CHAPTER 4.

DEFINITION OF TRACE FOSSIL ZONES (INTERVALS, SUBINTERVALS AND LEVELS)

DEFINITION OF TRACE FOSSIL ZONES (INTERVALS, SUBINTERVALS AND LEVELS)

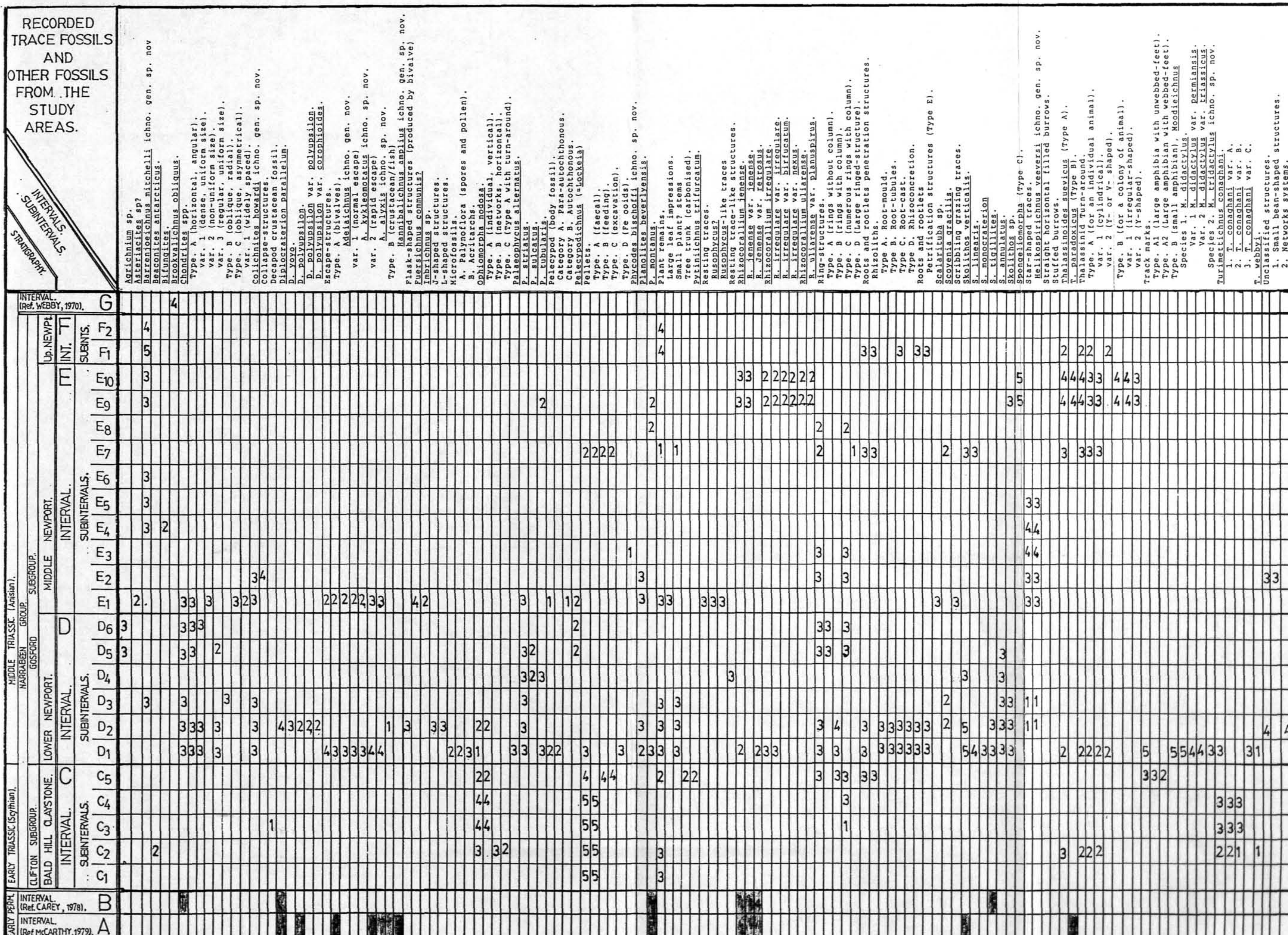
4.1. INTRODUCTION

Within the first 12 months of the project a subdivision of the Triassic rocks of the study area into trace fossil intervals and subintervals was made on the basis of a comprehensive reconnaissance of the Bald Hill Claystone, Newport Formation and Hawkesbury Sandstone in the Sydney Northshore region and on the basis of the ichnological sections that were logged in the study area during this period (Table 4.1; Text-Fig. 4.1). This scheme of trace fossil subdivisions also incorporates trace fossil intervals within the ichnologically known (i.e., previously described) Lower Permian formation of the southern Sydney Basin: specifically, the Wasp Head and Pebbly Beach Formations (cf. McCarthy 1979) and the Snapper Point Formation (cf. Carey 1978). The Wasp Head and overlying Pebbley Beach Formation, the basal-most marine units in the coastal area of the Sydney Basin, together comprise trace fossil interval A in this scheme. the overlying Snapper Point Formation comprises trace fossil interval B (Table 4.1; Text-Fig. 4.1). The ichnology of the overlying Permian and Triassic section between the top of the Snapper Point Formation and the basal Part of the Bald Hill Claystone remain undescribed (or need restudy) and hence are omitted from this scheme. The Triassic formations of the study area comprise trace fossil intervals C, D, E, F and G. Hereafter throughout the text of this report the code used for these trace fossil intervals and their component subintervals are prefixed with the letter "I" to

TABLE 4.1. Stratigraphic tabulation of the trace fossil intervals and subintervals in the ichnologically known coastal exposures of the southern and central Sydney Basin. Intervals A, B, and G are based respectively on the work of McCarthy (1979), Carey (1978) and Webby (1970). Intervals C - F stem from the present work.

