' is quite distinctive and may be a variant of *N carbonarius* occurring in finer-grained sediments. Typically, it possess a shallow byssal sinus and a carina of variable definition.

Comparison:- *N.* sp. cf. *N. quadratus* is a distinct from and may be distinguished through its U-shaped morphology.

Distribution:- *N.* sp. cf. *N. quadratus* occurs rarely throughout the range of *Naiadites* in Nova Scotia.

Genus ANTHRACONAUTA Pruvost, 1930

ANTHRACONAUTA PHILLIPSII (Williamson)

Pl. 4, figs. 10-14, 16.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	W	W/L
4	10	11.9	7.6	63.9	1.7	14.0	7.7	64.6	7.6	63.6	6.7	56.0
4	11	17.9	8.9	48.3	2.7	14.8	12.4	69.0	12.0	67.0	9.2	51.4
4	12	18.5	9.5	51.4	1.9	10.3	12.3	66.4	12.2	65.9	9.7	52.4
4	13	19.5	11.5	59.0	2.4	12.3	11.9	61.0	-		-	
4	14	19.7	10.6	50.6	2.5	12.9	13.3	67.3	13.8	69.9	11.4	57.7
4	16	11.3	7.1	63.1	1.3	10.1	7.2	63.9	7.4	65.4	6.7	59.3

Remarks:- A. phillipsii was recorded by Rogers (1965) from the Pictou/Morien Group of Nova Scotia, though no attempt was made to study the variation within this 'species' in Nova scotia. Variation has been fully discussed in Chapters 6 and 7.

A. phillipsii is the commonest form of Anthraconauta in Nova Scotia and the modal form within the variation is closely similar to the holotype (eg. Pl. 4, figs. 10 and 16). A trend towards elongation of the dorsal margin combined with lowered H/L and DM/L ratios is a particularly noticeable feature amongst the Nova Scotian shells (eg. Pl. 4, figs. 11-12), producing shells which approach A. wrighti. A further trend (see Figures 6. 28 & 6. 29) produces elongated forms that resemble A. tenuis or A. calveri sp. nov. depending upon the obliquity of the shell. As shown in earlier Chapters, these variational trends may be related to the palaeoenvironment in which the shells lived. There is a noticeable tendency amongst Nova Scotian A. phillipsii to trend towards shells with slightly longer anterior ends than in comparable British shells.

Amongst shells referred to this 'species' at Mabou Mines are several larger naiaditiform variants which display a slight umbonal swelling and slight carinal arching. Further work could possibly demonstrate a link between these early shells and Naiadites.

Comparison:- A. phillipsi s.s. is distinguishable from all of the Nova Scotian Naiadites by virtue of its subovate outline, shorter anterior end and absence of a carina. A comparison with other 'species' of Anthraconauta is given later.

Distribution:- A. phillipsii dominates the non-marine faunas of the Sydney and Mabou Mines coalfields, although it is rare in the Pictou coalfield. From the first and last records of A. phillipsii in these areas, it would appear to range from low in the *Lonchopteris* floral Zone (upper Westphalian C) to the Lloyd Cove seam (Cantabrian?/lower Stephanian).

ANTHRACONAUTA TENUIS (Davies & Trueman)

Pl. 4, fig. 15; Pl. 5, figs 1-4.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	W	W/L
4	15	17.3	9.6	55.3	2.0	11.6	9.6	55.3	12.5	72.3	8.8	51.0
5 HOLOTYPE	1	25.5	11.9	42.3	2.6	9.5	15.1	55.0	-	-	-	-
5	2	20.8	9.6	46.0	2.2	10.5	9.7	46.6	18.5	89.1	7.7	36.5
5	3	23.2	10.4	44.6	3.5	15.1	12.5	53.9	15.0	64.7	9.6	41.4
5	4	18.5	11.3	60.9	3.2	17.2	9.4	50.6	13.4	54.1	8.5	45.4

Remarks:- Vasey & Zodrow (1983) reported *A. tenuis* from the Sydney coalfield for the first time. Typical *A. tenuis s.s.* is a rare form and represents an extreme variant amongst Nova Scotian assemblages. The modal form is somewhat smaller, has a shorter dorsal margin, longer anterior end, higher W/L ratio and a lower b angle (see Figures 6.28, 6.29). Variation also occurs towards much higher H/L forms resembling *A. calveri*, though displaying much greater postero-ventral attenuation than this 'species'.

The Nova Scotian shells referable to *A. tenuis* possess a consistently longer anterior end than similar British shells, though they are of a comparable size.

Comparison:- *A. tenuis* is a distinctive form having a low H/L ratio and a long posterior end.

Distribution:- *A. tenuis* has been recorded only in the Sydney coalfield, although some shells were collected at Mabou that are referable to *A.* sp. cf. *A. tenuis*. It ranges from the Emery seam (or lower) to the Lloyd Cove seam (lower Westphalian D - lower Stephanian).

ANTHRACONAUTA CALVERI sp. nov (Vasey & Bowes, MS)

Pl. 5, figs 5-10, text-fig. 6. 28c.

Diagnosis:- Shell obliquely subovate and slightly attenuated postero-ventrally; posterior end rather narrowly rounded passing without angulation into the slightly convex ventral margin. Upper posterior margin straight or very slightly convex, subparallel to or slightly convergent with the ventral margin. Most ventral point of the shell well to the posterior end. Anterior end long and more acutely rounded than the posterior end. Dorsal margin straight and greater than half the length of the shell.

Type material:- The holotype is G.S.C. 77273 and the paratypes are G.S.C. 77275 and 77274 from above the Phalen seam, south of Whelan point, near Donkin, Sydney coalfield, Nova Scotia.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	DM	DM/L	D	D/L	W	W/L
5	5	16.0	11.1	69.0	4.1	26.0	10.3	64.0	11.8	73.5	9.4	58.5
5	6	15.8	10.5	66.7	3.9	24.5	10.3	65.0	11.9	75.0	10.2	64.5
5	7	15.6	11.5	70.0	4.2	26.5	10.0	64.0	12.5	79.8	9.7	61.4
5	8	19.2	11.8	61.0	4.5	23.5	11.4	59.0	13.4	70.0	11.2	58.0
5	9	15.3	9.6	63.0	3.7	24.0	10.4	68.0	11.8	77.0	9.9	64.5
5	10	16.8	11.0	65.6	3.3	19.7	10.3	61.0	12.1	72.0	9.8	58.3

Remarks:- The holotype is a laterally flattened right valve with a slightly crushed ventral margin. The paratypes both occur on the same piece of shale and are also laterally flattened.

Variation around the type specimen is shown in Figure 6.28c and two trends are apparent. A trend comprising increasing H/L ratios, decreasing length of dorsal margin and increasing D/L produces extremely attenuated variants with subparallel ventral and upper posterior margins. These variants are similar to A. tenuis (Figure 6.28c, shells L60, 2031, L1 and L25), but have a much smaller b angle than A. tenuis and a shorter dorsal margin. A second trend towards more subovate forms which recall A. phillipsii occurs through a decrease in postero-ventral attenuation and an increase in the length of the dorsal margin (eg. Figure 6.28c, shells 2051, 2038). However these variants have a much longer anterior end and a greater W/L ratio than A. phillipsii.

Comparison:- A. calveri most closely resembles A. phillipsii, but differs from this from in having a greater H/L ratio, a much larger and narrower anterior end, a straight upper posterior margin and a tendency for convergence of the ventral and upper posterior margins. A. calveri has a consistently longer anterior end and a higher H/L ratio than other Anthraconauta.

Distribution:- A. calveri is known only from the Linopteris obliqua floral Zone of the Sydney coalfield (Westphalian D-?lower Stephanian).

ANTHRACONAUTA sp. cf. A. PHILLIPSII (Williamson)

Text-fig. 6. 28d.

Remarks:- A. sp. cf. A. phillipsii is a form very close to A.

phillipsii but having a consistently higher D/L ratio and a slightly larger anterior end. Some postero-ventral elongation is also seen amongst these shells (Figure 6.28d, shells 3b, 62, 75 & 36).

Until such time as further collections are made, the true status of this form cannot be commented on.

Distribution:- Above the Phalen seam, south of Whelan point, near Donkin, Sydney coalfield.

ANTHRACONAUTA sp. cf. A. WRIGHTI (Dix & Trueman)

Text-fig. 6. 29d.

Remarks:- A. sp. cf. A. wrighti is an extreme variant amongst some assemblages collected from a coarser than usual sediment. It possess a very long dorsal margin and smaller posterior end but it has a much longer anterior end than A. wrighti s.s.

Distribution:- A. sp. cf. A. wrighti occurs sporadically as an extreme variant throughout the range of Anthraconauta in the Sydney coalfield.

Genus ANTHRACONAIA Trueman & Weir, 1946

ANTHRACONAIA sp. cf. A. PULCHELLA Broadhurst

Pl. 5, figs. 11-14, 16-17.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	HMA	HMA/L	HP	HP/L
5	11	6.8	3.7	54.6	1.8	27.1	2.3	34.3	2.5	37.3
5	12	7.5	3.9	52.4	1.7	22.8	2.0	27.1	2.3	30.7
5	13	8.3	4.5	53.8	2.6	30.1	2.8	33.6	2.9	35.8
5	14	7.8	4.6	58.5	2.3	29.6	3.0	38.1	2.3	29.6
5	16	10.5	6.0	57.1	2.7	25.9	3.3	31.6	3.6	34.3
5	17	13.4	7.1	53.1	3.2	23.9	4.5	33.4	4.3	31.9
HOLOTYPE from Weir, 1968, Pl. XLII, fig. 9.		13.0	7.0	54.0	3.3	25.0	5.5	42.3	7.2	55.4

Remarks:- *A*. sp. cf. *A. pulchella* is a small, possibly stunted, transversely elliptical, delicate form which bears considerable resemblance to *A. pulchella* *s.s*. Broadhurst of the lower Similis-Pulchra Chronozone of Lancashire. A common feature of the Nova Scotian shells is a tendancy for the umbonal growth lines to be forwardly tilted such that the shell takes on an *Anthracosia*-like appearance. Similarly, such forward tilting of juvenile growth lines occurs amongst Broadhurst's (1959) material (Weir, 1968, p. 377) (see Pl. 5, fig. 11 and Weir 1968, Pl. XLII, fig. 15.).

No internal or hinge details have been seen either in the Nova Scotian material or in the Lancashire shells of which Weir

(1968, p.377) says " the hinge is unknown and the true affinities of *A. pulchella* are uncertain ".

Variation within the Nova Scotian shells is shown in Figures 6.30 and 6.31. The major trend is one of increasing height and length of the anterior end, increasing H/L ratios and a trend towards subparallel ventral and dorsal margins. The more elongate and larger variants amongst the Lancashire shells are missing from the Phalen seam locality (Figure 6.30), but some elongate shells referable to *A. arenacea s.l.* do occur amongst the Glace Bay shells (Figure 6.31).

Although similar to *A. pulchella* in their general external shape, umbonal tilt and size, the Nova Scotia shells are provisionally referred to *A.* sp. cf. *A. pulchella* as they occur well within the Westphalian D (Tenuis Chronozone) of the Sydney coalfield and are much younger than the British shells. Certain morphological differences also occur, thus the anterior and posterior ends in the holotype are much lower and the posterior margin which tends to be only slightly convex and steeply inclined in the Lancashire shells is more strongly convex in the Nova Scotia shells.

Comparison:- *A.* sp. cf. *A. pulchella* Broadhurst differs from *A. pulchella* in the features mentioned above. *A. pulchra* (Hind) of the upper Similis-Pulchra Chronozone of Britain is somewhat larger, more elongate with a lower H/L ratio and has more prominant umbones. Other British shells of similar external morphology are much larger.

Distribution:- *A.* sp. cf. *A. pulchella* is known only from two discrete beds in the Sydney coalfield where it ranges from the roof of the Phalen seam to between the Backpit and Bouthillier seams of upper Westphalian D age.

ANTHRACONAIA sp. nov. A.

Pl. 5, fig. 15.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	HMA	HMA/L	HP	HP/L
5	15	7.0	4.8		2.2		2.5		2.7	
				68.2		31.8		35.7		38.6

Remarks:- These small, subelliptical, high H/L shells were not formally named due to poor preservation and the small number of specimens collected. The tendency for a slightly convex and inclined dorsal margin, long broad and low anterior end and forwardly tilted umbonal growth lines make this quite a distinct form. No internal details are known.

Distribution:- _A_. sp. nov. A. has been recorded only from two distinct shell beds between the Backpit and Bouthillier seams and betten the Harbour and Hub seams of the Sydney coalfield (upper Westphalian D).

ANTHRACONAIA sp. cf. A. SARAVANA (Schmidt)

Pl. 5, figs. 18-19, 23-24.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	HMA	HMA/L	HP	HP/L
5	18	5.0	2.7		1.4		1.4		-	
				53.3		28.0		28.0		
5	19	6.5	3.6		1.6		1.7		2.2	
				55.1		25.1		26.2		33.2
5	23	5.9	3.5		1.1		1.4		2.4	
				59.7		18.8		24.2		40.4
5	24	7.9	4.2		1.9		2.1		2.4	
				53.0		24.3		26.4		30.6

Remarks:- The type of *A. saravana* (Schmidt) is lost (see Eagar in press [1979]) and a search at its imprecisely defined horizon has failed to reveal further specimens (*ibid*.). Eagar (*ibid*., Pl. 1) usefully figures some shells referred to *A. saravana s.l*. from the Stephanian B of Germany and it is with these that comparison has been made.

The Nova Scotian shells are small and may be stunted, but display the parallelism of the ventral and dorsal margins characteristic of *A. saravana* (Pl. 5, fig. 19 for eg.). The umbones are low and indistinct, and on a level with the straight dorsal margin. The posterior margin is steeply inclined (nearly vertical) whilst the anterior end is high and relatively short. A feature of several of the Nova Scotian shells is the deep, concave antero-umbonal slope.

Variation within the *A*. sp. cf. *A. saravana* group takes place mainly in terms of increasing elongation and shortening of the anterior end (see Figure 6. 32 (2), shells 1799 & 1855). An opposite trend occurs towards more anthracosiid-like variants with higher H/L ratios (Figure 6.32 (2), shells 1820, 1824 and 16).

Comparison:- *A*. sp. *A. saravana* is a distinctive form due to a combination of the subparallelism of the ventral and dorsal margins, short, high anterior end, indistinct umbones and almost vertical posterior margin.

Distribution:- *A. saravana* in Europe is a Cantabrian-early Stephanian B form (Eagar in press [1979], in prep. [1983]). In the Sydney coalfield it occurs between the Harbour and Hub seams (possible Cantabrian).

ANTHRACONAIA sp. aff. A. SPECIOSA Eagar

Pl. 5, figs. 25-26; Pl. 6, figs 1-2, 9.

Measurements and form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	HMA	HMA/L	HP	HP/L
5	25	11.1	5.3	47.3	2.5	22.5	2.9	26.4	3.1	28.0
5	26	13.4	7.1	53.0	3.6	27.2	3.5	26.1	4.6	34.7
6	1	(7.8)	3.7	(47.4)	1.7	(22.2)	2.0	(25.6)	-	-
6	2	7.2	3.3	46.0	1.6	22.2	2.0	28.4	1.6	22.5
HOLOTYPE from Eagar, 1975, Pl. 20.		4.6	2.2	47.8	1.2	26.7	1.2	25.5	1.5	32.1

Remarks:- *A. speciosa* Eagar is smaller than the Nova Scotian shells being 4-6 mm in length (Eagar 1975, p.54). The holotype from above the Gallitzin coal, Pennsylvania (?Stephanian A), has subparallel ventral and dorsal margins and prominent, gently swollen umbones.

The Nova Scotian material, although larger, has similar form ratios (see above) combined with the general external morphology of the holotype. However, in the Nova Scotian shells, the umbo is not as swollen nor does it usually rise as high above the dorsal margin.

Variation within the *A.* sp. aff. *A. speciosa* group occurs mainly in terms of the H/L ratio and depth of the anterior end. Typically the modal form is a shell very similar to *A. speciosa s.s.* except that it is much larger. Arching of the dorsal margin and a more rounded postero-dorsal angle is a feature of many variants, producing a *Carbonicola*-like outline.

Comparison:- *A*. sp. cf. *A. speciosa* is distinguishhable from *A*. sp. cf. *A. saravana* in its lower H/L ratio, generally longer anterior end and its more inflated umbones which are often raised above the level of the dorsal margin. *A*. sp. nov. A and *A*. sp. cf. *A. pulchella* have higher H/L ratios and are generally less elongate.

Distribution:- *A*. sp. cf. *A. speciosa* is recorded from a single locality in the Sydney coalfield between the Harbour and Hub seams. It is probably a lower Stephanian A form in the Appalachians (Eagar 1975) and is considered here to occur in lower Stephanian, possibly Cantabrian strata.

ANTHRACONAIA sp. cf. A. PALATINA (Schmidt)

Remarks:- The type of *A. palatina* is lost (Eagar in press [1979]) and Schmidt's drawing (see Eagar *ibid*., Pl.1), although usefully stressing the wide angle at which growth lines commonly meet both the dorsal margin and the anterior umbonal slope, is a biological impossibility in that no space is left for the posterior extension of the ligament (*ibid*.).

A. palatina is a *Carbonicola*-like, dorsally-arched shell of moderate to high H/L ratio. The Nova Scotian shells which are referred to *A*. sp. cf. *A. palatina*, display both the dorsal arching and the general external morphology of *A. palatina*.

Variation occurs mainly in terms of the length of the anterior end combined with an approach to high, slightly prosogyrous umbones. The ventral margin is slightly convex and because of the backwardly inclined dorsal margin, tends to produce a rather narrow posterior.

The shells referred to *A.* sp. cf. *A. palatina* are not figured in the plates due to their small size and general poor state of preservation (but see Figure 6.32).

Comparison:- *A.* sp. cf. *A. palatina* is a distinct form with its dorsally-arched, *Carbonicola*-like outline. It resembles *A.* sp. nov. A in some features from which it may be distinguished by its lower and narrower anterior end and larger anterior.

Distribution:- As for *A.* sp. aff. *A. speciosa*.

ANTHRACONAIA ARENACEA (Dawson)

Pl. 6, figs. 3-8, 10.

Naiadites arenaceus DAWSON, 1860, p. 44.
Naiadites arenacea DAWSON, 1868, p. 205, text-fig. 45.
Anthracomya arenacea DAWSON, 1894, p. 128, text-fig. 10.
Anthraconaia arenacea ROGERS, 1965, p. 681, Pl. 85, figs. 17-22, 26, 27.

Diagnosis:- Shell subelliptical in profile. Umbones broad, slightly prosogyrous and very slightly raised above the dorsal margin. Anterior end short, broad, having a strongly curved margin. Ventral margin long, almost straight in the middle third, curving into a slightly expanded posterior end. A broad, gentle convexity runs from the umbo towards the postero-ventral extremity.