STRATIGRAPHIC UNITS (Fm./Mbr.)	STRATIGRAPHIC CODE	INTERVAL	SUBINTERVAL
Hawkesbury Sandstone	TR2h	**IG**	-
Newport Fm., Upper Mbr.	TR2n3	**IF**	IF2 IF1
Newport Fm., Middle Mbr.	TR2n2	**IE**	IE10 IE9 IE8 IE7 IE6 IE5 IE4 IE3 IE2 IE1
Newport Fm., Lower Mbr. & Garie Fm.	TR2n1 TR2g	**ID**	ID6 ID5 ID4 ID3 ID2 ID1
Bald Hill Claystone	TR1b	**IC**	IC5 IC4 IC3 IC2 IC1
Snapper Pt. Fm.	P1s	**IB**	-
Pebbley Beach Fm. & Wasp Head Fm.	P1p & P1w	IA	-

TEXT-FIG. 4.1. Stratigraphic distribution of trace fossils, body fossils, and plant remains in the study area. Four major assemblage zones of trace fossils are recognized: (1) subintervals IC1 - IC5 of interval IC in the Bald Hill Claystone; (2) subintervals ID1 - ID2 of interval ID in the Lower Newport Member (=Garie Formation); (3) subintervals ID5 & ID6 of interval ID in the upper part of Lower Newport Member and including also subinterval IE1 and possibly subinterval IE2 of interval IE in the Lower Part of Middle Newport Member; (4) subintervals IE7 - IE10 of interval IE in the upper part of Middle Newport Member. Trace fossil interval IF of the Upper Newport Member contains less abundant and less diverse trace fossils than the underlying trace fossil intervals. These four major stratigraphic assemblages of trace fossils defined on the basis of relative density and diversity of the trace are interpreted to define stratigraphic units that were influenced by marine conditions in a fluvially dominated estuary or coastal lagoon. (See also Text-Figs. 4.3, 5.2 & 5.3).



1 = RARE 2 = UNCOMMON 3 = COMMON 4 = ABUNDANT 5 = VERY ABUNDANT 6 = BIOTURBATED TOTALLY

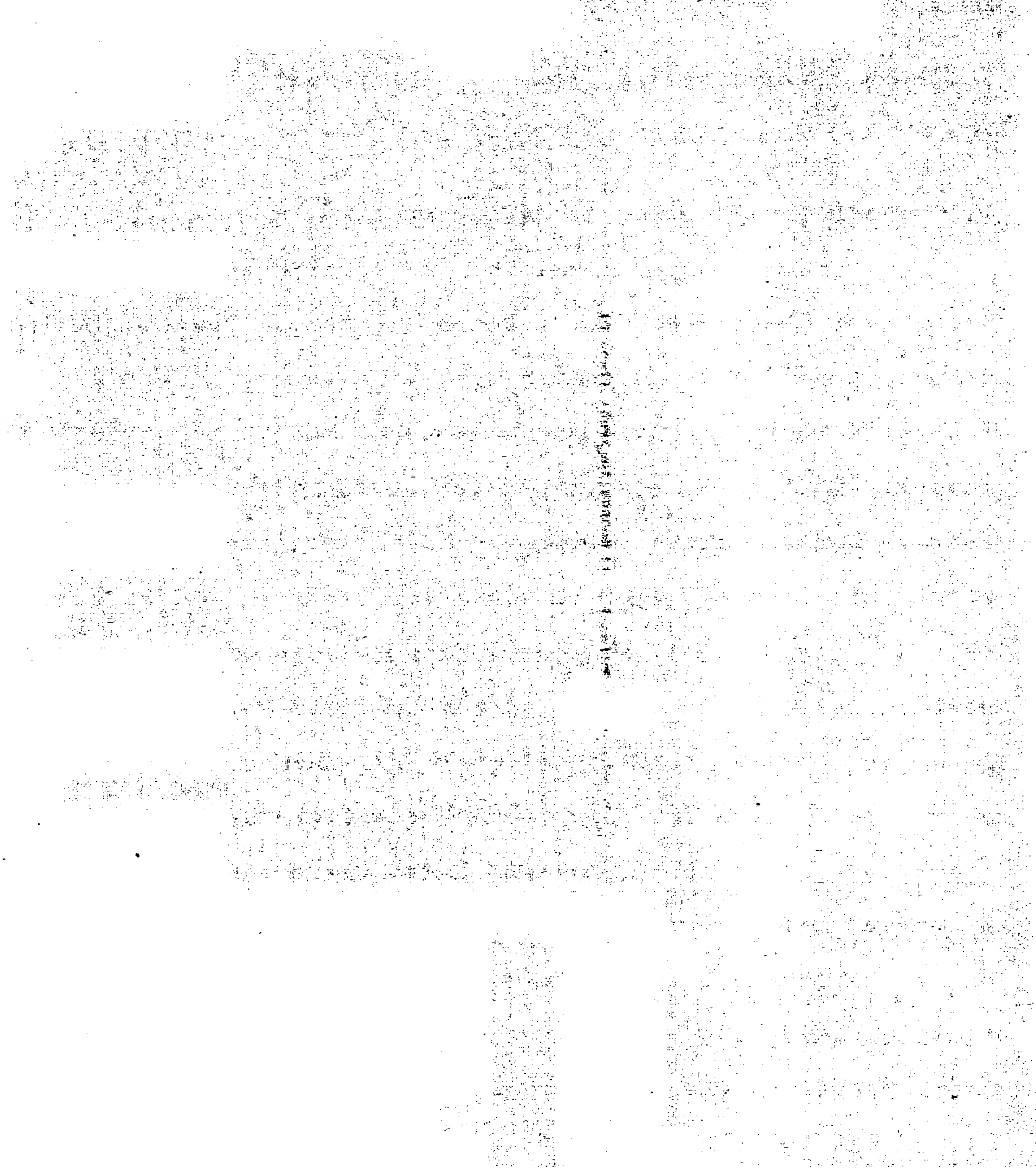
(RELATIVE ABUNDANCE SCALE SEMI-QUANTITATIVE)

TEXT-FIG. 4.1.

indicate "trace fossil interval/subinterval" (Table 4.1; Text-Fig. 4.1).