Type material:- The lectotype of *A. arenacea* is R.M. 3131 (Pl. 6, figs. 8, 10).

Measurements & form ratios:-

Pl.	fig.	L	H	H/L	A	A/L	HMA	HMA/L	HP	HP/L
6	3	13.8	6.7		4.3		3.4		3.6	
				48.3		31.4		24.8		26.3
6	5	6.7	3.3		2.1		1.3		2.4	
				48.7		31.5		18.9		36.2
6	6	9.5	4.1		2.2		2.2		2.4	
				43.0		22.9		22.9		25.7
6	7	25.6	8.5		7.3		4.3		6.1	
				33.2		28.2		16.6		23.8
6	8	28.0	10.3		4.4		5.2		6.3	
Holotype				36.8		15.6		18.4		22.5
6	9	28.0	10.2		4.4		5.1		5.9	
Holotype				36.4		15.6		18.2		21.2
(right valve).										

Remarks:- Rogers (1965, p. 681) gives a brief history of this 'species'. The type specimen is a natural cast of an articulated and open shell preserved in a fine-grained sandstone.

A. arenacea is a rare form in Nova Scotia and in the Sydney coalfield it is restricted to the coarser parts of lake delta sequences. Shells which are here referred to A. arenacea s.l. (Pl. 6, fig. 3) having a higher H/L ratio, longer anterior end and a shorter posterior collected from markedly dark coloured shales, are considered to represent a variational end point. Variation in the A. arenacea group occurs in terms of elongation, decreasing length and increasing hieght of the anterior end. As such , the type specimen is an extreme variant. The modal form is appears to be a smaller, less elongated shell with a longer anterior end (eg. Pl. 6, fig. 6). Some variants (which have not been figured) display an almost anthraconautiform outline (see Figure 6.31), in which there is marked posterior expansion behind a short dorsal margin.

Comparison:- Rogers (1965) gives a comparison of A. arenacea with several similar British forms the most similar of which is A. pruvosti (Tchernyshev). A. pruvosti is typically slightly less elongate, has a straighter ventral margin and a greater H/L ratio. The shell figured as Pl. 6, fig. 7 is somewhat similar to A. oblonga of the Lower Similis-Pulchra Chronozone of Britain, but A. oblonga is appreciably more elongate and has a higher anterior end.

Distribution:- A. arenacea occurs within the middle Linopteris obliqua floral Zone of Zodrow (1982) in the Sydney coalfield but is quite rare. It has also been recorded from strata of a similar age in the Pictou coalfield. A. arenacea would appear to be a good middle and upper Westphalian D indicator in Nova Scotia.

PLATES

PLATE ONE

PLATE ONE

FIGURE 1: *Carbonicola? angulata* (Dawson) Tracing of the type specimen R.M.3132 (from Rogers (1965, pl. 83, fig. 7). Canso Gp., Mabou X .

FIGURE 2: *Carbonicola?* sp. cf. *C. fallax* Wright GMV2599 X2.5 (see also Figure 4.10b), West Bay Fm. (Canso Gp.), Parrsboro roadcutting

FIGURE 3: *Carbonicola?* sp. cf. *C. fallax* Wright C1 X2.5 (see also Figure 4.10b), as fig. 2 above.

FIGURE 4: *Carbonicola?* sp. aff. *C?. angulata* (Dawson) GMV2587a X2.8 as for fig. 2.

FIGURE 5: *Carbonicola?* sp. aff. *C?. angulata* (Dawson) GMV2587b X2.4 as for fig. 2.

FIGURE 6: *Carbonicola?* sp. C2 X3.9, as for fig. 2 above.

FIGURE 7: *Carbonicola? angulata* (Dawson) Type specimen, R.M. 3132 X1.5, from Hind (1894, pl. 20, fig. 14). See also Rogers (1965, pl. 83, fig. 9). As for fig. 1 above.

FIGURE 8: *Carbonicola sculponeata* Rogers Holotype R.M.10011 X2. From Rogers (1965, pl. 83, fig. 6). As for fig. 1 above.

FIGURE 9: *Carbonicola?* sp. cf. *C. sculponeata* Rogers GMV2786 X2.6 (see also Figure 4.6a). Boss Point Fm., (Riversdale Gp.) of Boss Point, Joggins.

FIGURE 10: *Carbonicola? eagari* sp. nov. Holotype. GMV2792 X2.4. (See also Figure 4. 6a). Note forwardly tilted juvenile growth lines. Shell margins and growth lines retouched. As for fig. 9 above.

FIGURE 11: *Carbonicola? eagari* sp. nov. Holotype. GMV2792 X2.4. As for fig. 10 above but without retouching.

FIGURE 12: *Carbonicola? eagari* sp. nov. Paratype. GMV2782 X2.8. As for fig. 10 above.

FIGURE 13: *Carbonicola? eagari* sp. nov. Paratype. As fig. 12 above, retouched margins.

FIGURE 14: *Carbonicola?* sp. aff. *C?. eagari* sp. nov. Topotype. GMV2834 X2.3.

FIGURE 15: *Carbonicola?* sp. cf. *C. sculponeata* Rogers GMV2777 X3.7. As for fig. 10.

FIGURE 16: *Carbonicola? eagari* sp. nov. Topotype. BP0002 X2.8.

FIGURE 17: *Paracarbonicola? bradorica* (Dawson) Lectotype. R.M.2834 X5. From Rogers 1965, pl. 83, fig. 5). Canso Gp. ? of Baddeck. (See also Rogers *ibid*)

FIGURE 18: *Paracarbonicola? bradorica* (Dawson) Lectotype, lateral view, as fig. 17.

FIGURE 19: *Curvirimula? ovalis* (Dawson) Type specimen, R.M. 21170 X2.5 approx. Riversdale Gp., Parrsboro Fm of Parrsboro. (See also Rogers, 1965, pl. 85, figs. 2-5).

FIGURE 20: *Curvirimula belgica* (Hind) GMV587b X3.2. Port Hood Fm. (Riversdale Gp.), Cape Linzee Section, horizon PHd, Port Hood.

FIGURE 21: *Curvirimula belgica* (juv.) GMV578 X6.7. As for fig. 20 above.

FIGURE 22: *Curvirimula belgica* (Hind) GMV587a X4.4. As for fig. 20 above.

FIGURE 23: *Curvirimula* sp. cf. *C. belgica* (Hind) GMV580 X3.2, as for fig 20 above

FIGURE 24: *Curvirimula* sp. aff. *C. belgica* (Hind) GMV330a X4.1. N.S. Dept. of Mines & Energy Hole D.D.N.S.C.C.1, 128.89m, horizon CC1b, Chimney Corner.

FIGURE 25: *Curvirimula* sp. aff. *C. belgica* (Hind) GMV2222 X4.1, as for fig. 20, horizon PHd.

PLATE ONE

FIGURE 1: *Carbonicola? angulata* (Dawson) Tracing of the type specimen R.M.3132 (from Rogers (1965, pl. 83, fig. 7). Canso Gp., Mabou x .

FIGURE 2: *Carbonicola?* sp. cf. *C. fallax* Wright GMV2599 X2.5 (see also Figure 4.10b), West Bay Fm. (Canso Gp.), Parrsboro roadcutting

FIGURE 3: *Carbonicola?* sp. cf. *C. fallax* Wright C1 X2.5 (see also Figure 4.10b), as fig. 2 above.

FIGURE 4: *Carbonicola?* sp. aff. *C?. angulata* (Dawson) GMV2587a X2.8 as for fig. 2.

FIGURE 5: *Carbonicola?* sp. aff. *C?. angulata* (Dawson) GMV2587b X2.4 as for fig. 2.

FIGURE 6: *Carbonicola?* sp. C2 X3.9, as for fig. 2 above.

FIGURE 7: *Carbonicola? angulata* (Dawson) Type specimen, R.M. 3132 X1.5, from Hind (1894, pl. 20, fig. 14). See also Rogers (1965, pl. 83, fig. 9). As for fig. 1 above.

FIGURE 8: *Carbonicola sculponeata* Rogers Holotype R.M.10011 X2. From Rogers (1965, pl. 83, fig. 6). As for fig. 1 above.

FIGURE 9: *Carbonicola?* sp. cf. *C. sculponeata* Rogers GMV2786 X2.6 (see also Figure 4.6a). Boss Point Fm., (Riversdale Gp.) of Boss Point, Joggins.

FIGURE 10: *Carbonicola? eagari* sp. nov. Holotype. GMV2792 X2.4. (See also Figure 4.6a). Note forwardly tilted juvenile growth lines. Shell margins and growth lines retouched. As for fig. 9 above.

FIGURE 11: *Carbonicola? eagari* sp. nov. Holotype. GMV2792 X2.4. As for fig. 10 above but without retouching.

FIGURE 12: *Carbonicola? eagari* sp. nov. Paratype. GMV2782 X2.8. As for fig. 10 above.

FIGURE 13: *Carbonicola? eagari* sp. nov. Paratype. As fig. 12 above, retouched margins.

FIGURE 14: *Carbonicola?* sp. aff. *C?. eagari* sp. nov. Topotype. GMV2834 X2.3.

FIGURE 15: *Carbonicola?* sp. cf. *C. sculponeata* Rogers GMV2777 X3.7. As for fig. 10.

FIGURE 16: *Carbonicola? eagari* sp. nov. Topotype. BP0002 X2.8.

FIGURE 17: *Paracarbonicola? bradorica* (Dawson) Lectotype. R.M.2834 X5. From Rogers 1965, pl. 83, fig. 5). Canso Gp. ? of Baddeck. (See also Rogers *ibid*)

FIGURE 18: *Paracarbonicola? bradorica* (Dawson) Lectotype, lateral view, as fig. 17.

FIGURE 19: *Curvirimula? ovalis* (Dawson) Type specimen, R.M. 2170 X2.5 approx. Riversdale Gp., Parrsboro Fm of Parrsboro. (See also Rogers, 1965, pl. 85, figs. 2-5).

FIGURE 20: *Curvirimula belgica* (Hind) GMV587b X3.2. Port Hood Fm. (Riversdale Gp.), Cape Linzee Section, horizon PHd, Port Hood.

FIGURE 21: *Curvirimula belgica* (juv.) GMV578 X6.7. As for fig. 20 above.

FIGURE 22: *Curvirimula belgica* (Hind) GMV587a X4.4. As for fig. 20 above.

FIGURE 23: *Curvirimula* sp. cf. *C. belgica* (Hind) GMV580 X3.2, as for fig 20 above

FIGURE 24: *Curvirimula* sp. aff. *C. belgica* (Hind) GMV330a X4.1. N.S. Dept. of Mines & Energy Hole D.D.N.S.C.C.1, 128.89m, horizon CC1b, Chimney Corner.

FIGURE 25: *Curvirimula* sp. aff. *C. belgica* (Hind) GMV2222 X4.1, as for fig. 20, horizon PHc.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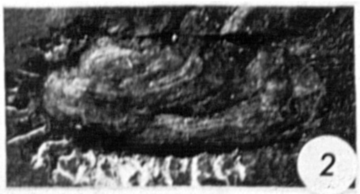
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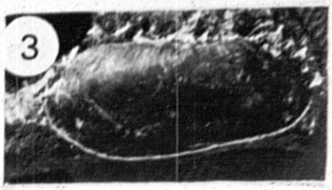
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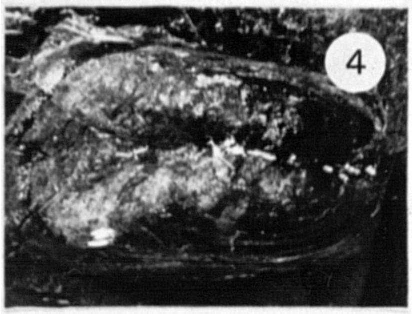
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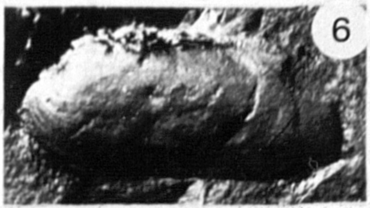
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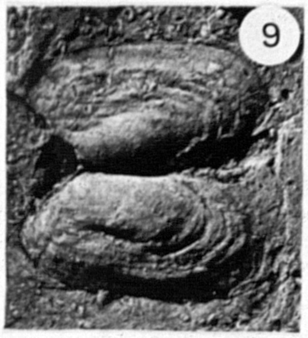
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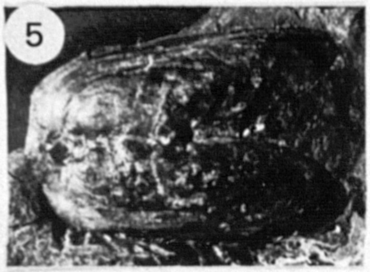
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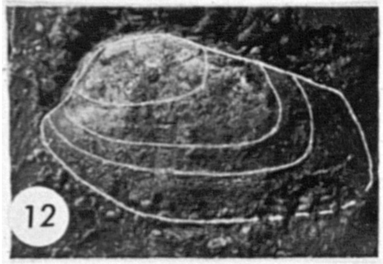
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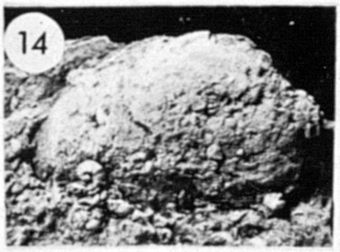
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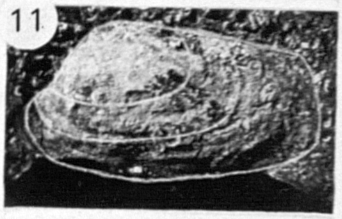
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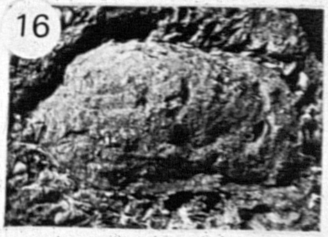
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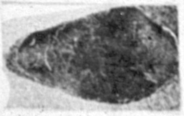
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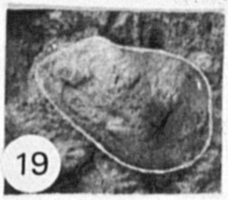
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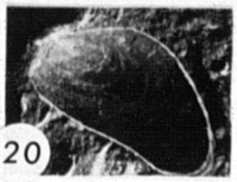
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PLATE TWO

PLATE TWO

FIGURE 1: *Curvirimula* sp. aff. *C*. *belgica* (Hind) GMV3161 X3.2, N.S. Dept. of Mines & Energy Hole D.D.N.S C C.1, 127.26 m, horizon CC1b, Chimney Corner (Riversdale Group).

FIGURE 2: *Curvirimula belgica* (Hind) GMV1230 X4.2, N.S. Dept. of Mines & Energy Hole D.D.N.S.C.C.3, 39.43m, horizon CC3b, Chimney Corner.

FIGURE 3: *Curvirimula* sp. cf. *C*., *trapeziforma* (Dewar) GMV328b X2, as for fig. 1 above, 128.55 m, horizon CC1b.

FIGURE 4: *Curvirimula* sp. cf. *C*. *trapeziforma* (Dewar) GMV1102 X3.8, as for fig. 2 above, 40.35 m, horizon CC3b, (see also Figure 4.31a).

FIGURE 5: *Curvirimula* sp. aff. *C*. *corvosa* Rogers GMV1239 X3.8, as for fig. 2 above, 40.35 m, horizon CC3b.

FIGURE 6: *Curvirimula* sp. aff. *C*. *trapeziforma* (Dewar) GMV1066 X3.8, as for fig 1 above, 127.5 m, horizon CC1b.

FIGURE 7: *Curvirimula mytiloides* (Dawson) Holotype. R M. 21163z X4 approx., Chimney Corner (Riversdale Gp.), Horizon CCc (roof of #5 seam). See also Rogers (1965, pl. 83, fig. 33) and also Vasey (1984, pl.1, figs, c & d).

FIGURE 8: *Curvirimula* sp.aff. *C*. *trapeziforma* (Dewar) GMV1281 X3, as for fig 2 above, 116.93 m, horizon CC1b.

FIGURE 9: *Curvirimula corvosa* Rogers Holotype. R.M 21163b, X . On the same peice of shale as fig. 17 above. Chimney Corner, Horizon CCc. See also Rogers (1965, pl. 84, figs. 29-30) and Vasey (1984, pl. 1, figs. a, b.).

FIGURE 10: *Curvirimula* sp. aff. *C*. *corvosa* Rogers GMV1094 X3 7 (*C*. *belgica* - like variant - see Figure 4. 30b and text). As for fig. 1 above, 128.9 m, horizon CC1b.

FIGURE 11: *Curvirimula* sp. aff. *C*. *attenuata* sp. nov. GMV330b X3.8, as for fig. 1 above, 128.9 m, horizon CC1b.

FIGURE 12: *Curvirimula attenuata* sp. nov. GMV2264 X3 4. Cape Linzee Section, Port Hood, Port Hood Fm (Riversdale Gp.), horizon PHc.

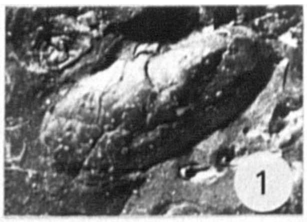
FIGURE 13: *Curvirimula attenuata* sp. nov. GMV1096 X3.7, as for fig. 1 above, 129. 09 m, horizon CC1b. (See also Figure 4. 30c).

FIGURE 14: *Curvirimula attenuata* sp. nov. GMV1071 X3.8, as for fig. 1 above, 128. 04 m, horizon CC1b. (See also Figure 4. 30c).

FIGURE 15: *Curvirimula attenuata* sp. nov Holotype. GMV1075 X4.4, as for fig. 1 above, 128. 25 m, horizon CC1b. (See also Figure 4. 30c).

FIGURE 17: *Curvirimula attenuata* sp. nov. Paratype. GMV1239b X3 8, as for fig. 2 above, 40.35 m, horizon CC3c. (See also Figure 4. 30c).

FIGURE 16: *Naiadites* sp. GMV1413 X5.6 Internal view of hinge and anterior musclature. N.S. Dept. of Mines & Energy Hole D.D.N.S.R.H. 7, 149' 8", River Hebert, Cumberland Group. Compare with Newell (1940, 1942).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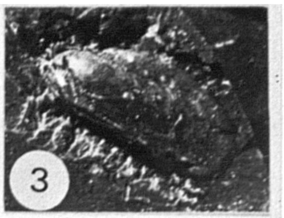
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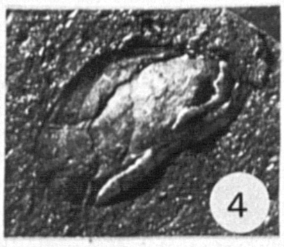
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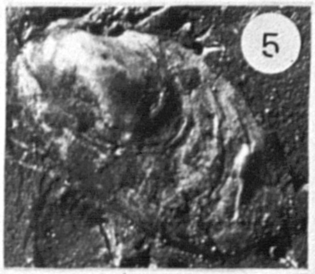
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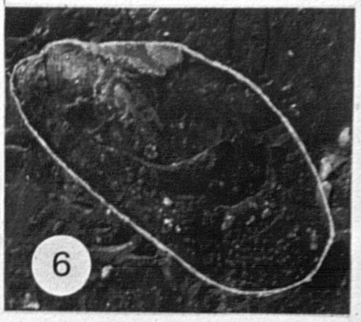
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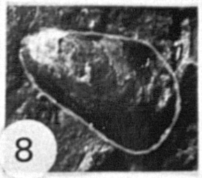
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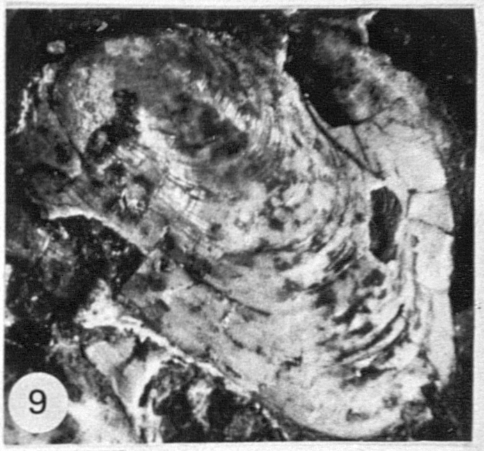
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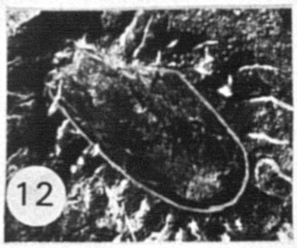
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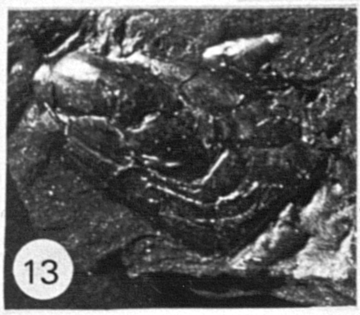
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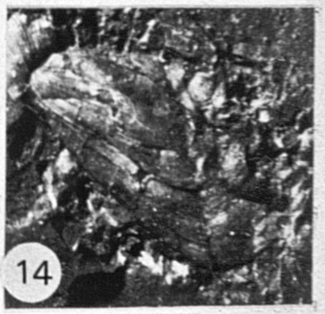
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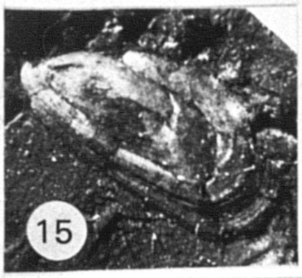
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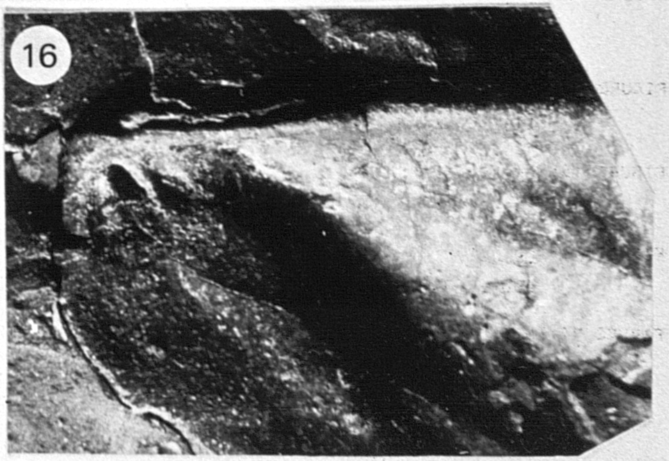
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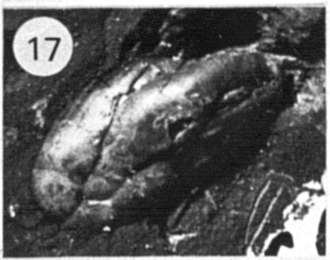
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PLATE THREE

PLATE THREE

FIGURE 1: *Naiaidites longus* Dawson Internal view, B.M L47801 X2 5 See also Rogers (1965, pl. 83, fig. 25) and compare with Newell (1940, 1942), Joggins

FIGURE 2: *Naiadites carbonarius* Dawson Lectotype. R.M. 21172a X2.5 approx. See also Newell (1942, pl. 15, fig. 2b) and Rogers (1965, pl. 83, fig. 10-13). Middle Coal Formation of Dawson, Joggins

FIGURE 3: *Naiadites* sp. aff. *N. carbonarius* Dawson GMV1281b X2.4. N.S. Dept. of Mines & Energy Hole D.D.N.S.C.C.3, 116.93 m, horizon CC3e, Chimney Corner (Riversdale Group).

FIGURE 4: *Naiadites carbonarius* Dawson GMV2228 X2.4. Cape Linzee Section, Port Hood, horizon PHd. Port Hood Formation,(Riversdale Group). See also Figure 4. 19)

FIGURE 5: *Naiadites carbonarius* Dawson GMV2221 X2.1 As for fig. 4 above, horizon PHd. See Figure 4. 19.

FIGURE 6: *Naiadites* sp. cf. *N. daviesi* Dix & Trueman GMV2628 X2.9. Farrell Brook Section, Parrsboro (Parrsboro Formation, Riversdale Group). *N. carbonarius* - like variant - see Figure 4. 14a.

FIGURE 7: *Naiadites* sp. aff. *N carbonarius* Dawson GMV1281b X2.4 As for fig. 3 above, 38.78 m, horizon CC3e

FIGURE 8: *Naiadites carbonarius* Dawson GMV1315 X2 8. N S. Dept. of Mines & Energy Hole D.D.N S.C C 3, 161.76 m, horizon CC3f.

FIGURE 9: *Naiadites* sp. cf. *N. productus* (Brown) GMV2215 X2.4. As for fig. 4 above, horizon PHd. See also Figure 4.19.

FIGURE 10: *Naiadites* sp. cf. *N. triangularis* (J. de C. Sowerby) GMV1342 X1.9 N.S. Dept. of Mines & Energy Hole D.D.N.S.R.H.8, 222' 6½".

FIGURE 11: *Naiadites* sp. aff. *N. productus* (Brown) GMV2629a X2.6. Coastal section, Parrsboro. Parrsboro Formation (Riversdale Gp.).

FIGURE 12: *Naiadites carbonarius* Dawson GMV225 X2. N.S. Dept. of Mines & Energy Hole D.D.N.S.P.H.2, 661.56 m, Port Hood Fm., Port Hood.

FIGURE 13: *Naiadites* sp. cf. *N. triangularis* (J. de C. Sowerby) GMV1192b X1.5. As for fig. 3 above, 196.77 m, horizon CC3j.

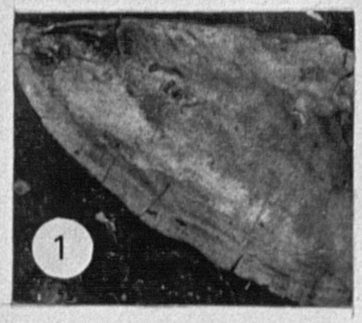
FIGURE 14: *Naiadites* sp. aff. *N. daviesi* Dix & Trueman GMV2653 X3.6. As for fig. 6 above.

FIGURE 15: *Naiadites* sp. aff. *N. productus* (Brown) GMV1152 X2.5. As for fig. 3 above, 166.01 m, horizon CC3g.

FIGURE 16: *Naiadites subtruncatus* (Brown) GMV578 X1.2. As for fig. 4 above, horizon PHc.

FIGURE 17: *Naiadites* sp. aff. *N. productus* (Brown) GMV2512 X2.9. Chimney Corner coastal section, horizon CCd, (Riversdale Gp).

FIGURE 18: *Naiadites subtruncatus* (Brown) GMV575 X2.2. As for fig. 16 above. See also Figure 4.19.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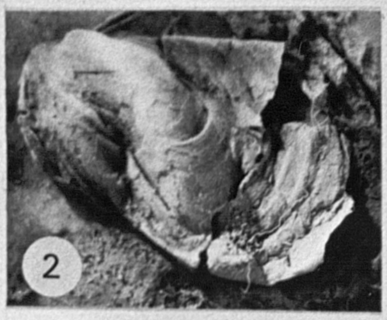
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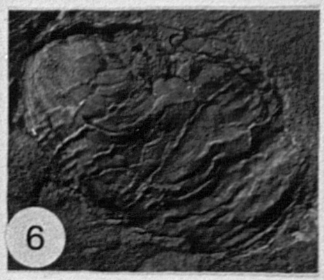
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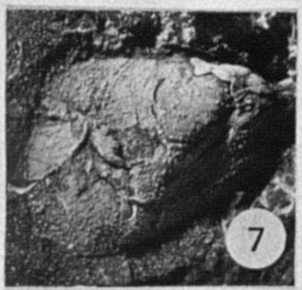
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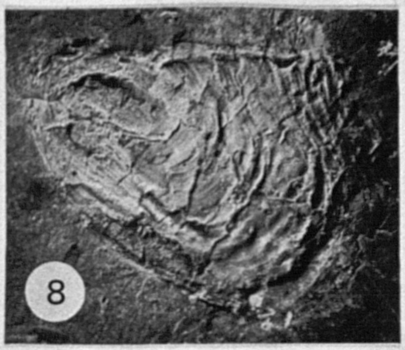
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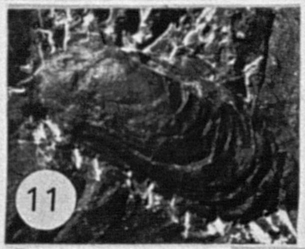
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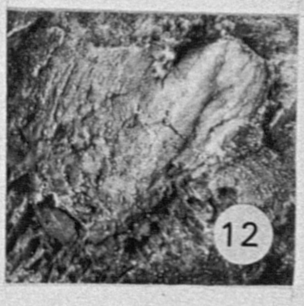
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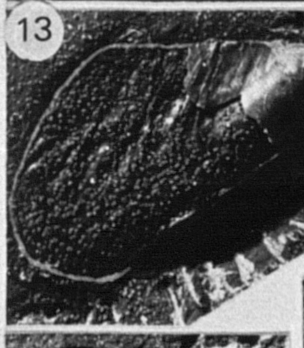
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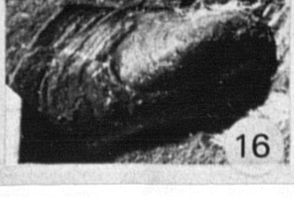
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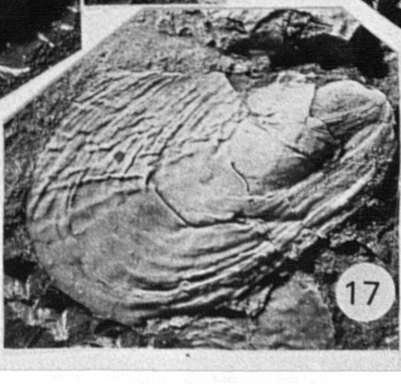
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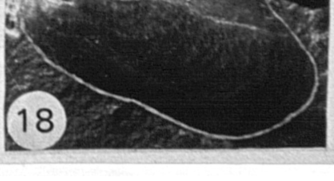
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PLATE FOUR

PLATE 4

1 - *Naiadites* sp. aff. *N*. *subtruncatus* (Brown) GMV1192 X2.3, N.S. Dept. of Mines & Energy Hole d.d.n.s.c.c.-3, 198.63 m, Horizon CC3j (Riversdale Group).

2 - *Naiadites* sp. cf. *N*. *productus* (Brown) (a *N*. *subtruncatus*-like variant) GMV2629b X2.4, coastal section, Parrsboro, Parrsboro Formation (Riversdale Group). See also Figure 4.14b).

3 - *Naiadites* *subtruncatus* (Brown) GMV2224 X4. Cape Linzee section, Port Hood, Port Hood Fm. (Riversdale Group). Horizon PHd, See also Figure 4.19.

4 - *Naiadites* sp. cf. *N*. *quadratus* (J. de C. Sowerby) GMV1361 X3.9, N.S. Dept. of Mines & Energy Hole D.D.N.S.R.H.-8, 226' 1'', Cumberland Group of River Hebert.

5 - *Naiadites* sp. aff. *N*. *subtruncatus* (Brown) GMV2633 X3, Coastal section, Parrsboro, as for Figure 2 above.

6 - *Naiadites* sp. cf. *N*. *daviesi* Dix & Trueman GMV1415 X2.4, as for Figure 4 above except Hole D.D.N.S.R.H.-7, 149' 1½".

7 - *Naiadites* sp. aff. *N*. *productus* (Brown) GMV1402 X4.2, as for Figure 6 above, 254' 7½".

8 - *Naiadites* sp.cf. *N*. *quadratus* (J. de C. Sowerby) GMV1315 X2.6, As for Figure 1 except Horizon CC3f, 161.76 m.

9 - *Naiadites* sp. aff. *N* *productus* (Brown) GMV1208 X2.8, as for Figure 1 above, 205.72 m, Horizon CC3k.

10 - *Anthraconauta* *phillipsii* (Williamson) GMV115a X3, N.S. Dept. of Mines & Energy Hole P1, 1453', Above Harbour seam, Sydney offshore.

11 - *Anthraconauta* *phillipsii* (Williamson) G.S.C. 77252 (GMV179) X2. N.S. Dept. of Mines & Energy Hole PA-8-79, 84' 1½". Between the Harbour & Hub seams, Sydney coalfield.

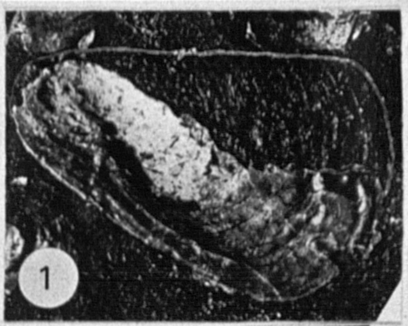
12 - *Anthraconauta* *phillipsii* (Williamson) G.S.C 77253 (GMV477) X2. Lingan shore, between Harbour & Hub seams (about 2.4 m above the algal limestone), Sydney coalfield.

13 - *Anthraconauta* *phillipsii* (Williamson) Holotype M.M. L10106, X2 approx. Ardwick, Manchester. (See also Hind (1893, Pl. x, fig. 27), Hind (1895, Pl.xvi, fig. 10), Dix & Trueman (1931, Pl. xvii, figs 1a, 1b) an Trueman & Weir (1960 Pl. xxxii, fig. 1).

14 - *Anthraconauta* sp. aff. *A*. *phillipsii* (Williamson) L54a X2.2, south of Whelan Point, above Phalen seam, Sydney coalfield.

15 - *Anthraconauta* sp. aff. *A*. *tenuis* (Davies & Trueman) L54b, X2.8, as for Figure 14.

16 - *Anthraconauta* sp. aff. *A*. *phillipsii* (Williamson) L1b X3, as for Figure 14 above.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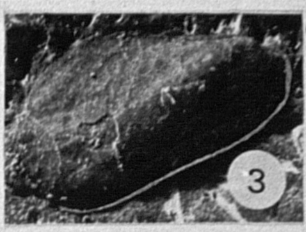
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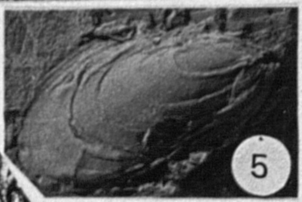
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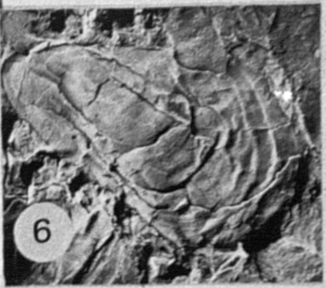
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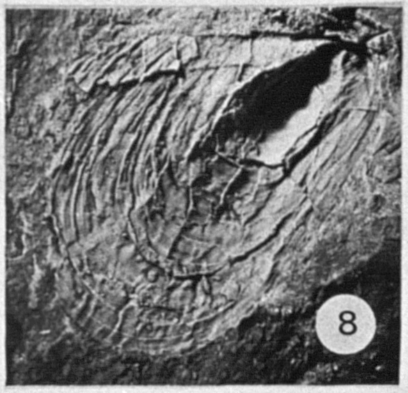
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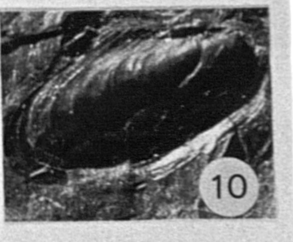
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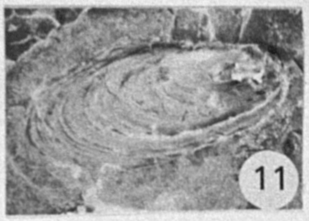
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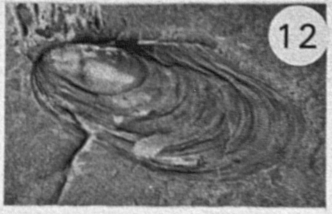
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PLATE FIVE

PLATE 5

1 - Anthraconauta tenuis (Davies & Trueman) Holotype, B.M. L52589 X2 approx. Rhos, Pontardave, Glamorgan. Tenuis Chronozone. (see also Davies & Trueman 1927, Pl. xvi, fig. 8, Weir 1960, Pl. xxxii, fig. 23, and Eagar 1973, Pl. 1, fig. 11).

2 - Anthraconauta tenuis (Davies & Trueman) SW65 X3. South of Whelan Point, Donkin, Sydney. Above the Phalen seam. (See also Figure 6. 28).

3 - Anthraconauta tenuis (Davies & Trueman) G.S.C. 77256 (GMV502) X2, East side of Schooner Cove, Sydney coalfield. Between Emery & Phalen seams.

4 - Anthraconauta sp. cf. A. tenuis (Davies & Trueman) L42 X2.2. Lingan shore, Sydney coalfield. Between the Harbour & Hub seams. (See also Figure 6.29).

5 - Anthraconauta calveri sp. nov. (Vasey & Bowes MS) Holotype G.S.C. 77273 X2 (GMV2844). Roof of the Phalen seam, south of Whelan Point, Sydney. (See Figure 6. 28).

6 - Anthraconauta calveris sp. nov. Paratype G.S.C. 77275 X2 (GMV2824b), as for Figure 5 above.

7 - Anthraconauta calveri sp. nov. Paratype G.S.C. 77274 X2 (GMV2824c), as for Figure 5 above.

8 - Anthraconauta calveri sp. nov. Topotype G.S.C. 77277 X2 (GMV2845), as for Figure 5 above.

9 - Anthraconauta sp. aff. A. calveri sp. nov. G.S.C. 77276 X2 (GMV2843), as for Figure 5 above.

10 - Anthraconauta calveri sp. nov. Topotype GMV2847 X2, as for Figure 5 above.