4.2. TRACE FOSSIL ZONES OF THE STUDY AREA

Cowan's stratigraphy and stratigraphic logs of the study area (Text-Fig. 1.6, & Enclosure III.3) formed the stratigraphic basis of the present work. A phase of reconnaissance of each different formation and of each of the three members of the Newport Formation was undertaken at the outset to resolve the ichnotaxonomic nature, diversity and distribution of the various trace fossils that occur in these strata, followed by a period of initial ichnological section-logging within each formation and member containing biogenic structures. The Hawkesbury Sandstone does not contain trace fossils in the coastal exposures (though some are present in the neighbouring hinterland region, e.g., Brookvalichnus Webby, 1970) and hence was not a primary focus of attention within the study area itself. During the reconnaissance phase of the work, and subsequently, Cowan's numerous detailed stratigraphic logs measured throughout the length of the study area provided the primary guide as to the stratigraphic and geographic distribution of the trace fossils since zones of burrowing were recorded on these logs and the detailed stratigraphy of the logs facilitated lateral correlation of the strata, including beds or zones with distinctive trace fossil assemblages, from headland to headland (cf. Enclosures III.1 & III.3). In this way a comprehensive overview of both the stratigraphic and north-south geographic distribution of the occurrence of individual ichnotaxa and trace fossil assemblages was obtained



TEXT-FIG. 4.2. Geographic distribution of trace fossils, body fossils, and plant remains in the study area. The numbered subareas of the study area are arranged with Barrenjoey Head (area 1 in the north) at the top and North Head, Middle Head, South Head and Dunbar Head (areas 21, 22, 23 and 24 respectively, all in the south) at the bottom. Major trace fossil distributions are confined to the central and northern parts of the area where the Bald Hill Claystone, Lower Newport Member and Middle Newport Member are exposed. In contrast, in the southern part of the study area where the Upper Newport Member and Hawkesbury Sandstone are exposed, the trace fossil distribution is low both in terms of diversity and density (see Enclosure III.1).

RECORDED TRACE FOSSILS AND OTHER FOSSILS FROM THE STUDIED AREAS.

No.	AREAS OF STUDY	AREA CODES	Agrichnium sp.	Asteriacites sp?	Barrenjoeichnus mitchelli ichno. gen. sp. nov	Beaconites antarcticus.	Bifungites.	Brookvalichnus obliquus.	Chondrites spp.	Type. A (horizontal, angular).	var. 1 (dense, uniform size).	var. 2 (non-uniform size).	var. 3 (regular, uniform size).	Type. B (oblique, radial).	Type. C (oblique, asymmetrical).	var. 1 (widely spaced).	Colichnites howardi ichno. gen. sp. nov.	Collapse-structures.	Decapod crustacean fossil.	Diplocraterion parallelum.	D. yoyo.	D. polyupsilon.	D. polyupsilon var. polyupsilon.	D. polyupsilon var. corophioides.
1	BARRENJOEY HEAD.	1			5																			
2	PALM BEACH NORTH.	4a																						
3	PALM BEACH SOUTH.	4b			4																			
4	LITTLE HEAD.	7			3																			
5	CAREEL HEAD.	9			3																			
6	BANGALLEY HEAD NORTH.	8a															3							
7	BANGALLEY HEAD SOUTH.	8b					2										3	4						
8	St. MICHAELS CAVE.	5							3	3			3	3				3						
9	HOLE IN THE WALL.	11							3					3				2						
10	BILGOLA HEAD & BILGOLA BEACH.	10 a,b		2					3	3	3		3		2	2	3							
11	NEWPORT (LITTLE REEF).	12																		4	3	2	2	2
12	BUNGAN HEAD.	13							3	3		2												
13	MONA VALE HEAD.	14	3						2	3	2		2											
14	WARRIEWOOD BEACH.	6																						
15	TURIMETTA HEAD.	2				2			3	3	3													
16	NARRABEEN HEAD.	15																						
17	CALLAROY BASIN.	16																						
18	LONG REEF POINT HEAD.	3																	1					
19	DEE WHY HEAD.	17																						
20	CURL CURL HEAD.	18																						
21	CABBAGE TREE BAY.	19			3																			
22	BLUE FISH POINT HEAD	20			3																			
23	NORTH HEAD.	21																						
24	MIDDLE HEAD.	22																						
25	SOUTH HEAD.	23																						
27	DUNBAR HEAD.	24																						
28	BEACON HILL QUARRY.	26						4																
29	OURIMBAH QUARRY.	27																						
30	NORTH HEAD (GARIE).	25																						

No.	AREAS OF STUDY	AREA CODES	Escape-structures.	Type. A (bivalves).	Adelaichnus ichno. gen. nov.	var. 1 (normal escape)	A. kykleomotatus ichno. sp. nov.	var. 2 (rapid escape)	A. alyxis ichno. sp. nov.	Type. B (crustacean/fish)	Hannibalichnus amplius ichno. gen. sp. nov.	Flask-shaped structures (produced by bivalve)	Fuersichnus communis?	Imbrichnus sp.	J-shaped structures.	L-shaped structures.	Microfossils.	A. Palynoflora (spores and pollen).	B. Acritarchs.	Ophiomorpha nodosa.	Type. A (individual, vertical).	Type. B (networks, horizontal).	Type. C (Type A with turn-around).	Palaeophycus alternatus.
1	BARRENJOEY HEAD.	1																						
2	PALM BEACH NORTH.	4a																						
3	PALM BEACH SOUTH.	4b																						
4	LITTLE HEAD.	7																						
5	CAREEL HEAD.	9																						
6	BANGALLEY HEAD NORTH.	8a																						
7	BANGALLEY HEAD SOUTH.	8b																						
8	St. MICHAELS CAVE.	5	2							1	1		4				2	2						
9	HOLE IN THE WALL.	11																						
10	BILGOLA HEAD & BILGOLA BEACH.	10 a,b												2										3
11	NEWPORT (LITTLE REEF).	12										3			3	3								
12	BUNGAN HEAD.	13	3	3	3	3	3													3	3			
13	MONA VALE HEAD.	14	4	4	3	3	3	4	4															
14	WARRIEWOOD BEACH.	6															2	2	3					
15	TURIMETTA HEAD.	2															2	2		4	3	4	2	
16	NARRABEEN HEAD.	15																						
17	CALLAROY BASIN.	16																						
18	LONG REEF POINT HEAD.	3																						
19	DEE WHY HEAD.	17																						
20	CURL CURL HEAD.	18																						
21	CABBAGE TREE BAY.	19																						
22	BLUE FISH POINT HEAD	20																						
23	NORTH HEAD.	21																						
24	MIDDLE HEAD.	22																						
25	SOUTH HEAD.	23																						
27	DUNBAR HEAD.	24																						
28	BEACON HILL QUARRY.	26																						
29	OURIMBAH QUARRY.	27																						
30	NORTH HEAD (GARIE).	25																						

No.	AREAS OF STUDY	AREA CODES	P. striatus.	P. sulcatus.	P. tubularis.	Pelecypod (body fossil).	Category A. Para-autochthonous.	Category B. Autochthonous.	Pelecypodichnus (=Lockeia)	Pellets.	Type. A (faecal).	Type. B (feeding).	Type. C (excavation).	Type. D (Fe ooids)	Phycodes bischoffi ichno. sp. nov.	Planolites beverleyensis.	P. montanus.	Plant remains.	Large leaf impressions.	Small plant? stems	Tree trunk (carbonised).	Pytinichnus trifurcatum.	Resting traces.	Rusophycus?
1	BARRENJOEY HEAD.	1																4						
2	PALM BEACH NORTH.	4a																						
3	PALM BEACH SOUTH.	4b			2												2							
4	LITTLE HEAD.	7								2	2	3	3			3		1			1			
5	CAREEL HEAD.	9																						
6	BANGALLEY HEAD NORTH.	8a													1	3		2	1		2			
7	BANGALLEY HEAD SOUTH.	8b																						
8	St. MICHAELS CAVE.	5	3		3													3		3				
9	HOLE IN THE WALL.	11	3													2								
10	BILGOLA HEAD & BILGOLA BEACH.	10 a,b			3				2	2				3		3	3	3		3			3	
11	NEWPORT (LITTLE REEF).	12																						
12	BUNGAN HEAD.	13	3							3		3	3			3		3			1		3	3
13	MONA VALE HEAD.	14		2		1		1	2															
14	WARRIEWOOD BEACH.	6				2	2		2									3						
15	TURIMETTA HEAD.	2								5	5													
16	NARRABEEN HEAD.	15																						
17	CALLAROY BASIN.	16																						
18	LONG REEF POINT HEAD.	3																3		3		2		
19	DEE WHY HEAD.	17																						
20	CURL CURL HEAD.	18																						
21	CABBAGE TREE BAY.	19																						
22	BLUE FISH POINT HEAD	20																						
23	NORTH HEAD.	21																						
24	MIDDLE HEAD.	22																						
25	SOUTH HEAD.	23																						
27	DUNBAR HEAD.	24																						
28	BEACON HILL QUARRY.	26																						
29	OURIMBAH QUARRY.	27																						
30	NORTH HEAD (GARIE).	25																						