11 - Anthraconaia sp. cf. A. pulchella Broadhurst G.S.C. 77259 X4.5 (GMV64a). N.S. Dept. of Mines & Energy Hole H6, Donkin offshore area (46° 31'N. 59° 49'W). Above the Phalen seam. Note forwardly tilted umbonal growth lines. Photo N.J. Riley (See also Figure 6.30).

12 - Anthraconaia sp. cf. A. pulchella Broadhurst S13 X2.8, south of Whelan Point, Donkin, above Phalen seam, Sydney coalfield.

13 Anthraconaia sp. cf. A. pulchella Broadhurst S9 X2.8, as for Figure 12 above.

14 - Anthraconaia sp. cf. A. pulchella Broadhurst S2 X3.2, as for Figure 12 above.

15 - Anthraconaia sp. nov. A G.S.C. 77262 (GMV1493) X4. Sydney Mines, above Backpit seam, Sydney coalfield, Photo by N.J. Riley. (See also Figure 6.31).

16 - Anthraconaia sp. cf. A. pulchella Broadhurst G1b X2.5. Glace Bay section, between the Backpit and Bouthillier seams, Sydney coalfield.

17 - Anthraconaia sp. cf. A. pulchella Broadhurst G1a X2.5 as for Figure 16 above.

18 - Anthraconaia sp. cf. A. saravana (Schmidt) GMV1864 X4.5, New Aberdeen section, Sydney coalfield. Between the Harbour and Hub seams. (See also Figure 6.32).

19 - Anthraconaia sp. cf. A. saravana (Schmidt) NA5 X3.8, as for Figure 18 above.

20 - Anthraconaia sp. G2 X2.5, as for Figure 16 above.

21 - Anthraconaia sp. NA4 X3 as for Figure 18 above.

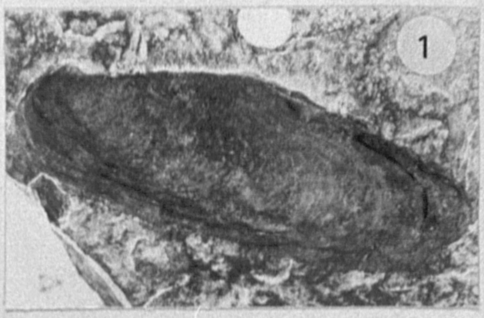
22 - Anthraconaia sp. GMV1687 X2.8 as for Figure 18 above.

23 - Anthraconaia sp. cf. A. saravana (Schmidt) NA14 X3.6, as for Figure 18 above.

24 - Anthraconaia sp. cf. A. saravana (Schmidt) NA6 X3.6, as for Figure 18 above.

25 - Anthraconaia sp. aff. A. speciosa Eagar GMV1825 X2.8, as for Figure 18 above.

26 - Anthraconaia sp. aff. A. speciosa Eagar GMV1783 X2.8, as for Figure 18 above.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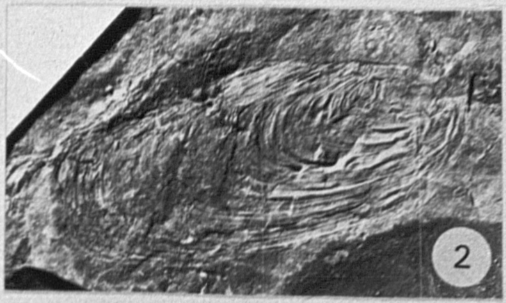
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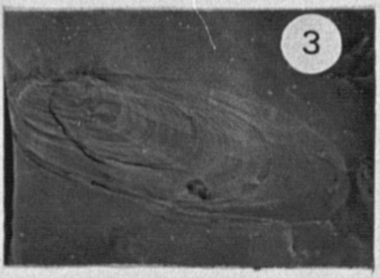
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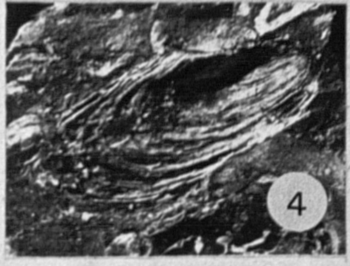
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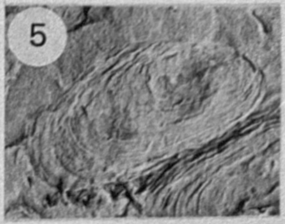
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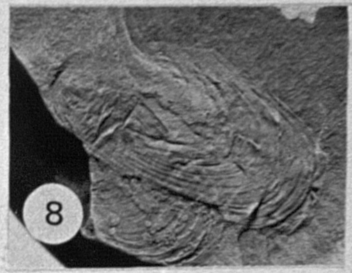
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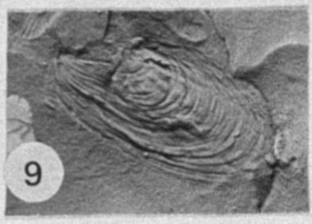
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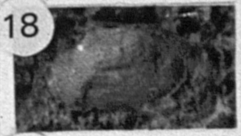
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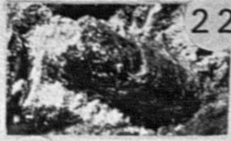
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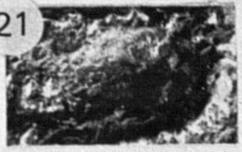
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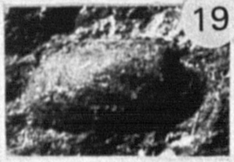
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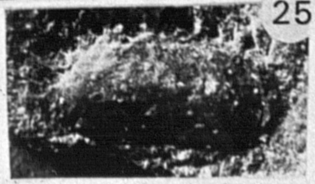
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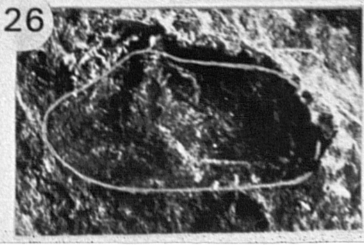
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PLATE SIX

PLATE 6

1 - *Anthraconaia* sp. aff. *A. speciosa* Eagar G.S.C. 77266 (GMV1823) X4.2. New Aberdeen section, between Harbour & Hub seams. Photo by N.J. Riley. (See also Figure 6.32)

2 - *Anthraconaia* sp. aff. *A. speciosa* Eagar G.S.C. 77269 (GMV1802b) X4.2, as for Figure 1 above.

3 - *Anthraconaia* sp. aff. *A. arenacea* (Dawson) G6 X3. Glace Bay section, between the Backpit and Bouthillier seams, Sydney coalfield. (See also Figure 6.31).

4 - *Anthraconaia* sp. (of the *A. arenacea* group) G6b X3, as for Figure 3 above.

5 - *Anthraconaia* sp. cf. *A. arenacea* (Dawson) GMV159a X4.5. N.S. Dept. of Mines & Energy Hole P4, 1164', Donkin area offshore, Photo by N. J. Riley. (See also Figure 6.31).

6 - *Anthraconaia arenacea* (Dawson) GMV159b X4.5, as for Figure 5 above.

7 - *Anthraconaia arenacea* (Dawson) GMV1423 X2, N.S. Dept. of Mines & Energy Hole P19, Stellerton coalfield.

9 - *Anthraconaia* sp. cf. *A speciosa* Eagar GMV1788 X4.5 as for Figure 1 above.

8 - *Anthraconaia arenacea* Lectotype R.M. 3131. Coal formation, Pictou Group, N.S.

10 - *Anthraconaia arenacea* Lectotype. Left valve, as for Figure 8 above.

PLATE 6

1 - *Anthraconaia* sp. aff. *A*. *speciosa* Eagar G.S.C. 77266 (GMV1823) X4.2. New Aberdeen section, between Harbour & Hub seams. Photo by N.J. Riley. (See also Figure 6.32)

2 - *Anthraconaia* sp. aff. *A*. *speciosa* Eagar G.S.C. 77269 (GMV1802b) X4.2, as for Figure 1 above.

3 - *Anthraconaia* sp. aff. *A*. *arenacea* (Dawson) G6 X3. Glace Bay section, between the Backpit and Bouthillier seams, Sydney coalfield. (See also Figure 6.31).

4 - *Anthraconaia* sp. (of the *A*. *arenacea* group) G6b X3, as for Figure 3 above.

5 - *Anthraconaia* sp. cf. *A*. *arenacea* (Dawson) GMV159a X4.5. N.S. Dept. of Mines & Energy Hole P4, 1164', Donkin area offshore, Photo by N. J. Riley. (See also Figure 6.31).

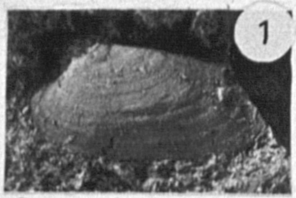
6 - *Anthraconaia* *arenacea* (Dawson) GMV159b X4.5, as for Figure 5 above.

7 - *Anthraconaia* *arenacea* (Dawson) GMV1423 X2, N.S. Dept. of Mines & Energy Hole P19, Stellerton coalfield.

9 - *Anthraconaia* sp. cf. *A* *speciosa* Eagar GMV1788 X4.5 as for Figure 1 above.

8 - *Anthraconaia* *arenacea* Lectotype R.M. 3131. Coal formation, Pictou Group, N.S.

10 - *Anthraconaia* *arenacea* Lectotype. Left valve, as for Figure 8 above.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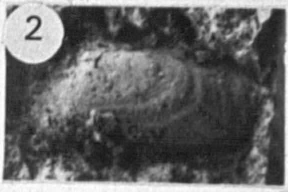
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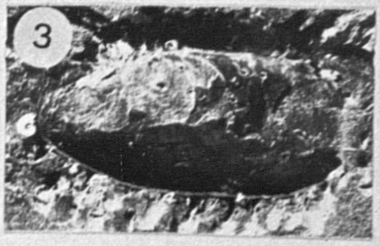
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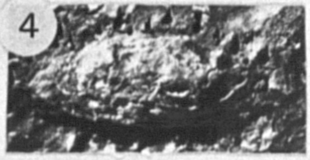
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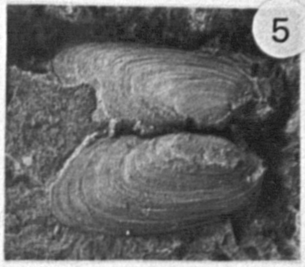
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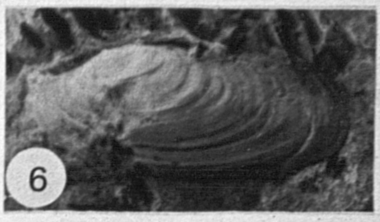
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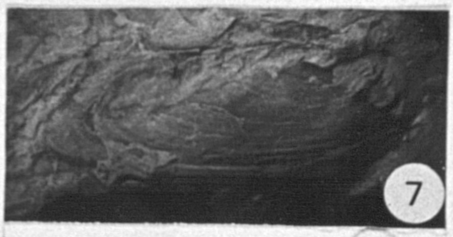
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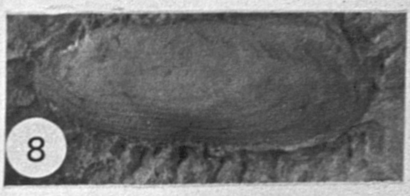
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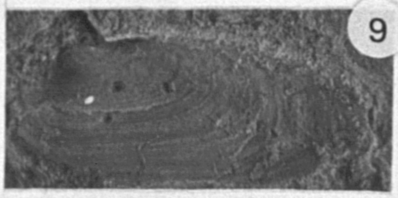
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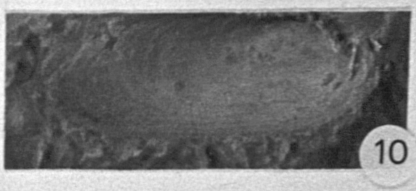
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APPENDIX A.

RESULTS OF CLUSTER ANALYSES AND RAW DATA (IN RATIOS).

1. Carbonicola ? from Boss Point.

Data:

Spec. No.	H/L	A/L	HMA/L	D/L	W/L	HH/L	HP/L	Z/L
2780	50.9	27.6	27.1	47.3	64.6	98.2	33.3	19.1
0001	60.4	28.2	32.6	52.7	69.6	96.7	39.1	16.3
2793	58.1	28.5	30.1	54.8	67.9	100.0	33.4	20.3
0002	53.7	20.0	31.1	38.7	63.0	96.9	35.5	19.0
2818	56.9	29.2	33.9	37.9	70.0	96.7	37.6	18.0
2829	53.4	28.3	30.5	51.3	66.8	96.0	33.1	19.7
2780b	54.3	25.7	33.3	47.9	65.2	92.2	32.3	20.2
2777	50.8	26.9	27.3	47.7	65.2	97.6	29.3	18.4
2782	55.2	25.7	33.2	41.7	66.9	94.6	38.1	19.3
2792	53.2	25.5	32.9	47.4	65.3	98.0	37.0	19.4
2794	58.0	25.7	39.3	56.2	68.4	94.8	35.7	23.0
2787	57.1	30.5	36.0	53.7	69.2	96.0	34.0	18.0
2883	56.7	23.8	34.1	53.0	67.3	97.7	34.1	17.5
2814	55.8	22.0	33.8	46.0	68.3	96.0	34.3	22.8
2839	58.4	28.8	35.1	39.3	75.4	95.0	38.5	23.6
2801	55.6	25.9	27.7	53.5	63.9	99.7	29.9	17.6
2786	50.9	24.8	31.2	43.4	61.0	96.9	32.1	21.0
2786b	54.6	30.6	30.9	52.2	67.6	97.9	35.2	18.4
2838	52.3	31.4	34.1	43.4	66.1	95.6	30.0	17.5
2838b	51.2	27.0	25.2	54.5	62.0	99.5	31.1	16.5

STATISTICS:

Number of specimens: 20

Numeric variables: 8

Population statistics :	mean	s.d.	min.	max.
H L	54.9	2.8	50.8	60.4
A L	26.8	2.9	20.0	31.4
HMA L	31.9	3.4	25.2	39.3
D/L	48.1	5.8	37.9	56.2
HH L	96.8	1.9	92.9	100.0
HP L	34.2	2.9	29.3	39.1
Z L	19.3	2.1	16.3	23.6

PRINCIPAL COMPONENTS ANALYSIS:

Eigenvalues: 2.8 : 1.53 : 0.92 : 0.83 : 0.51 : 0.22 : 0.19

Cum. var. %: 40 : 62 : 75 : 87 : 94 : 97 : 100

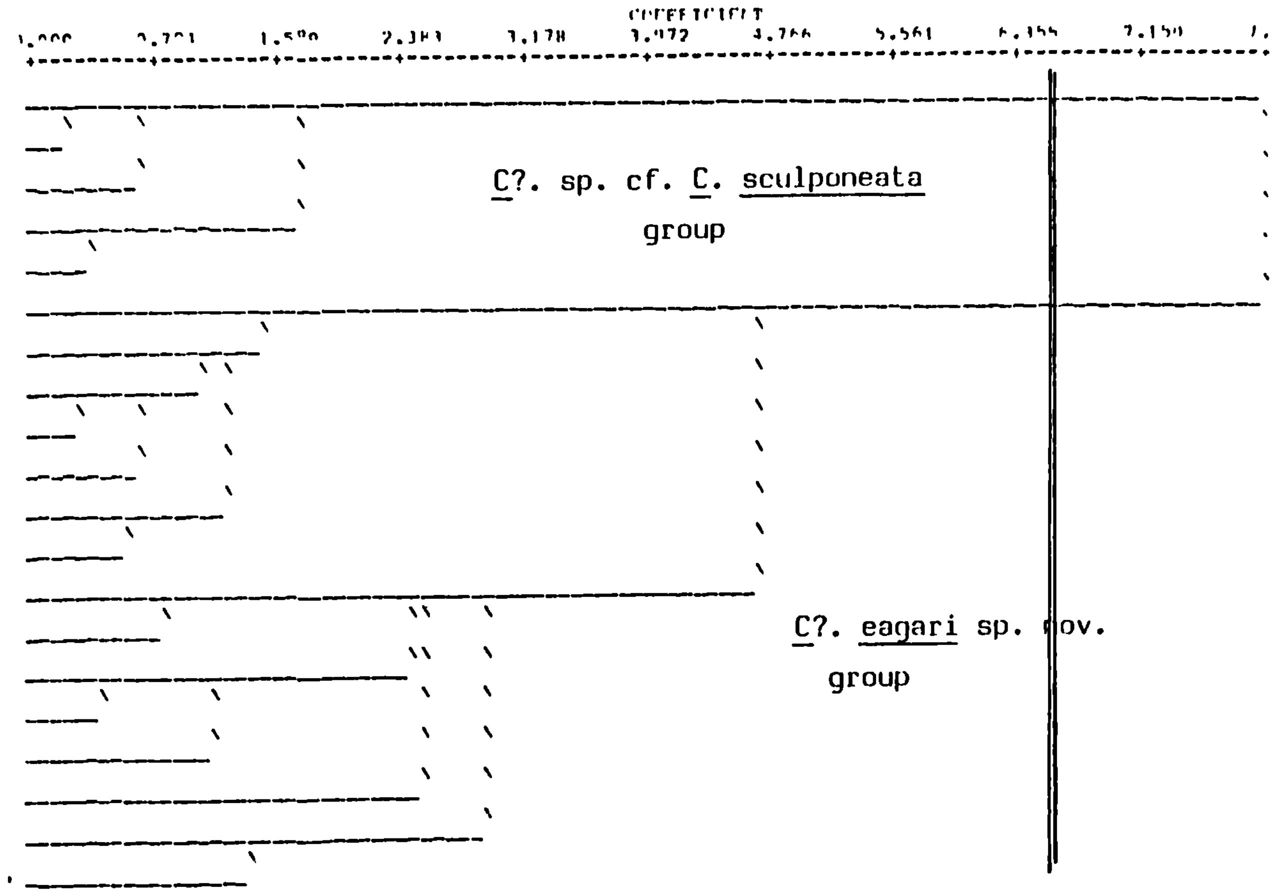

FIGURE A.1: PHENOGRAM OF THE CARBONICOLA? FAUNA FROM BOSS POINT

EIGENVECTORS:-

1: 0.38H/L, 0.53HMA/L, -0.44HH/L, 0.45HP/L, 0.36Z/L
2: 0.52H/L, 0.49A/L, 0.53D/L, -0.32Z/L
3: 0.69A/L, -0.51D/L, -0.35Z/L
(only values greter than 0.30 are shown)

CLUSTER MEANS:-

H/L	52.0	55.9
A/L	26.0	29.9
HMA/L	27.5	33.4
D/L	49.7	47.7
HH/L	98.4	96.2
HP L	31.0	35.2
Z/L	18.5	19.5
No.	5	15
	Carbonicola? sp. cf. C. sculponeata	Carbonicola? eagari sp. nov.

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2. CARBONICOLA? SPP. FROM THE WEST BAY FORMATION OF PARRSBORO.