No.	AREAS OF STUDY	AREA CODES	Rusophycus-like traces	Resting trace-like structures.	Rhizocorallium jenense.	R. jenense var. jenense.	R. jenense var. retrosus.	Rhizocorallium irregulare.	R. irregulare var. irregulare.	R. irregulare var. birfucatum.	R. irregulare var. nexus.	Rhizocorallium uliarense.	R. uliarense var. planuspirus.	Ring-structures.	Type. A (rings without column).	Type. B (rings with column).	Type. C (numerous rings with column).	Type. D (Large ringed-structure).	Roots and rootlets penetration structures.	Rhizoliths.	Type A. Root-mould.	Type B. Root-tubules.	Type C. Root-cast.	Type D. Rhizoconcretion.
1	BARRENJOEY HEAD.	1																						
2	PALM BEACH NORTH.	4a																						
3	PALM BEACH SOUTH.	4b			3	3		2		2	2	2	2	3			3		3	3			3	
4	LITTLE HEAD.	7												2				2	3					
5	CAREEL HEAD.	9																						
6	BANGALLEY HEAD NORTH.	8a												3			3							
7	BANGALLEY HEAD SOUTH.	8b																						
8	St. MICHAELS CAVE.	5			3		3												4	4	3	3		3
9	HOLE IN THE WALL.	11																						
10	BILGOLA HEAD & BILGOLA BEACH.	10 a,b		3																				
11	NEWPORT (LITTLE REEF).	12																						
12	BUNGAN HEAD.	13	3		2	2								4		4	4							
13	MONA VALE HEAD.	14			3			3	3					3	3									
14	WARRIEWOOD BEACH.	6																	3	3	3	3		2
15	TURIMETTA HEAD.	2												3		3								
16	NARRABEEN HEAD.	15																						
17	CALLAROY BASIN.	16																						
18	LONG REEF POINT HEAD.	3												2			2		3					
19	DEE WHY HEAD.	17																						
20	CURL CURL HEAD.	18																						
21	CABBAGE TREE BAY.	19																						
22	BLUE FISH POINT HEAD	20																						
23	NORTH HEAD.	21																						
24	MIDDLE HEAD.	22																						
25	SOUTH HEAD.	23																						
27	DUNBAR HEAD.	24																						
28	BEACON HILL QUARRY.	26																						
29	OURIMBAH QUARRY.	27																						
30	NORTH HEAD (GARIE).	25																						

No.	AREAS OF STUDY	AREA CODES	Roots and rootlets	Petrification structures (Type E).	Scalarituba sp.	Scoyenia gracilis.	Scribbling grazing traces.	Skolithos verticalis.	S. linearis.	S. monocraterion	S. tigillites.	S. annulatus.	Skolithos sp.	Spongeliomorpha (Type C).	Star-shaped traces.	Helikospirichnus veeversi ichno. gen. sp. nov.	Straight horizontal filled burrows.	Stuffed burrows.	Thalassinoides suevicus (Type A).	T. paradoxicus (Type B).	Thalassinid Turn-around.	Type. A (for an individual animal).	var. 1 (cylindrical).	var. 2 (Y- or V- shaped).
1	BARRENJOEY HEAD.	1																						
2	PALM BEACH NORTH.	4a																	2		2	2		2
3	PALM BEACH SOUTH.	4b											3	5					4	4	4	3	3	
4	LITTLE HEAD.	7	3	3		2													3	3	3	3		
5	CAREEL HEAD.	9																						
6	BANGALLEY HEAD NORTH.	8a													4	4	2							
7	BANGALLEY HEAD SOUTH.	8b										3			4	4								
8	St. MICHAELS CAVE.	5	3	4	3			3				3			3	3								
9	HOLE IN THE WALL.	11				2							4		2	2								
10	BILGOLA HEAD & BILGOLA BEACH.	10 a,b	3	3									3						2		2	2	2	
11	NEWPORT (LITTLE REEF).	12																						
12	BUNGAN HEAD.	13	2	2						4	4													
13	MONA VALE HEAD.	14					3					3												
14	WARRIEWOOD BEACH.	6									3	2												
15	TURIMETTA HEAD.	2															3	3	3		2	2	2	
16	NARRABEEN HEAD.	15																						
17	CALLAROY BASIN.	16																						
18	LONG REEF POINT HEAD.	3	3	3					4	2														
19	DEE WHY HEAD.	17																						
20	CURL CURL HEAD.	18																						
21	CABBAGE TREE BAY.	19																						
22	BLUE FISH POINT HEAD	20																						
23	NORTH HEAD.	21																						
24	MIDDLE HEAD.	22																						
25	SOUTH HEAD.	23																						
27	DUNBAR HEAD.	24																						
28	BEACON HILL QUARRY.	26																						
29	OURIMBAH QUARRY.	27																						
30	NORTH HEAD (GARIE).	25																						

No.	AREAS OF STUDY	AREA CODES	Type. B (for a colony of animal).	var. 1 (irregular-shaped).	var. 2 (Y-shaped).	Track marks.	Type. A1 (large amphibia with unwebbed-feet).	Type. A2 (Large amphibian with webbed-feet).	Type. B (small amphibian). Moodieichnus	Species 1. M. didactylus.	Var. 1 M. didactylus var. permiansis.	Var. 2 M. didactylus var. triassicus.	Species 2. M. tridactylus ichno. sp. nov.	Turimettichnus conaghani.	1. T. conaghani var. A.	2. T. conaghani var. B.	3. T. conaghani var. C.	T. webbyi.	Unclassified structures.	1. Small bean-shaped structures.	2. Networks systems.
1	BARRENJOEY HEAD.	1																			
2	PALM BEACH NORTH.	4a																			
3	PALM BEACH SOUTH.	4b	4	4	4																
4	LITTLE HEAD.	7																			
5	CAREEL HEAD.	9																			
6	BANGALLEY HEAD NORTH.	8a																	3	3	
7	BANGALLEY HEAD SOUTH.	8b				3			3	3	3	3	3								
8	St. MICHAELS CAVE.	5				5			5	5	3	3	3	4			4				
9	HOLE IN THE WALL.	11												3			3				
10	BILGOLA HEAD & BILGOLA BEACH.	10 a,b												3			3	1			
11	NEWPORT (LITTLE REEF).	12																	4		4
12	BUNGAN HEAD.	13												3			3				
13	MONA VALE HEAD.	14																			
14	WARRIEWOOD BEACH.	6																			
15	TURIMETTA HEAD.	2				3	3	3						4	4	3		2			
16	NARRABEEN HEAD.	15																			
17	CALLAROY BASIN.	16																			
18	LONG REEF POINT HEAD.	3												2	2						
19	DEE WHY HEAD.	17																			
20	CURL CURL HEAD.	18																			
21	CABBAGE TREE BAY.	19																			
22	BLUE FISH POINT HEAD	20																			
23	NORTH HEAD.	21																			
24	MIDDLE HEAD.	22																			
25	SOUTH HEAD.	23																			
27	DUNBAR HEAD.	24																			
28	BEACON HILL QUARRY.	26																			
29	OURIMBAH QUARRY.	27																			
30	NORTH HEAD (GARIE).	25																			