RAW DATA:-

spec no.	H/L	A/L	HMA/L	D/L	HH/L
2589b	37.9	25.0	20.0	81.2	95.7
2588	42.8	29.4	20.2	63.1	94.1
2589a	44.7	30.3	14.3	85.1	94.1
2575	35.8	23.1	9.8	69.7	95.4
2594	41.7	26.8	13.6	73.8	95.5
F2	38.3	26.7	14.7	66.6	96.7
2587	35.7	22.1	13.9	72.5	98.6
2578b	35.6	22.8	15.4	75.4	97.0
F1	33.4	24.9	16.1	63.5	97.6
2594	40.5	29.7	16.2	33.4	97.8
C1	45.7	27.1	18.4	45.0	99.8
D1	43.3	32.3	23.2	54.2	100.0
2599	43.0	25.6	18.2	63.7	97.7
2594b	45.0	20.8	19.6	61.6	99.5
B1	41.2	17.5	16.9	48.4	99.1
E1	42.8	20.7	24.6	46.5	100.0
2600	47.3	21.4	17.8	62.3	95.5
C2	46.7	20.1	21.9	41.9	95.6

STATISTICS

Total number of specimens: 19

Number of variable: 5

Population statistics:-

	Mean	S.D.	Min.	Max.
H L	40.9	4.3	33.4	47.3
A/L	24.7	4.0	17.5	32.3
HMA/L	17.5	3.6	9.8	24.6
D/L	61.6	13.6	33.4	85.1
HH/L	97.2	1.9	94.1	100.0

Correlation chart:-

A L	0.07			
HMA L	0.51	-0.01		
D L	-0.36	0.12	-0.49	
HH L	0.06	-0.17	0.43	-0.54
	H L	A L	HMA L	D/L

EIGENVALUES:- 2.22, 1.17, 0.80, 0.49, 0.32

percentage

variance 44.5, 67.7 83.7 93.6, 100

EIGENVECTORS:-

1: 0.41H/L, 0.55HMA, -0.55D/L, 0.47HH/L

2: 0.52H L, 0.72A L, -0.40HH/L

3: -0.51H/L, 0.68A L, 0.49HH L

CLUSTER STATISTICS:-

H/L	38.2	43.9
A L	25.4	23.9
HMA L	15.5	19.7
D L	71.3	56.8
HH L	96.3	98.3
	Carbonicola? angulata group.	Carbonicola? sp. cf. C. fallax.

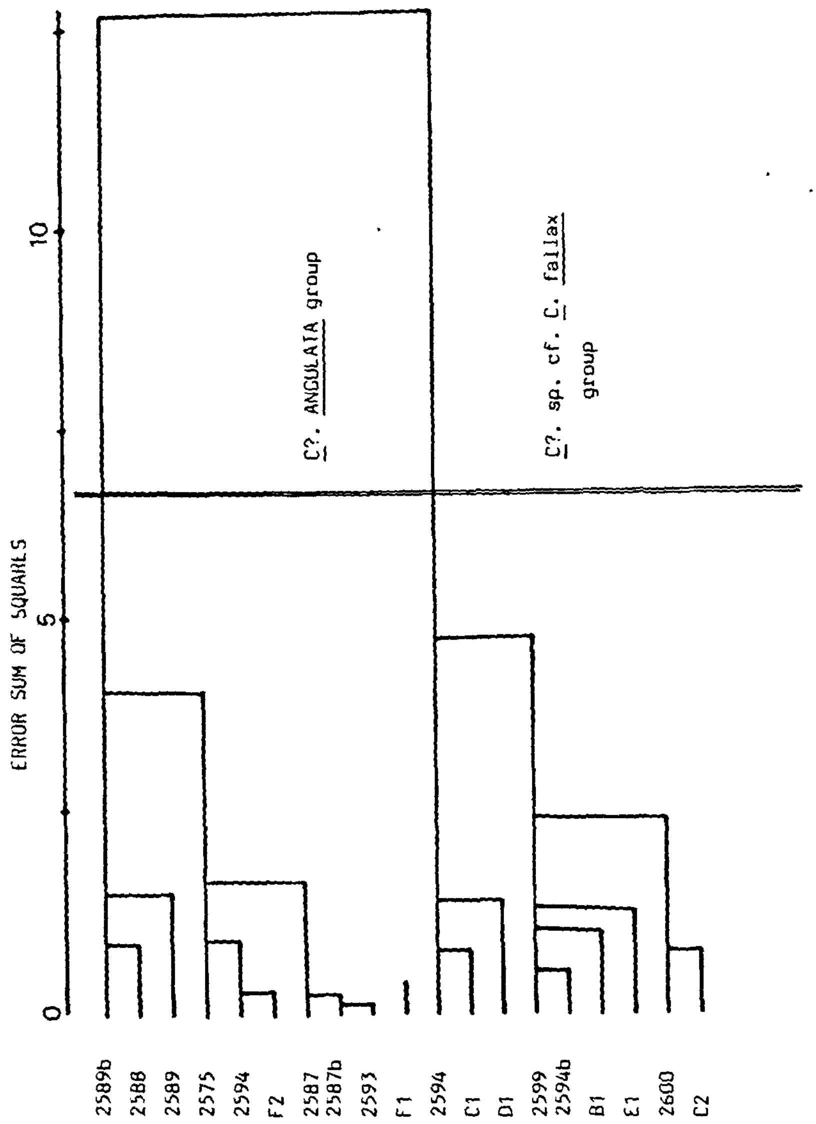


FIGURE A.2: PHENOGRAM OF *CARBONICOLA?* FROM PARRSBORO

3. Naiadites spp. from Port Hood.

RAW DATA:

	H/L	A/L	DM/L	D/L	HH/L	U/L	PE/L
2250	69.3	17.0	76.4	83.0	83.0	4.6	24.6
2251	67.2	16.3	87.8	76.7	88.2	0.0	37.2
2281	83.3	21.9	81.4	69.6	86.0	0.3	49.8
2245	79.2	13.2	80.9	79.6	76.7	1.1	42.2
2221	78.3	16.2	82.6	71.4	92.1	4.1	45.3
2224	66.1	20.9	74.7	82.1	89.2	2.0	30.5
2228	87.6	14.0	87.1	76.7	84.3	5.6	42.5
2229	68.7	15.6	71.7	80.7	83.2	2.2	29.5
2216	73.9	11.5	71.7	69.2	74.0	3.5	39.2
2256	69.6	15.0	75.0	80.0	91.7	1.8	34.2
2215	55.4	9.8	61.8	63.0	65.4	3.1	27.6
2276	64.5	16.6	71.7	79.1	94.5	0.0	32.2
2213	67.6	14.7	73.1	70.7	89.4	0.3	48.5
2237	71.6	14.5	76.7	77.7	89.2	2.4	29.4
2236	70.3	27.6	78.0	83.4	83.5	0.9	25.2
580	64.8	17.0	68.8	75.0	89.5	4.3	33.1
574b	67.9	24.4	67.9	81.6	88.3	0.0	27.1
578	60.5	18.7	77.0	84.0	94.2	2.2	28.6
575	55.5	19.2	77.2	76.4	88.1	3.2	29.3
2231	74.9	17.4	71.0	77.5	83.8	2.0	35.6

Population statistics:-

Total number of specimens - 20

Number of variables - 7

	mean	s.d.	Min.	Max.
H/L	69.8	8.2	55.4	87.6
A L	17.1	4.2	9.8	27.6
DM L	75.6	6.4	61.8	87.8
D L	76.9	5.6	63.0	84.0
HH L	85.7	7.1	65.4	94.5
U L	2.2	1.8	0.0	5.6
PE L	34.6	7.8	24.6	49.8

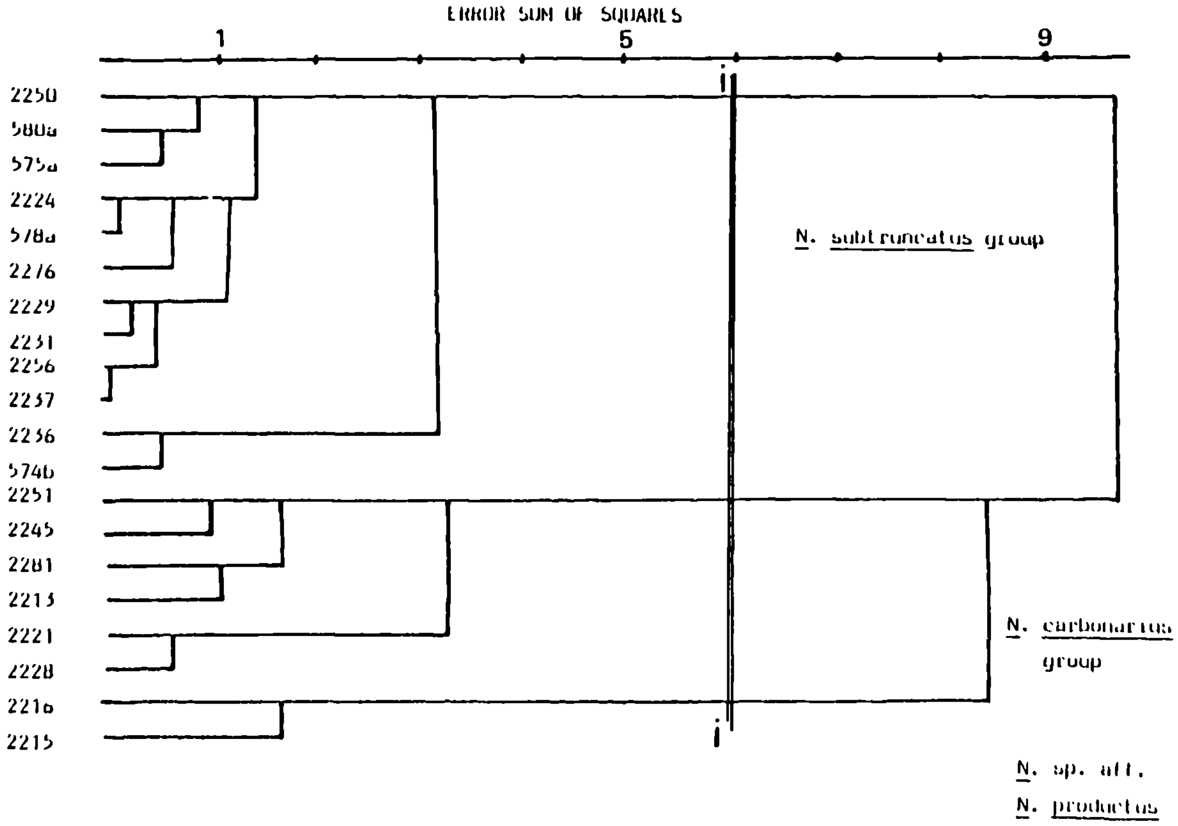
Correlation table:

	H L	A L	DM L	D L	HH L	U L	PE L
H L		-0.02	0.56	-0.03	-0.11	0.12	0.64
A/L			0.12	0.53	0.43	-0.39	-0.26
DM L				0.21	0.32	0.04	0.44
D L					0.49	-0.15	-0.51
HH L						-0.22	0.05
U L							-0.08

EIGENVALUES: 2.33, 2.12, 1.07, 0.66, 0.42, 0.34, 0.07

% variance : 33.2, 63.4, 78.8, 88.1, 94.2, 99.0, 100

FIGURE A.3: Phenogram of Naiadites spp. from Port Hood.



VECTORS:

1: 0.49A/L, 0.53D/L, 0.37HH/L, -0.43PE/L
2: 0.51H/L, 0.58DM/L, 0.36HH/L, 0.42PE/L
3: 0.36D/L, 0.81U/L, -0.34PE/L

Cluster statistics-

H/L	67.0	77.2	64.7
A L	18.7	16.1	10.7
DM L	73.8	82.1	66.8
D/L	80.0	74.1	66.1
HH/L	88.2	86.1	69.7
U/L	2.1	1.9	3.3
PE/L	29.9	44.3	33.4
No.	12	6	2
	N. subtruncatus group	*N. carbonarius* group	*Naiadites* cf. *N. productus*

* *

4. Parrsboro *Naiadites* spp.

Raw Data:

	H L	A L	DM/L	D/L	HH/L	U/L	PE/L
2628	80.0	20.0	76.8	66.9	95.6	0.0	53.8
2624b	61.0	17.2	68.0	82.2	84.0	0.0	24.1
2624	88.4	16.1	59.7	55.9	76.8	8.3	41.9
2624c	91.2	16.3	62.8	74.0	88.3	3.5	41.6
2623	84.6	21.0	71.8	79.0	85.1	5.6	33.5
2629b	61.2	18.7	62.1	78.7	83.5	2.4	22.9
2629	56.2	19.6	76.3	76.2	85.4	2.8	25.8
2619	63.1	17.6	72.5	72.5	86.5	0.0	41.2
2610	63.3	14.8	73.0	68.5	90.9	0.0	38.7
2606	66.7	17.0	72.3	73.8	85.9	2.7	33.3
2627	54.6	17.1	63.6	73.5	97.1	0.0	36.5
2636	64.2	21.8	69.3	76.2	87.8	2.0	34.0
2621	76.3	13.8	64.6	75.2	88.6	0.0	38.0
2621b	90.8	20.0	67.6	67.6	94.1	0.0	50.9
2646	56.5	19.8	75.8	81.5	96.4	0.0	25.8
2637	53.9	10.7	59.2	77.7	93.4	0.0	28.3
2646b	72.9	16.9	66.5	70.8	82.0	3.6	39.4
2648	69.3	14.2	62.5	82.6	80.9	1.7	27.7
2652b	65.1	14.8	73.3	74.4	84.2	3.0	32.5
2652	71.5	21.1	61.8	75.5	81.4	0.0	32.2
2653	67.1	16.6	65.9	73.3	86.2	0.0	32.9
2647	67.3	14.9	64.7	77.8	87.8	1.5	34.3
2653b	80.5	21.8	68.3	81.6	83.3	1.0	41.6

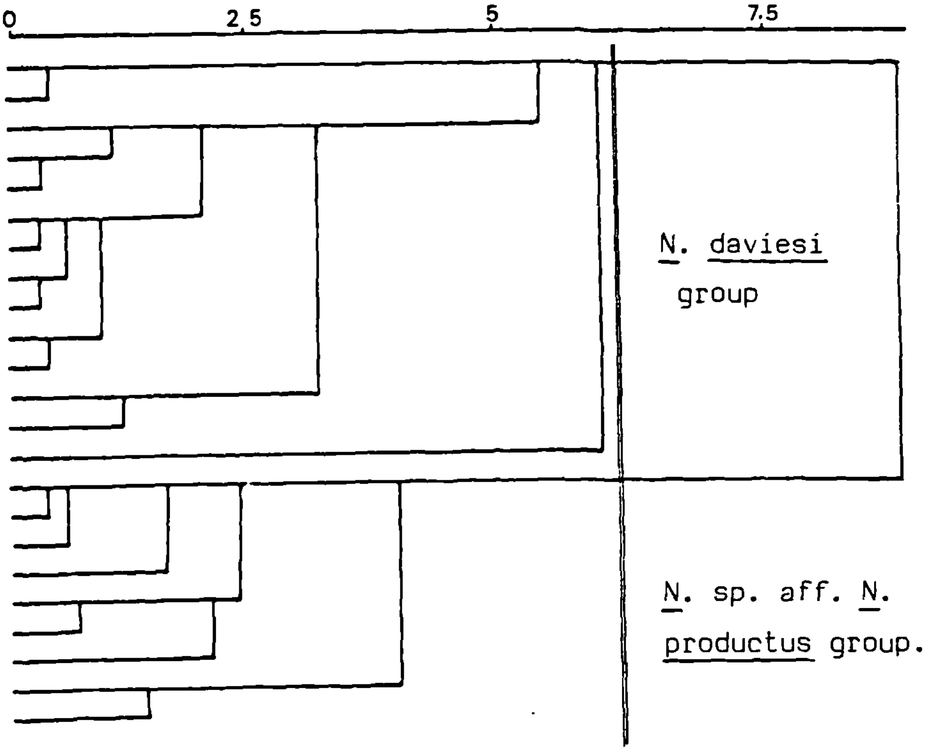


FIGURE A.4: Phenogram of Naiadites spp. from Parrsboro.

```
Population statistics:
Number of individuals?23
Number of variables-7
                    mean        S.D.        MIN.        MAX.
H/L                 68.7        11.2        54.0        91.2
A L                 17.5         2.9        10.7        21.8
DM/L                68.3         6.1        59.3        81.6
D L                 75.5         5.4        65.9        85.4
HH L                86.8         5.8        76.3        97.1
U/L                  1.6         2.2         0.0         8.3
PE/L                35.2         7.9        22.9        53.8

Correlations-
             H/L    A/L    DM/L    D/L    HH/L    U/L    PE/L
H/L                 0.25   0.01  -0.44   -0.14   0.48    0.66
A L                        0.51   0.14   -0.09   0.07    0.15
DM L                              0.18    0.09  -0.22    0.19
D L                                      -0.28  -0.09   -0.74
HH L                                            -0.55    0.32
U L                                                      0.00

EIGENVALUES: 2.36, 1.81, 1.62, 0.45, 0.34, 0.32, 0.10
% variance : 33.7, 59.5, 82.7, 89.2, 94.1, 98.6, 100

VECTORS:
1: 0.55H/L, -0.52D L, 0.60PE/L
2: 0.64HH/L, -0.64U/L
3: 0.67A L, 0.66DM/L, 0.31D L


CLUSTER STATISTICS:
H L            70.7           65.6
A L            16.1           19.5
DM L           67.2           69.9
D L            72.3           80.5
HH L           88.4           84.2
U L             1.4            1.7
PE L           38.8           29.7
            N. productus    N. daviesi
               group           group
```

5. *Curvirimula* spp. from Port Hood.