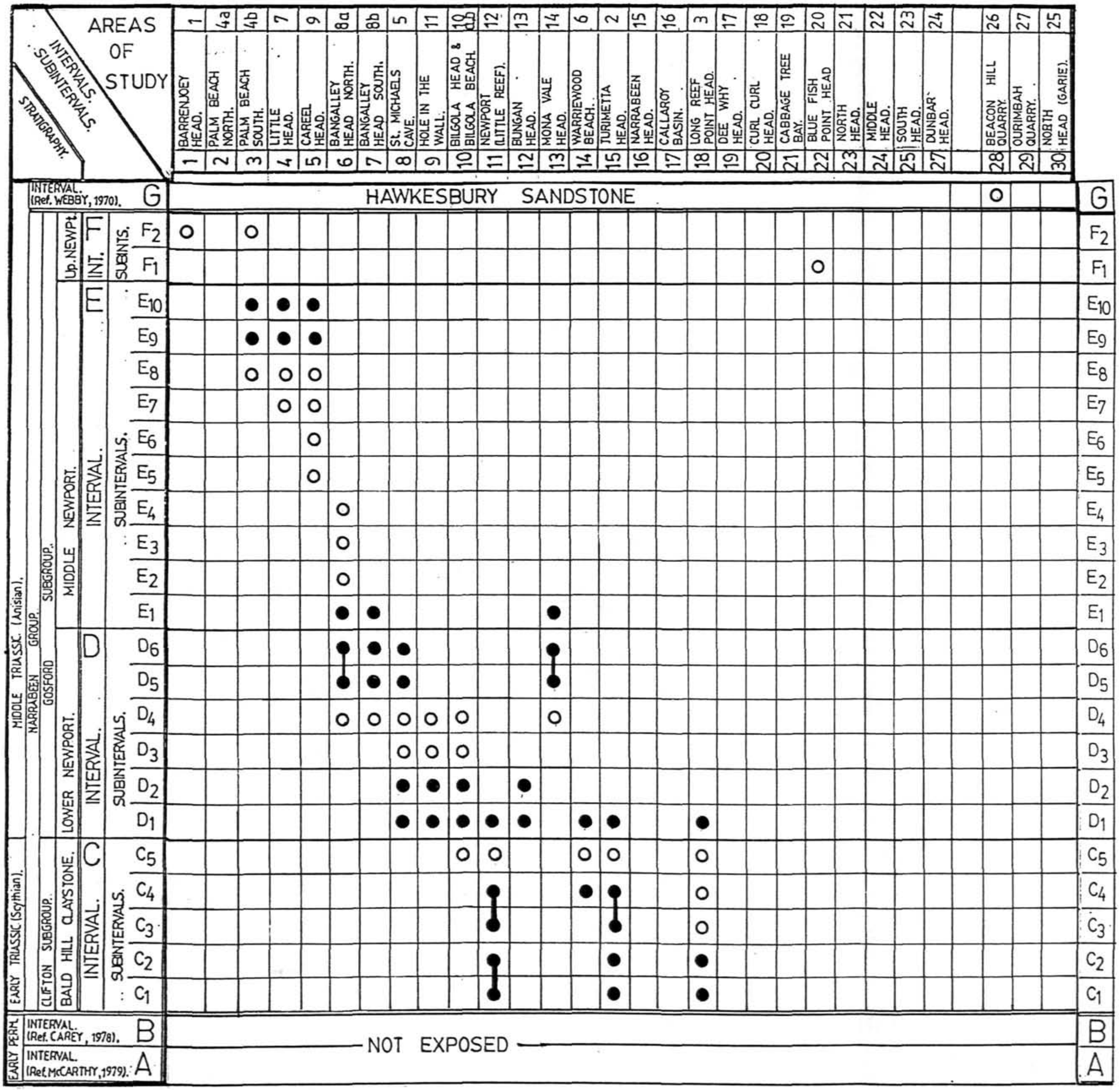
1 = RARE 2 = UNCOMMON 3 = COMMON 4 = ABUNDANT 5 = VERY ABUNDANT 6 = BIOTURBATED TOTALLY

(RELATIVE ABUNDANCE SCALE SEMI-QUANTITATIVE)

TEXT-FIG. 4.2.

(e.g., Enclosure III.4; see also Text-Figs. 4.2 & 4.3). This knowledge then permitted subdivision of the stratigraphic section into the stratigraphically successive separate trace fossil intervals IC to IG, the boundaries between them being placed at the existing formation and member boundaries because these major stratigraphic boundaries can also be seen to limit or define obvious discontinuites in the assemblages of trace fossils (Text-Fig. 4.1). Accordingly, interval IC comprises the top 30 m of the Bald Hill Claystone as exposed in the study area (the thickest exposure in the study area being at Long Reef), interval ID comprises the thin and discontinuously developed Garie Formation and overlying Lower Member of the Newport Formation, interval IE comprises the Middle Member of the Newport Formation, Interval IF comprises the Upper Newport Member, and interval IG the Hawkesbury Sandstone (Table 4.1 & Text-Fig. 4.1). With the exception of interval IG, each of these trace fossil intervals can be subdivided into thinner subzones or subintervals on the basis of the presence of distinctive suites or assemblages of trace fossils from one bed to another (cf. Enclosure III.4). These discrete trace fossil subzones are herein termed trace fossil subintervals and are coded with a numerical subscript immediately following the letter indicating the interval, e.g., ID2, IC5 etc. (cf. Enclosures III.3, III.4, & III.8). Inasmuch as the beds/bedsets which contain these separate and distinctive trace fossil suites are commonly separated from one another by intervening beds/bedsets that are barren of trace fossils, the upper and lower stratigraphic boundaries of these subintervals are not necessarily stratigraphically contiguous (e.g., Enclo-

TEXT-FIG. 4.3. Stratigraphic distribution (vertical axis) versus geographic distribution (horizontal axis) of the trace fossil subintervals in the study area. Open circles indicate non-marine affinity of the trace fossil assemblages or suites and solid circles indicate marine affinity of these assemblages or suites. Solid circles with connecting vertical bars indicate locally coalesced trace fossil subintervals (see also Text-Fig. 5.3).



● Shallow-marine assemblage or brackish-marine assemblage

○ Non-marine assemblages

Coalesenced interval

TEXT-FIG. 4.3.

sure III.4. logged section 2.2.1). In this sense these subinterval subdivisions are probably more appropriately termed zones, but the former term is retained because of its more immediate terminological relationship to the word "interval". Some subintervals can be further subdivided into what are here called "levels" (e.g., Enclosure III.4, logged sections 1.1.1 & 1.1.2.). This situation usually arises where temporarily successive generations of vertical burrows overprint older generations of the same kind of burrow in the immediately and successively underlying beds (e.g., Plates 55, 56, 57, & 74 Fig. d; Enclosure III.5). These separate `levels' are coded with an additional numerical subscript after the subinterval number in the code, e.g., IF.2.1, IF.2.2, etc. (Enclosure III.4, logged sections 1.1.1, 1.1.2; & Enclosure III.5). It should be emphasized that in this usage the term `level' refers to the discrete bedding plane at which or from which the downward penetrating vertical shafts arise. It does not refer to or include the thickness of underlying sediment penetrated by these shafts. The thickness of sediment between two successive `levels' from which vertical burrows arise is here termed a `bioturbation zone' (cf. Plate 74, Fig. d; Enclosure III.5).

On the basis of the population density and distribution of the index ichnotaxon/ichnotaxa in these trace fossil zones (intervals and subintervals), they can be regarded as assemblage zones and named after these index ichnotaxon/ichnotaxa. According to the distribution charts illustrated in Text-Figs. 4.1, 4.3 and 5.3 there are four major diverse trace fossil assemblage zones in the study area. Most of these zones are characteristic of marine-influenced episodes (but interval F is doubtfully marine and interval G is non-marine). Intervals and subintervals involved in these assemblage zones are interval C, and subintervals D1 - D2, D5 - D6 and E1, and E9 - E10 (cf. Text-Fig. 5.3). These assemblage zones can be named after their index ichnotaxon as follows:

Rhizocorallium-Thalassinoides assemblage zone - subintervals IE9 - IE10;

Helikospirichnus veeversi assemblage zone - subintervals ID5 - ID6, and IE1;

Skolithos-Diplocraterion assemblage zone - subintervals ID1 - ID2;

Turimettichnus-Ophiomorpha assemblage zone - subintervals IC1 - IC4.

There are also subordinate inextensive non-marine trace fossil zones lying between these extensive shallow-marine assemblage zones (cf. Text-Fig. 5.3).

The distribution of these trace fossil zones in the study area will be discussed in detail in the last part (Part 3, Chapter 18) of this volume. The interpretation of the marine versus non-marine affinity of these zones will also be discussed in the same part (Chapter 19).

CHAPTER 5.

GENERAL CLASSIFICATION OF THE PALAEOENVIRONMENTS AND SUMMARY OVERVIEW OF THE STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF PALAEOENVIRONMENTS IN THE STUDY AREA

GENERAL CLASSIFICATION OF THE PALAEOENVIRONMENTS AND SUMMARY OVERVIEW OF THE STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF PALAEOENVIRONMENTS IN THE STUDY AREA

5.1. INTRODUCTION

The definition and classification of depositional environments relative to the geographic and environmental distribution of trace fossils in both modern and ancient settings has been extensively researched in recent decades beginning with Seilacher (1964). There is general agreement on the classification of depositional environments from this perspective and among the more recent and comprehensive reviews of such classifications are those of Seilacher (1970), Chamberlain (1978) and Miller & Knox (1985). These classifications focus more particularly on the benthonic characteristics of aquatic environments for obvious reasons but ichnological knowledge about the non-marine environments (both aquatic and non-aquatic) is still poor compared to our ichnological knowledge about the spectrum of shallow- and deep-marine environments.