Raw Data:

	H/L	A/L	DM/L	W/L	HH/L	U L
2255	70.1	26.3	74.6	74.8	90.7	0.0
2264	73.5	25.2	70.3	66.5	87.6	1.2
2279	72.7	22.6	66.8	71.0	89.0	2.7
2280	81.3	16.8	66.9	66.6	86.7	0.0
2258	82.0	17.3	60.6	66.8	82.3	2.5
2234	83.6	20.4	71.7	77.9	84.6	2.7
2270	60.5	24.0	68.3	60.5	86.0	0.0
2274	73.3	13.9	67.6	64.3	82.4	0.0
2270b	64.5	21.5	58.8	55.4	81.0	0.6
2212	59.8	17.2	65.0	59.8	90.2	0.1
2273	76.0	20.5	64.6	68.6	89.8	0.0
2222	68.7	15.3	73.5	76.7	93.1	0.0
587c	67.7	22.2	64.2	60.2	85.7	1.4
587b	65.5	17.1	55.1	54.0	80.2	1.3
587	73.5	22.2	66.5	68.9	83.7	2.0
2237	68.9	16.7	53.3	57.7	75.0	1.0
2306b	63.5	22.7	76.6	72.5	88.7	0.0
2306	77.8	21.2	60.4	71.1	79.0	2.8

Population statistics:

Number of specimens-18

Number of variables-6

	mean	S.D.	Min.	Max.
H L	72.5	8.2	59.8	91.5
A L	20.2	3.5	13.8	26.3
DM L	66.9	8.3	53.3	91.0
W L	66.4	8.3	54.0	84.6
HH L	85.4	4.9	75.0	93.1
U L	1.4	1.9	0.0	7.1

Correlations:

	H L	A L	DM/L	W L	HH L	U L
H/L		0.0	0.5	0.7	0.2	0.7
A L			0.3	0.2	0.3	0.2
DM L				0.8	0.7	0.5
W L					0.6	0.5
HH L						0.1

EIGENVALUES: 3.34, 1.22, 0.92, 0.31, 0.13, 0.09

% variance : 55.7, 76.0, 91.3, 96.4, 98.4, 100

EIGENVECTORS:

1: 0.41H/L, 0.51DM/L, 0.51W/L, 0.37HH L, 0.38U/L

2: -0.52H/L, 0.44A/L, 0.55HH/L,-0.46U/L

3: -0.81A/L, 0.36HH/L, -0.39U/L.

ONE CLUSTER ONLY

* *

6. <u>Curvirimula</u> spp. from Chimney Corner.

1218A	89.8	18.6	65.5	66.1	6.3	68.8
1216B	83.8	24.3	58.2	74.7	2.6	83.3
1230A	59.5	28.3	62.3	64.5	2.2	91.6
1202A	93.8	27.0	48.7	73.4	0.0	87.5
1216A	64.5	19.9	67.0	56.1	0.0	90.8
1237C	75.9	20.0	59.5	67.4	00.0	86.9
1237D	81.8	18.7	65.8	64.6	4.3	83.7
1237A	88.9	29.0	64.2	87.8	3.4	82.9
1226B	83.7	10.6	80.5	82.0	0.0	93.5
1226C	76.3	21.4	62.9	67.0	2.5	86.3
1240A	74.2	16.3	56.4	63.4	0.1	82.9
1245A	54.6	15.6	70.2	63.0	0.0	95.1
1219A	65.1	21.0	75.7	71.6	2.9	86.6
1229A	57.6	16.6	57.8	59.4	4.3	77.9
1224A	79.5	22.0	70.0	69.3	4.0	80.5
1227A	78.9	23.2	55.5	65.4	2.3	89.5
1226A	97.0	16.5	44.4	70.3	4.3	69.4
1214A	83.0	25.1	66.4	76.2	0.0	91.1
1237B	72.5	30.3	68.4	68.9	3.9	86.0
1216C	58.5	18.6	75.1	68.4	0.0	82.4
1247A	64.1	14.1	54.7	65.3	0.0	96.9
1247B	81.7	24.7	51.6	73.9	1.9	87.0
1249A	70.8	21.7	66.4	71.8	0.0	93.6
1239A	88.2	22.0	52.2	67.6	5.1	82.1
1241A	82.1	20.1	70.2	73.7	2.1	85.7
1239B	70.0	21.1	60.3	59.5	3.0	78.5
1219B	66.1	18.6	60.3	59.2	2.5	80.0
1241B	73.9	16.8	48.3	60.1	2.2	76.5
1242A	84.8	24.5	62.5	70.1	5.7	87.0
1242B	100.7	21.3	51.1	76.8	2.6	82.0
1093A	101.7	22.0	58.2	73.3	4.7	82.4
1093B	72.6	14.1	64.9	57.1	2.4	76.6
1057A	90.6	26.1	63.4	75.6	2.1	95.4
1102A	75.6	15.5	56.5	64.8	0.2	80.1
1168A	93.8	18.8	55.1	63.4	2.9	75.7
1071A	85.0	18.5	55.5	62.9	4.7	76.0
1096B	86.2	29.0	64.8	73.7	4.2	86.9
1096A	79.3	16.9	49.7	59.3	4.6	83.5
1094A	83.4	22.6	65.4	78.1	0.5	93.5
1092A	71.4	20.1	74.9	73.0	3.6	68.2
1058A	84.2	22.2	60.4	66.3	5.2	81.5
1090A	78.8	19.7	66.2	67.5	0.0	82.7
1075A	84.5	21.3	47.5	61.8	2.2	78.5
1116A	74.9	19.3	67.4	69.3	0.3	87.1
1091A	78.3	17.4	62.6	69.0	0.0	87.9
1069A	85.0	23.1	63.3	79.4	0.0	90.1
1058B	79.2	16.9	50.7	60.4	4.8	71.7
1097A	57.0	19.3	65.3	65.3	0.0	91.8
2491A	60.0	13.4	70.5	59.5	1.9	81.2
2424A	84.3	28.1	57.6	74.3	0.0	83.3
2499A	57.1	17.7	58.9	56.0	0.0	90.1
2430A	61.0	27.6	71.1	73.3	0.0	96.5
2427A	71.8	32.6	74.3	80.4	4.7	95.0
2429A	78.8	17.0	65.3	70.6	0.0	66.6
2444A	67.0	20.7	67.5	67.1	0.0	89.5
2445A	72.0	21.4	71.8	72.5	0.0	88.5
2432A	72.6	23.5	54.6	65.0	1.7	77.1
2428A	72.0	20.9	71.7	70.0	5.2	83.2

Population statistics-
Total number of individuals-57
Number of variables--6

	mean	S.D.	MIN.	MAX.
H/L	77.0	11.3	54.6	101.7
A/L	20.9	4.5	10.6	32.6
DM/L	62.0	8.0	44.4	80.5
W/L	68.3	6.9	56.0	87.8
U/L	2.1	1.9	0.0	6.3
HH/L	85.0	6.6	68.6	96.9

Correlation table-

	H/L	A/L	DM/L	W/L	U/L	HH/L
H L		0.2	-0.4	0.4	0.4	-0.3
A L			0.0	0.5	0.2	0.3
DM/L				0.3	-0.2	0.5
W L					0.0	0.4
U L						-0.5

EIGENVALUES: 2.22, 1.88, 0.82, 0.68, 0.28, 0.13
% variance : 39.6, 68.3, 82.0, 93.3, 97.9, 100

EIGENVECTORS-
1: 0.34H/L, -0.5DM/L, 0.44W L, -0.59hh/L
2: 0.52H/L, 0.55A/L, 0.61W/L
3: -0.36H L, 0.54DM/L, 0.69U/L

CLUSTER STATISTICS-

H L	77.2	84.7	68.9
A L	18.1	24.5	19.1
DM L	56.1	61.6	66.5
W L	61.7	73.3	67.7
U L	3.4	2.8	0.5
HH L	76.3	86.2	89.1
No.	14	22	21
	_C._ _attenuata_ sp. nov. group.	_C._ _corvosa_ group.	_C._ sp. aff. _C._ _trapeziforma_ group.

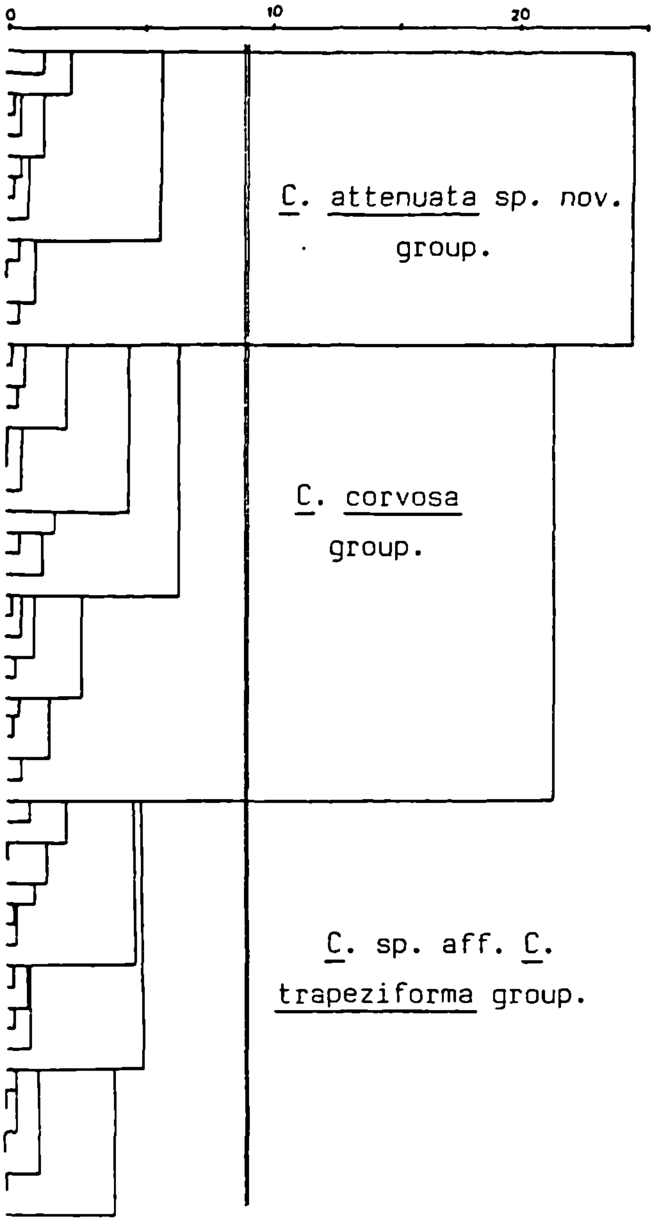


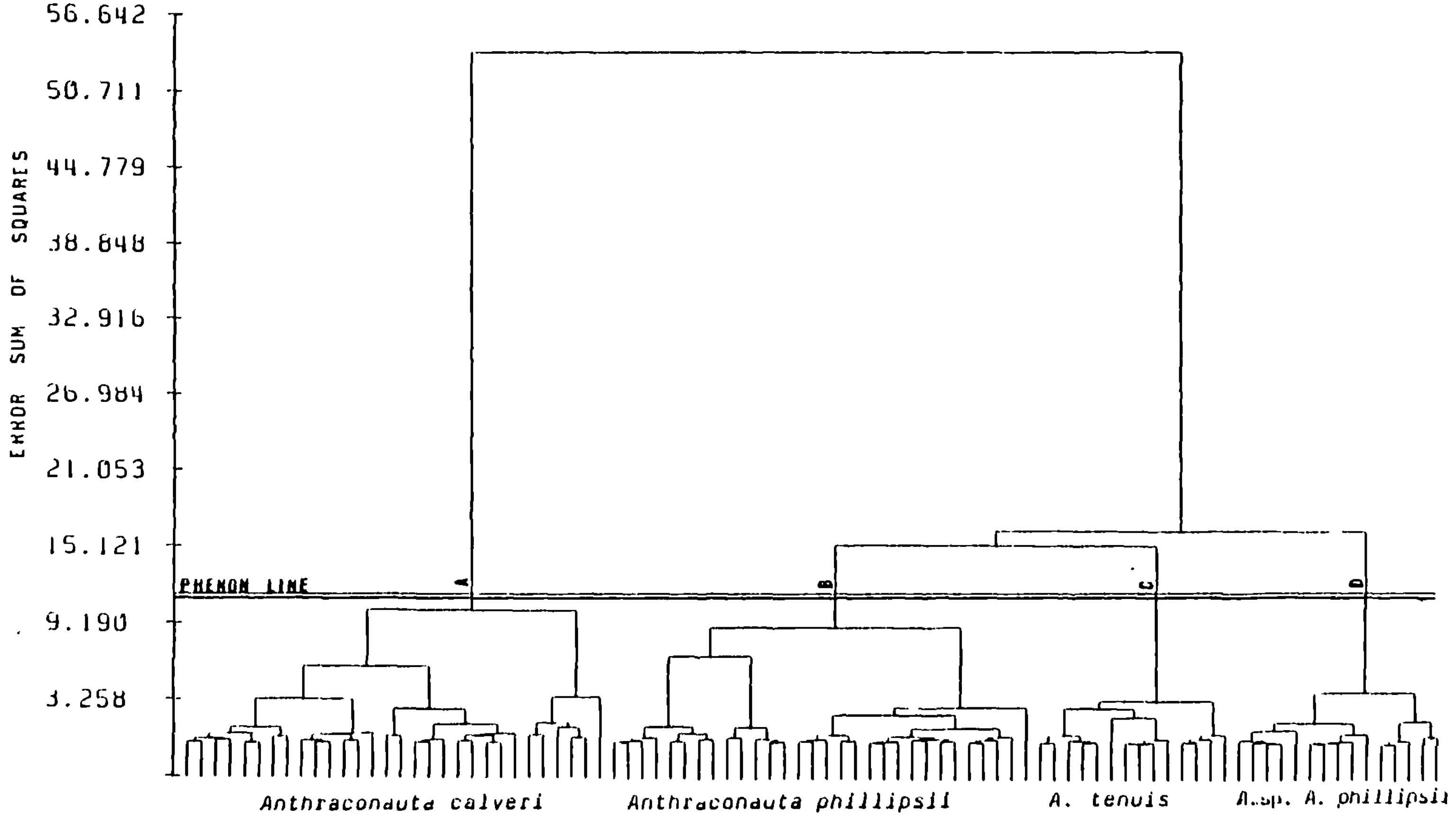
FIGURE A.6: Phenogram of Curvirimula spp. from Chimney Corner.

7. Anthraconauta from above the Phalen seam.

H/L	A/L	DM/L	D/L	W L	Spec.
62.2	19.8	60.3	67.3	60.4	2051
50.2	19.8	60.5	70.3	53.0	2041
61.5	20.1	61.0	69.1	62.3	2038
66.4	18.4	59.3	71.1	60.8	2038b
75.8	19.3	61.2	67.7	64.5	2038c
66.3	18.0	65.3	62.1	65.5	2044
56.6	19.5	53.8	75.9	48.6	2026
61.1	17.9	58.0	68.3	58.2	2036
54.8	15.0	57.0	80.0	54.1	2037
72.6	16.4	56.6	80.8	62.2	2031
87.7	27.1	63.1	79.2	61.4	2030
60.5	20.6	63.6	77.9	58.1	2033
53.0	14.5	52.8	63.0	51.7	2030b
59.2	17.3	56.7	73.7	55.7	2047
61.1	25.2	60.7	75.2	55.8	2035
56.7	12.5	56.0	72.8	51.6	2046
51.5	16.2	61.1	76.4	56.7	2047b
51.4	18.1	62.4	62.0	53.8	2034
55.4	16.8	60.2	68.8	53.8	2056
46.6	17.3	63.5	62.8	51.4	2053
55.7	14.3	64.1	72.8	55.7	2053b
64.9	22.4	52.0	80.1	52.5	2055b
61.3	18.1	52.5	83.5	49.3	2055
63.5	16.4	54.1	95.3	46.6	2138
61.3	15.2	60.4	73.4	56.2	2138b
48.5	15.5	54.8	69.5	48.9	SW48b
61.1	18.0	62.4	76.4	53.0	SW48
54.1	20.3	57.6	81.8	46.2	SW15
56.0	25.3	64.9	67.9	55.1	SW16
56.2	18.3	56.6	74.0	55.2	SW17
62.8	20.2	60.8	84.7	54.3	SW25
53.2	20.0	58.9	76.8	47.9	SW24
67.9	20.7	61.8	72.6	53.7	SW18
49.9	16.5	56.9	75.9	53.0	SW19b
55.1	15.9	61.3	73.9	56.8	SW23
57.5	18.3	59.8	73.8	55.3	SW22b
53.3	16.5	59.6	82.9	55.2	SW20
59.1	22.0	62.4	74.5	59.3	SW19
72.6	21.3	69.0	70.6	72.3	SW22
65.2	19.5	57.5	77.4	53.0	SW21
59.6	22.9	60.7	72.4	55.9	SW44
50.4	17.3	53.4	81.2	46.4	SW41b
50.5	19.5	58.8	67.6	51.2	SW45
53.3	15.8	56.4	64.2	51.0	SW45b

H/L	A/L	DM/L	D/L	W/L	Spec.
51.8	15.7	54.2	78.3	46.8	SW46
57.8	17.8	65.2	69.9	55.7	SW41
55.6	16.4	54.7	75.7	50.1	SW37
62.7	23.1	59.8	72.4	54.6	SW38
53.2	13.7	49.0	69.5	49.3	SW36
62.0	22.8	63.2	78.5	56.4	SW34
67.5	22.4	67.5	71.1	59.3	SW33
49.9	15.6	56.7	60.0	49.6	SW33b
41.6	14.7	65.3	75.4	45.7	SW12
48.1	16.1	62.4	80.6	48.1	SW10
47.6	18.0	60.2	76.4	49.7	SW9c
63.2	18.3	52.5	71.9	53.4	SW14
75.1	22.9	65.8	75.0	64.3	SW7b
58.4	16.4	59.5	76.3	52.1	SW7a
67.1	19.2	63.7	63.7	57.0	SW8
51.5	19.6	60.2	79.1	51.0	SW9
48.8	15.2	52.8	70.0	46.4	SW3b
66.4	20.0	59.8	82.0	57.4	SW1
51.0	16.4	55.6	67.1	47.4	SW6
47.3	20.6	61.1	53.9	51.7	SW5
57.5	22.3	61.9	68.5	60.3	SW3c
65.8	20.0	52.6	83.4	51.7	SW28
58.0	12.8	56.2	74.0	52.8	SW28b
53.9	16.9	51.4	51.5	48.2	SW27
47.2	19.5	59.3	67.9	47.8	SW26
53.6	17.6	54.5	78.5	45.5	SW29
54.4	20.6	55.4	75.7	48.5	SW28c
52.4	17.6	52.9	67.4	49.3	SW32
45.2	13.0	53.0	62.4	45.2	SW30
50.5	14.3	52.2	82.8	47.6	SW65
58.9	19.5	63.1	81.9	58.3	SW64
46.0	18.8	60.0	76.1	46.0	SW63
56.7	9.8	49.4	77.0	47.4	SW62
69.7	22.9	58.4	77.9	58.7	SW61c
53.2	20.2	58.5	59.8	52.5	SW61
71.4	17.0	57.3	88.7	56.0	SW60
65.6	21.2	59.7	74.0	60.0	SW61b
60.5	16.1	56.3	81.7	55.1	SW59
63.8	19.8	56.6	79.8	51.8	SW59b
42.0	12.1	60.5	77.3	47.9	SW51
63.5	12.8	67.1	76.2	61.9	SW49
54.6	12.7	56.9	66.6	52.7	SW50
53.4	15.3	56.7	58.0	49.8	SW54
53.0	20.1	60.6	67.8	55.8	SW55
60.7	17.6	57.3	66.7	59.1	SW55b

FIGURE A.7: PHENOGRAM OF <u>ANTHRACONAUTA</u> SPP. FROM ABOVE THE PHALEN SEAM



Population statistics-
Total number of individuals-89
Number of variables-5

	mean	S.D.	MIN.	MAX.
H/L	57.8	8.1	41.6	87.7
A/L	18.2	3.2	9.8	27.1
DM/L	58.7	4.2	49.0	69.0
D L	73.2	7.5	51.5	95.3
W/L	53.7	5.3	45.2	72.3

Correlations-

	H/L	A/L	DM/L	D L	W/L
H/L:		0.47	0.24	0.26	0.72
A L			0.41	0.05	0.41
DM/L				-0.08	0.61
D L					-0.05

EIGENVALUES: 2.45, 1.15, 1.65, 0.62, 0.12

% variance : 49.1, 72.1, 85.1, 97.6, 100

EIGENVECTORS:

1: 0.52H L, 0.46A L, 0.45DM L, 0.57W/L

2: 0.34H L, -0.36DM L, 0.85D/L

3: -0.57A L, 0.64DM/L, -0.43W L

CLUSTER STATISTICS-

H L	65.6	53.1	56.8	52.7
A L	20.8	17.1	18.6	14.5
DM L	61.3	60.4	54.6	54.0
D/L	58.9	72.7	80.3	66.2
W L	74.0	53.0	48.7	49.4
No.	30	30	14	15
	A. calveri sp. nov. group.	A. phillipsii group.	A. tenuis group.	A. sp. cf. A. phillipsii group.

* * *

8. Anthraconauta spp. from between the Harbour and Hub seams.

For raw data - see over page.

Population statistics-

Total number of specimens-91

Number of variables-5

	mean	S.D.	MIN.	MAX.
H L	55.9	5.0	40.8	75.0
A L	15.6	3.3	8.2	25.5
DM L	61.3	5.1	47.0	73.5
D L	73.5	6.6	58.1	88.5
W L	55.1	5.3	39.2	69.2

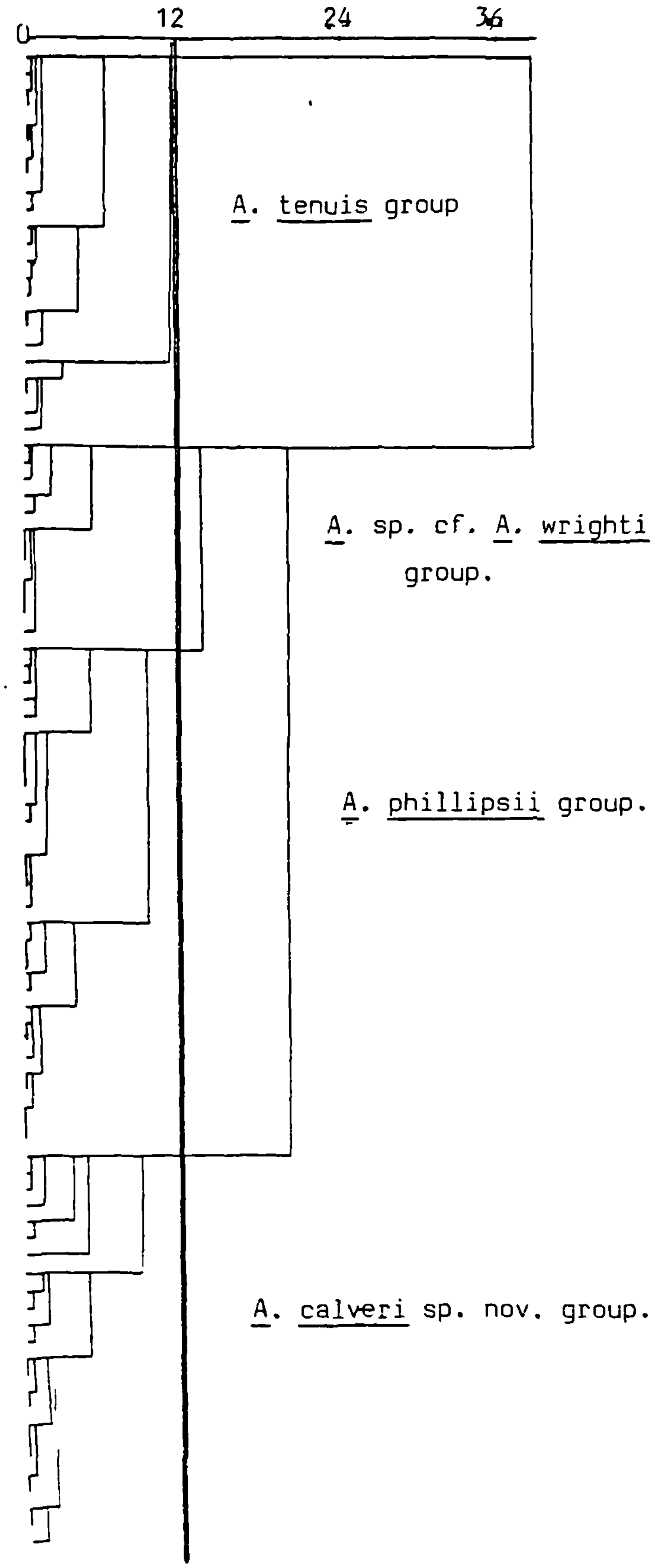
Correlations-

	A L	DM L	D L	W L
H L	0.2	0.02	-0.06	0.40
A/L		0.07	-0.05	0.11
DM L			-0.02	0.69
D L				-0.26

RAW DATA:

H/L	A L	DM/L	D L	W/L	No.
56.9	12.3	57.1	82.9	54.5	1858
54.0	12.3	73.5	78.0	63.5	1872b
54.2	14.7	57.5	79.5	50.0	1904
46.8	14.5	68.4	71.5	58.4	1849
58.7	22.0	64.1	70.2	59.7	1869
53.5	12.9	68.2	79.9	58.9	1870
65.0	17.3	69.7	68.7	69.2	1848
50.7	17.2	72.4	73.9	58.0	1872
54.7	12.8	64.2	73.9	54.5	1849b
54.4	17.6	68.1	88.5	61.1	1889
61.9	16.2	58.2	82.4	51.8	1869b
48.0	11.2	56.9	71.8	50.8	1869
57.5	16.9	66.0	64.3	63.4	1877
55.2	16.9	55.8	62.9	51.6	1912
58.0	14.5	63.2	70.0	57.2	1900
59.0	14.5	57.1	64.5	59.0	1873
52.4	19.1	63.3	71.7	53.5	1902
54.8	10.5	62.9	77.3	56.1	1854
54.6	15.4	61.0	63.4	53.9	1873b
60.6	14.5	64.2	72.0	58.1	1865
63.4	15.6	56.8	79.0	56.2	1856
58.9	12.6	58.9	73.5	57.9	1880
52.2	11.3	61.1	77.2	53.2	1886
55.5	9.2	54.3	78.8	48.4	1913
59.7	14.5	63.3	82.7	62.5	1878
52.8	12.0	56.2	82.4	49.3	439
40.8	15.9	47.0	72.2	39.2	439b
56.5	15.4	57.8	77.2	49.0	439c
53.2	14.9	60.1	70.6	50.2	286-4
57.2	8.2	63.6	78.2	53.9	392
54.2	18.0	61.1	74.6	54.9	392b
58.7	12.7	65.6	66.6	66.7	397
65.1	13.8	54.3	78.6	54.9	393
48.2	16.2	58.1	83.7	47.0	486
50.2	16.0	66.5	75.3	53.5	477
54.2	21.2	66.7	76.2	66.1	477b
67.3	14.4	64.3	73.1	61.5	396
56.2	15.8	65.9	82.8	52.1	445
52.7	18.3	62.2	73.7	52.4	445b
52.9	15.6	60.3	71.0	54.8	471
75.0	21.5	56.6	67.5	62.1	2182
64.2	17.6	48.2	77.6	48.0	179
52.3	12.6	56.5	66.1	49.5	2180
57.1	11.8	51.2	79.0	46.2	2177
47.9	20.2	53.2	77.1	41.7	2181
58.5	18.0	61.5	75.1	58.3	614
54.4	13.8	65.2	65.2	56.8	179
61.1	21.7	56.1	65.7	56.1	187
56.2	15.8	66.8	74.4	57.3	181
51.7	10.3	73.4	82.2	58.5	E203
60.4	20.4	67.1	59.0	63.3	E200d
51.1	12.8	68.3	63.9	57.5	E200
55.7	18.8	62.4	71.7	54.9	E201
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	E200c

H/L	A/L	DM/L	D/L	W/L	NO.
58.0	12.0	61.9	61.6	57.0	E200b
52.8	12.7	61.8	78.9	54.9	L14
55.1	14.1	53.8	77.5	46.3	L24
52.4	15.8	62.9	71.9	54.3	L26
47.1	17.9	65.5	65.9	54.1	L28
55.2	19.2	61.2	68.6	54.2	L15
54.6	16.5	63.4	77.3	55.2	L20
47.4	15.5	61.0	81.7	43.7	L18
55.8	18.5	62.8	84.8	55.1	L19
55.3	13.0	60.1	76.5	55.2	L12
54.2	23.1	56.5	62.5	57.0	L11
56.8	15.4	64.5	76.4	61.0	L13
58.3	16.0	62.8	66.2	55.1	L6b
57.7	18.6	61.7	79.0	51.6	L6
58.5	16.8	64.7	74.3	59.2	L9
54.5	15.6	64.3	67.4	57.6	L6
66.3	19.9	65.7	71.9	57.1	L2
56.2	25.5	65.3	77.1	56.1	L5
60.5	13.3	64.8	68.6	62.2	L1
59.7	17.9	65.3	76.6	57.1	L3
59.3	20.6	58.7	73.3	54.7	L7
54.2	16.2	54.6	75.7	48.3	L40b
61.1	22.8	66.5	75.1	58.4	L40
49.4	13.9	56.0	74.5	44.1	L42
53.2	12.6	53.6	79.8	51.7	L36b
54.1	12.2	54.6	58.1	53.0	L36
60.8	12.7	58.7	70.9	56.2	L39
53.4	17.3	62.0	75.1	56.6	L46a
60.0	18.7	60.0	86.7	49.0	L45
55.2	14.1	62.5	70.2	58.8	L44
51.4	17.5	62.4	75.8	55.4	L47
62.9	13.8	63.0	75.1	61.4	L48
54.7	10.9	61.1	71.4	56.4	L48b
55.4	11.4	59.9	58.9	57.1	L50
56.8	18.3	58.5	70.4	53.7	L49
51.7	11.3	58.3	64.5	49.9	L51
52.6	15.1	54.9	80.0	51.3	L50
64.0	17.3	65.2	73.0	57.0	L53


0
12
24
36
A. tenuis group
A. sp. cf. A. wrighti group.
A. phillipsii group.
A. calveri sp. nov. group.

EIGENVALUES: 1.96, 1.08, 0.98, 0.84, 0.13
% variance 39.3, 61.0, 80.5, 97.3, 100

EIGENVECTORS-
1: 0.42H/L, 0.52DM/L, 0.68W/L
2: 0.51H/L, 0.62A/L, -0.55DM/L
3: 0.3A/L, 0.92D/L

CLUSTER STATISTICS-

H/L	55.0	54.6	53.7	60.4
A/L	15.2	12.3	15.6	17.7
DM/L	56.3	65.1	61.9	63.6
D L	79.7	78.9	68.9	71.0
W L	49.1	57.4	54.8	60.0
No.	23	12	32	24
	A. tenuis group.	*A.* sp. cf. *A. wrighti* group.	*A. phillipsii* group.	*A. calveri* sp. nov. group.

* *

9. *Anthraconaia* sp. from above the Phalen seam.

Raw data-

No.	H/L	A/L	HMA/L	Z/L	HH/L
73BC	53.5	35.2	28.5	18.8	97.5
67B	51.9	25.4	28.0	18.4	95.0
67	51.4	19.8	38.7	22.1	89.2
64	53.1	31.2	29.2	17.7	98.2
64B	58.7	29.7	33.2	18.2	98.2
73BB	52.5	28.7	28.7	15.8	98.5
73BA	56.6	30.8	37.1	19.3	96.0
S1	57.0	31.2	33.3	12.5	100.0
S2	53.7	29.9	33.7	17.9	95.5
S2B	56.2	34.7	32.6	15.6	98.1
S4	53.6	30.5	20.3	18.9	95.0
S18	63.0	32. 6	38.2	17.8	97.0
S19	63.4	32.2	35.9	18.3	98.2
S22	58.8	35.2	30.6	18.7	97.7
S7	55.0	45.3	28.1	12.1	95.8
S9	56.1	35.4	28.7	21.2	97.8
S13B	49.6	26.5	26.2	20.4	96.2
S13	47.4	29.3	29.6	14.4	98.6

Population statistics-
Total number of specimens-18
Total number of variables-5

	mean	S.D.	MIN.	MAX.
H L	55.1	4.2	47.4	63.4
A L	31.3	5.2	19.8	45.3
HMA L	31.4	4.7	20.3	38.7
Z L	17.7	2.7	12.1	22.1
HH/L	96.8	2.4	89.2	100.0

Correlation table-

	H/L	A/L	HMA/L	Z/L
A L	0.37			
HMA L	0.48	-0.02		
Z L	0.0	-0.50	0.09	
HH L	0.3	0.46	-0.16	-0.52

EIGENVALUES: 2.13, 1.49, 0.68, 0.53, 0.17
% variance : 42.6, 72.4, 85.9, 96.5, 100

EIGENVECTORS-
1: 0.57A/L, -0.52Z/L, 0.56HH L
2: 0.67H L, 0.72HMA L
3: 0.36H L, 0.41A/L, -0.5HMA L, 0.67Z L

ONE CLUSTER ONLY = A. sp. cf. A. pulchella

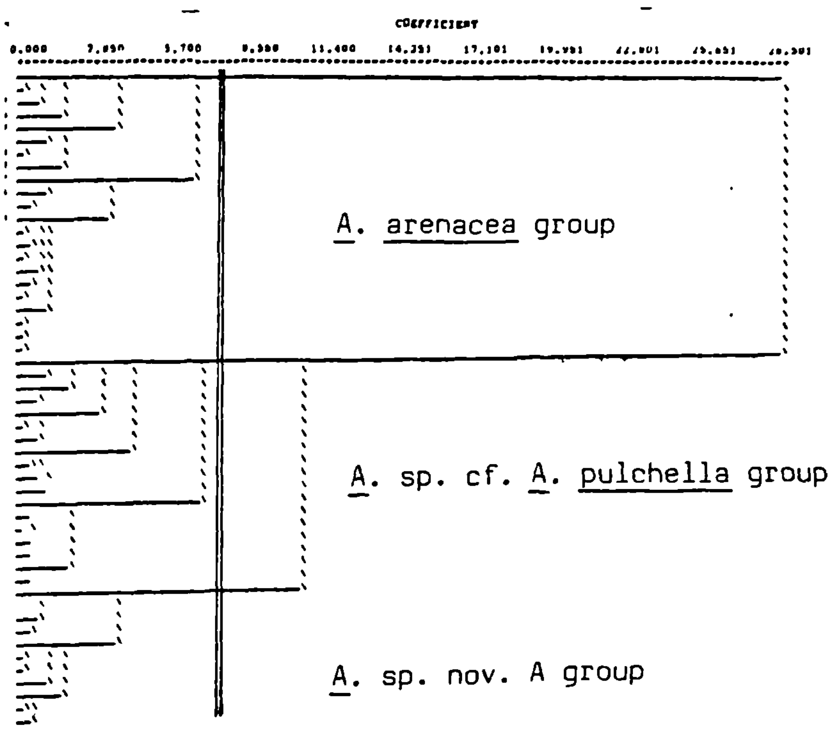
* * *

10. Anthraconaia spp. from between the Harbour and Hub seams.

Raw Data:

GB25A	51.9	27.3	13.4	15.4	95.4
GB16A	42.4	36.7	8.9	10.6	100.0
GB01B	59.6	36.0	29.2	15.0	98.1
GB01A	57.8	36.7	23.7	16.0	98.0
GB22A	52.1	34.5	30.0	9.6	97.8
GB02A	54.2	30.4	21.1	16.0	96.2
GB06A	45.5	34.4	22.5	13.7	100.0
GB07A	61.6	27.9	30.7	16.3	98.8
GB23A	51.6	32.8	26.6	19.8	98.0
GB27A	57.7	34.9	25.5	16.1	100.0
1996A	52.6	22.7	23.5	17.4	98.6
1993A	56.7	29.5	25.0	16.5	99.3
1985A	52.3	34.8	29.9	18.8	98.6
1982A	61.5	31.0	32.3	14.2	96.2
1966B	54.6	26.2	31.2	13.6	99.3
1966A	54.5	26.6	29.3	17.5	99.1
1976A	57.6	34.5	31.2	16.5	96.8
1971A	51.2	18.5	29.9	16.1	99.3
1987A	50.2	26.6	25.6	14.7	98.3
154B	47.4	26.8	17.2	17.5	93.7
154A	46.5	25.7	15.3	17.1	93.3
159A	46.8	29.9	17.6	15.2	95.5
159B	45.6	32.0	18.9	16.7	99.2
153A	39.8	12.8	16.5	19.6	97.2
159C	40.1	21.7	17.9	19.0	96.0
1501A	56.4	42.9	40.3	20.6	90.0
1493A	69.2	42.1	36.5	8.3	98.1
1516A	63.4	42.5	33.3	11.5	97.5
1577B	62.2	44.4	37.5	17.1	91.4
1577A	56.6	35.8	36.1	8.5	96.1
1495A	61.8	32.8	29.4	17.2	96.0
552A	52.6	40.0	33.5	16.7	95.0

FIGURE A.10:PHENOGRAM OF ANTHRACONAIA SPP. FROM BETWEEN THE BACKPIT AND PHALEN SEAMS.



Population statistics-

	mean	S.D.	MIN.	MAX.
H/L	53.6	6.9	39.8	69.2
A/L	31.7	7.2	12.8	44.4
HMA/L	26.2	7.7	8.9	40.3
Z/L	15.8	3.2	8.3	20.8
HH/L	97.2	2.5	90.0	100.0

Correlation table-

	H/L	A/L	HMA/L	Z/L
A/L	0.57			
HMA/L	0.74	0.53		
Z/L	-0.27	-0.38	-0.13	
HH/L	-0.04	-0.22	-0.16	-0.22

EIGENVALUES: 2.40, 1.22, 0.77, 0.37, 0.24
% variance : 48.0, 72.4, 87.9, 95.3, 100.0

EIGENVECTORS:
1: 0.57H L, 0.54A/L, 0.55HMA/L
2: -0.63Z/L, 0.76HH/L
3: 0.35H L, -0.35A/L, 0.39HMA/L, 0.57Z/L, 0.53HH/L.

CLUSTER STATISTICS-

H L	46.2	55.9	60.0
A L	27.8	30.8	40.4
HMA L	16.9	28.5	35.6
Z L	16.1	16.8	12.6
HH L	96.7	98.4	95.2
No.	10	16	6
	A. arenacea group.	_A._ sp. cf. _A. pulchella_ group.	_A._ sp. nov. A group.

* * * * * * * * * * * * * * * * * * * *

11: _Anthraconaia_ spp. from between the Harbour & Hub seams.
Population statistics-
Total number of specimens-54
Number of variables-5

	mean	S.D .	MIN.	MAX.
H/L	54.0	6.6	40.6	69.5
A L	30.4	6.0	13.7	45.6
HMA L	29.9	5.4	19.7	41.3
Z L	14.8	3.3	8.3	21.2
HH L	97.3	2.3	91.6	100.0

Correlation table-

	H/L	A/L	HMA/L	Z L
A L	0.5			
HMA L	0.6	0.28		
Z/L	-0.06	-0.61	-0.14	
HH L	-0.1	0.05	-0.17	-0.07

EIGENVALUES: 2.11, 1.30, 0.88, 0.49, 0.22
% variance : 42.3, 68.2, 85.5, 95.5, 100.0

EIGENVECTORS:
1: 0.53H/L, 0.56A/L, 0.49HMA/L, -0.40Z/L
2: 0.34H/L, -0.34A/L, 0.40HMA/L, 0.56Z/L, -0.54HH/L
3: 0.34H/L, 0.42/L, 0.83HH/L.

CLUSTER STATISTICS-

H/L	58.7	60.5	48.6	56.8	51.6
A/L	31.7	38.4	29.5	30.2	24.5
HMA/L	22.2	34.3	26.2	35.9	28.2
Z/L	16.5	12.2	13.2	15.0	18.5
HH/L	94.6	98.3	98.8	94.7	98.1
No.	4	10	17	12	11
	A. sp. indet.	*A.* sp.cf. *A. saravana*	*A.* sp. aff. *A. speciosa*	*A.* sp. nov.	*A.* sp. cf. *A. palatina*

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1684A 60.2 11.7 37.7 66.0 67.6 52.2 50.4
1682A 57.6 21.0 28.3 32.6 72.4 65.9 59.6
1683A 47.9  9.2 25.9 44.6 55.2 67.3 49.0
1688A 63.4  6.5 27.8 65.6 60.8 56.9 25.5
1683A 55.6 14.4 39.7 60.0 66.0 40.3 47.1
1687A 50.6  6.4 26.0 68.7 54.7 80.7 43.3
1806B 59.0 16.3 35.0 53.3 63.0 50.0 43.3
1806A 46.1 12.3 31.6 53.5 58.2 62.5 52.1
1776A 57.9 19.9 38.7 67.2 69.7 46.2 54.6
1775A 54.8 14.4 29.8 46.5 69.2 56.3 64.8
1802A 48.6 10.1 31.2 63.5 55.3 65.5 44.1
1779A 55.1 18.9 41.1 50.6 66.3 46.2 49.1
1810A 46.8 14.4 29.2 63.6 59.9 69.8 54.5
1818A 61.2 14.2 32.3 46.9 69.2 47.1 56.8
1824A 59.9  7.5 28.9 45.6 67.6 60.7 59.9
1823A 49.6  8.1 30.6 54.6 60.3 65.8 47.5
1622A 61.8 15.9 25.4 50.6 70.2 51.1 65.9
1825A 47.2 11.6 29.2 63.0 59.2 68.2 53.6
1799A 43.7 14.5 20.0 75.3 56.4 75.0 63.4
1855A 42.7 13.9 17.6 23.7 56.4 78.6 74.7
1831A 53.4 15.7 24.2 57.7 65.5 70.3 51.6
1832A 59.4 23.3 26.4 30.2 66.0 59.8 49.0
1763A 48.6 13.2 31.6 63.2 67.6 97.3 45.1
1766A 40.4  4.4 26.5 57.2 67.0 53.8 44.6
1782A 52.8 16.0 28.5 45.0 58.6 53.7 39.2
1795A 58.7 11.5 41.3 65.1 68.3 43.1 48.8
1797A 42.8 12.1 37.5 50.4 48.7 31.5 52.0
1796A 65.9 19.0 31.2 66.6 73.5 66.2 49.1
1820A 46.8 12.0 33.6 61.4 56.6 50.0 52.7
1620A 58.1 15.4 25.0 55.7 66.9 78.9 53.8
1627A 60.7 17.8 36.6 36.8 74.8 61.7 51.9
1777A 48.2 15.5 46.0 66.5 60.6 70.6 60.0
1774A 52.2 17.4 36.0 41.5 65.2 60.5 60.6
1780A 56.4 13.6 33.4 36.2 58.9 63.2 48.3
1665A 63.7 25.9 23.6 45.1 72.4 61.0 86.0
1767A 53.3 16.6 41.5 67.8 65.1 32.1 55.4
1778A 48.1 13.0 24.7 61.2 57.3 67.7 51.0
1829A 48.2 16.4 21.5 42.4 55.6 80.3 57.3
1817A 41.8  9.4 20.1 46.3 54.2 83.1 53.3
1619A 60.4 17.5 36.4 83.3 73.1 51.2 57.7
1809A 57.7 13.8 37.1 43.2 66.8 43.2 46.5
1640A 70.0  8.4 45.2 55.5 78.1 33.6 51.0
1864A 60.0 16.6 36.6 61.0 75.4 41.8 66.6
1604A 57.2 21.0 33.6 52.8 69.0 57.4 47.2
1813A 48.4 12.5 28.8 63.7 53.1 47.2 64.1
```

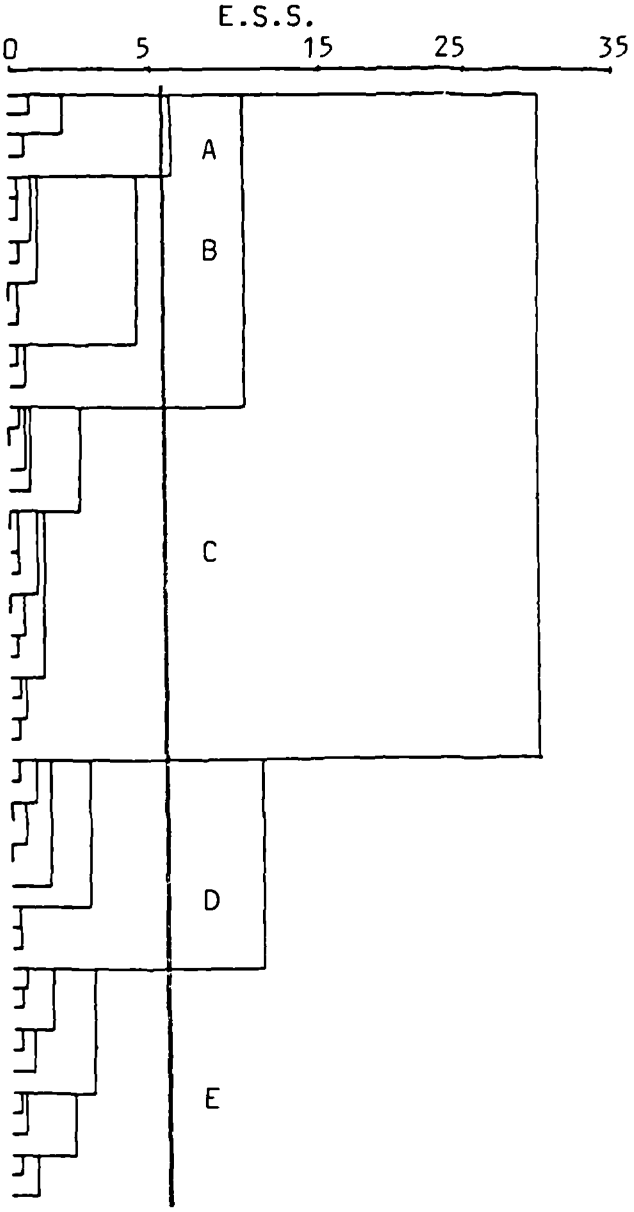

FIGURE A.11: Phenogram of Harbour - Hub seam interval *Anthraconaia* spp. Where A = *A.* sp. indet., B = *A.* sp. cf. *A. palatina*, C = *A.* sp. aff. *A. speciosa*, D = *A.* sp. cf. *A. saravana*, E = *A.* sp. nov. A.

APPENDIX B

APPENDIX B

A REVIEW OF HIERARCHICAL CLUSTERING METHODS.

The basic procedure of all these methods is similar (Chapter 3) and differences in the methods arise because of the different ways of defining distance or simmilarity between an individual and a group of individuals, or between two groups of individuals. Some methods are only suitable for use with a distance matrix. Examples cited here are based on Everitt (1974) with some additional notes from Wishart (1978).

1. SINGLE LINKAGE METHOD.

This method can be used with either simmilarity or distance measures. Groups initially consisting of single individuals are fused according to the distance between their nearest neighbours (such that the groups with the smallest distance (or greatest simmilarity) are fused). Each fusion cycle decrements by one the total number of groups. The simmilarity between clusters X and Y is defined as the highest single similarity coefficient or smallest distance) between two individuals, one from each cluster.

e.g. Suppose five individuals are to be classified, and the matrix of distances between the individuals matrix D1), is as follows;

$$D1 = \begin{array}{c|ccccc|} & 1 & 2 & 3 & 4 & 5 \\ 1 & 0.0 & 2.0 & 6.0 & 10.0 & 9.0 \\ 2 & 2.0 & 0.0 & 5.0 & 9.0 & 8.0 \\ 3 & 6.0 & 5.0 & 0.0 & 4.0 & 5.0 \\ 4 & 10.0 & 9.0 & 4.0 & 0.0 & 3.0 \\ 5 & 9.0 & 8.0 & 5.0 & 3.0 & 0.0 \end{array}$$

In this matrix the element in the ith row and jth column gives the distance, d_{ij}, between individuals i and j .

STAGE 1: Fuse individuals 1 and 2 to form group d_{12}, since this is the smallest entry in D1. The distance between this group and the three remaining individuals 3, 4 and 5, may be obtained from D1 as follows:

$$d_{12)3} = \min\{d13, d23\} = d23 = 5.0$$

$$d_{12\,4} = \min\{d14, d24\} = d24 = 9.0$$

$d(12)5 = \min\left\{d15,\ d25\right\} = d25 = 8.0$

This results in a new matrix (D2) giving inter-individual distances, and group-individual distances.

$$D2 = \begin{array}{|c|cccc|} & (12) & 3 & 4 & 5 \\ (12) & 0.0 & 5.0 & 9.0 & 8.0 \\ 3 & 5.0 & 0.0 & 4.0 & 5.0 \\ 4 & 9.0 & 4.0 & 0.0 & 3.0 \\ 5 & 8.0 & 5.0 & 3.0 & 0.0 \end{array}$$

STAGE 2: The smallest entry in D2 is d45 and so individuals 4 and 5 are fused to form group d(45) and the distances now become:

$d(12\ 3 = 5.0$

$d\ 12\ \ 45\ = \min\left\{d14,\ d15,\ d24,\ d25,\right\} = d25 = 8.0$

$d\ 45\ 3 = \min\left\{d34,\ d35\right\} = d34 = 4.0$

resulting in matrix D3:

$$D3 = \begin{array}{|c|ccc|} & (12) & 3 & 45) \\ (12) & 0.0 & 5.0 & 8.0 \\ 3 & 5.0 & 0.0 & 4.0 \\ (45) & 8.0 & 4.0 & 0.0 \end{array}$$

STAGE 3: The smallest entry is now d(45 3 and so individual 3 is added to the group containing indivduals 4 and 5. Finally fusion of the two remaining groups occurs to form a single group containing all five individuals. The dendrogram showing these fusions is given in Figure B.1.

DRAWBACKS: Single linkage will find 'straggling' clusters, and often fails to partition large populations due to chaining.

2.COMPLETE LINKAGE.

This method is exactly the opposite of the single linkage method in that the simmilarity between clusters X and Y is the smallest single simmilaritv coefficient between two individuals, one from each cluster.

e.g. Using this method for the distance matrix D1 of the previous example, fusion begins with groups 1 and 2. The distance between the group and the three remaining individuals 3, 4 and 5 are obtained from D1 as follows;

$d(12)3 = \max\{d13,\ d23\} = d23 = 6.0$

$d(12)4 = \max\{d14,\ d24\} = d14 = 10.0$

$d(12)5 = \max\{d15,\ d25\} = d14 = 9.0$

The final result is the dendrogram shown in Figure B.2.

DRAWBACKS: Complete linkage finds spherical clusters, but is liable to produce irregular results because the simmilarity criterion is determined for only two individuals and does not measure group structure.

3. GROUP AVERAGE METHOD.

The simmilarity between two clusters X and Y is the average of all the simmilarity (or distance coefficients for pairs of individuals, one from each cluster.

DRAWBACKS: This method represents an attempt to take account of group structure and finds spherical clusters. However, the concept of an average correlation coefficient is not entirely acceptable to some statisticians.

4. CENTRIOD CLUSTER ANALYSIS.

Groups are depicted to lie in euclidean space, and are replaced on formation by the co-ordinates of their centroid. The distance between groups is defined as the distance between the group centroids. The procedure then is to fuse groups according to the distance between their centroids, the groups with the smallest distances being fused first.

DRAWBACKS: The results obtained with this method often exhibit the chaining effects associated with the single linkage method. If the sizes of the two groups to be fused are very different, the centroid of the new group will be very close to that of the larger group and may remain within that group; the characteristic properties of the smaller group are then virtually lost.

5. MEDIAN CLUSTER ANALYSIS.

This method was an attempt to alleviate the latter problem mentioned with the previous clustering method. The strategy can be made independent of group size by assuminng that the groups to be fused are of equal size, the apparent position of the new group will then always be between the two groups to be fused.

DRAWBACKS: Distance measures only may be used with this method and chaining effects occur.

6. WARD'S METHOD.

Ward (1963, proposed that at any stage of an analysis, the loss of information which results from the grouping of individuals into clusters can be measured by the total sum of the squared deviations of every point from the mean of the cluster to which it belongs. At each step in an analysis, the fusion of every possible pair of clusters is considered and the two clusters whose fusion results in the least increase in the error sum of squares ESS) are fused.

The error sum of squares is given by;

$$E.S.S. = \sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2$$

where x_i= the score of the ith individual.

e.g. Take five individuals to be clustered using Ward's method on the basis of their values on a single variable:

		Variable value.
INDIVIDUAL	1	1
	2	2
	3	7
	4	9
	5	12

STAGE 1: Each individual is regarded as a single member cluster and so ESS is zero. The two individuals whose fusion results in the minimum increase in the ESS form the first group. In the above example, this is groups 1 and 2 and the ESS becomes 0.5.

STAGE 2: The next two groups whose fusion results in the second smallest rise in the ESS - level are fused. This continues until all the individuals are fused and the results are summarised in Figure 8.3.

DRAWBACKS: Valid only with distance coefficients.

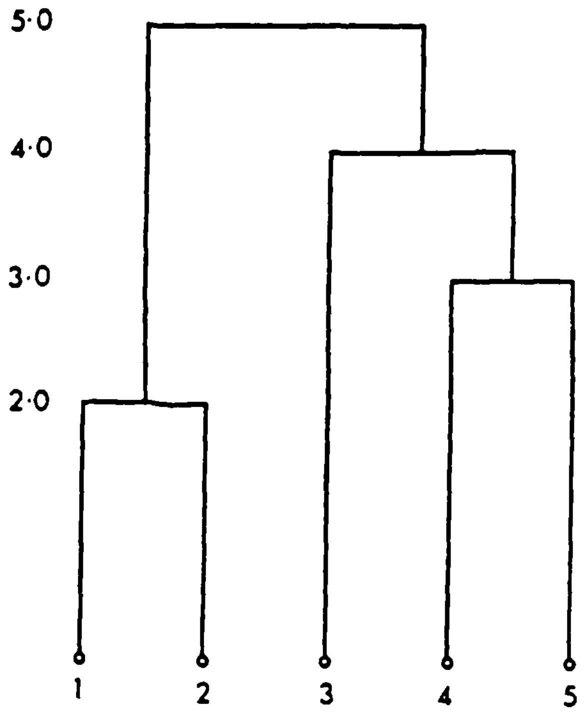

FIGURE B.1: SINGLE LINKAGE DENDROGRAM.

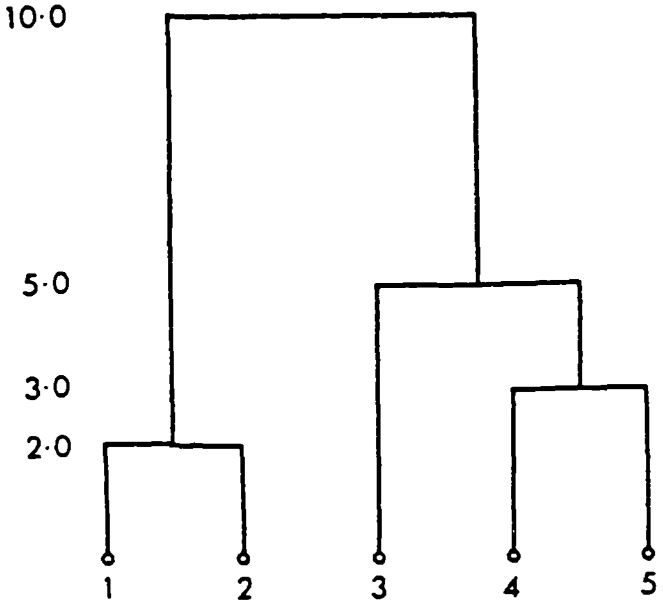

FIGURE B.2: COMPLETE LINKAGE DENDROGRAM.

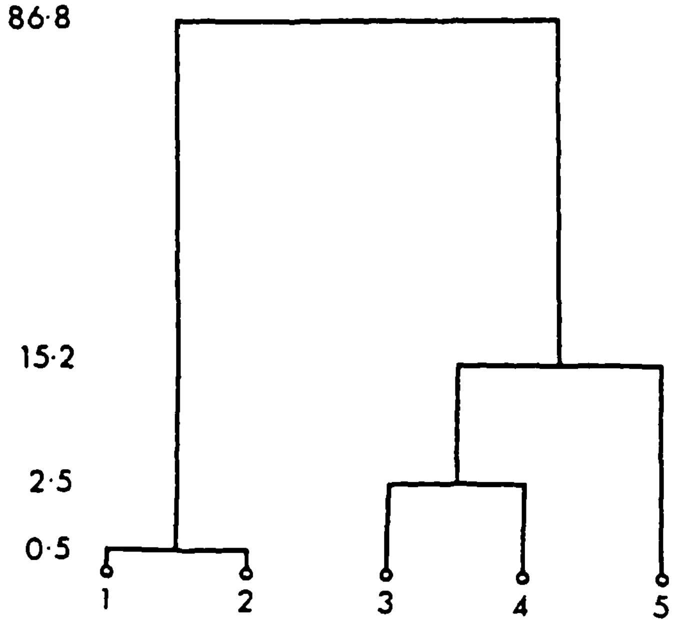

FIGURE B.3: WARD'S CLUSTERING DENDROGRAM.

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(See inside back cover for reprints of published papers).