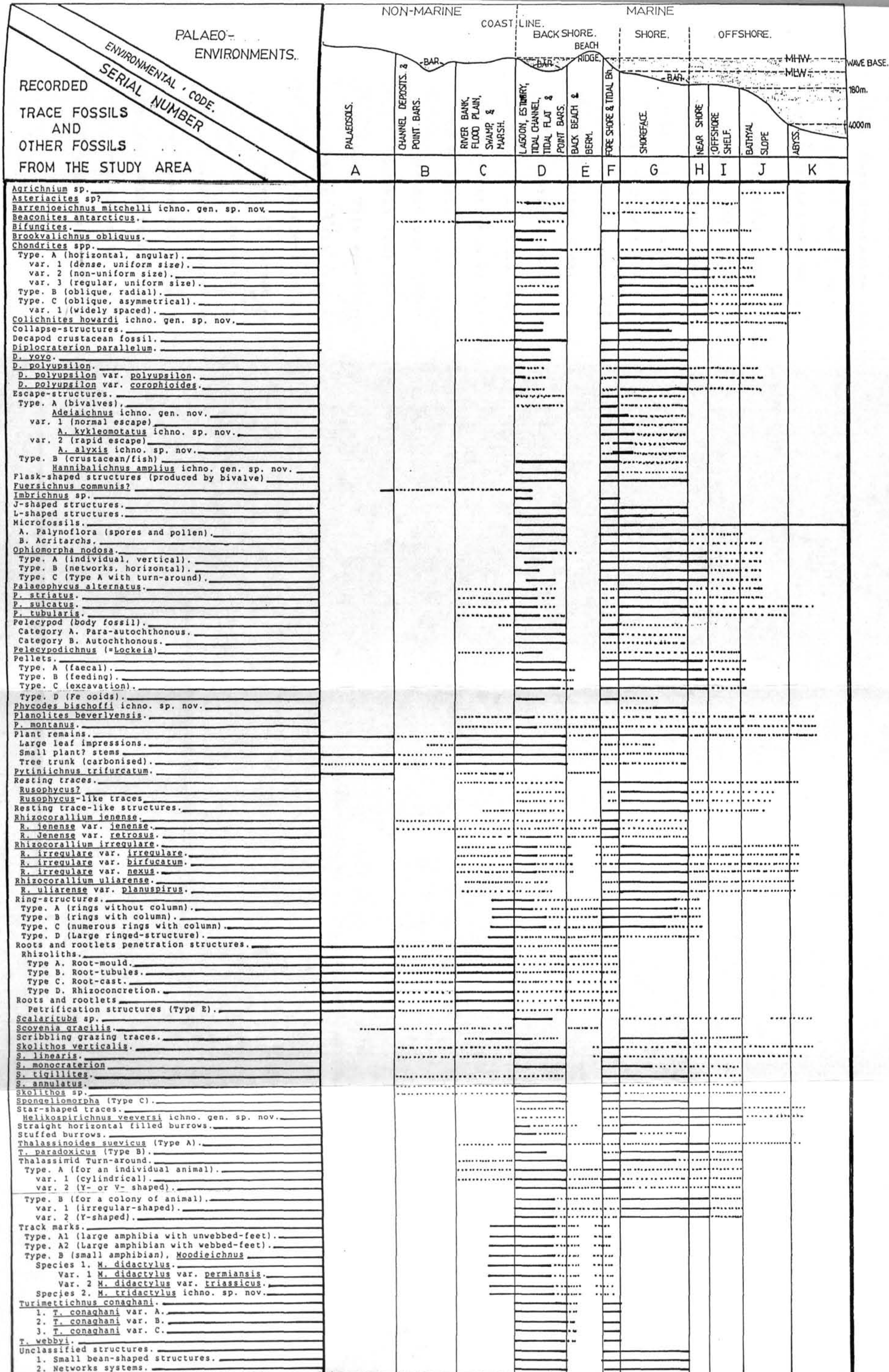
5.2. CLASSIFICATION OF DEPOSITIONAL ENVIRONMENTS

The classification of depositional environments used in this report follows that of Chamberlain (1978) and Miller & Knox (1985) and is detailed in Text-Fig. 5.1 and Table 5.1. Inasmuch as the rocks of the study area are demonstrably of fluvial origin with subordinate paralic influence (Cowan, 1985; Packham, 1976; Retallack, 1973, 1975, 1977 & 1980; and this study) the deeper-marine environments depicted in the general scheme of Text-Fig. 5.1 and Table 5.1 are not relevant to the present study. The

TABLE 5.1. Spectrum and classification of depositional environments related to the distribution of different trace fossils as shown in Text-Fig. 5.1 (environmental distribution chart). Classification partly after Chamberlain (1978) and Miller & Knox (1985).

ENVIRONMENTAL CODES	ENVIRONMENTS AND	SUBENVIRONMENTS
NON-MARINE		
EA	TERRESTRIAL	Palaeosols
EB	FLUVIAL CHANNEL	Channel-floor, channel-bars Point-bars
EC	FLUVIAL OVERBANK	Leeve bank, flood basin Swamp and marsh
SHALLOW-MARINE		
ED	BACKSHORE	Lagoon & estaury deposits Tidal-channel Tidal-channel point-bar Tidal-flat Tidal-delta
EE	BACKSHORE AND BARRIER ISLAND	Beach-ridge and aeolian dunes Lagoonal beach Washover lobes
EF	FORESHORE	Ocean-beach/tidal-beach Tidal-delta.
EG	SHOREFACE	Sublittoral zone Sandbar
EH	OFFSHORE	Nearshore zone
EI	"	Offshore shelf
DEEP-MARINE		
EJ	OCEANIC	Bathyal slope
EK	"	Abyssal plain and hills

TEXT-FIG. 5.1. Palaeoenvironmental distribution of trace fossils, body fossils, and plant remains in the study area. The major environmental distribution of indices shows unequivocally that the environment of deposition of these sediments encompassed a complex comprising a shallow coastal estuary or lagoon, open shallow-marine and non-marine (fluvial and emergent) areas. The classification of non-marine and marine environments is modified with additions from Chamberlain (1978) (see also Table 5.1 and Text-Fig. 5.2.). Solid horizontal lines show inferred environmental range of individual trace fossils in the study area and dotted lines show the total range of individual trace fossils globally according to the literature.


NON-MARINE
MARINE
COAST LINE.
BACK SHORE.
SHORE.
OFFSHORE.
BEACH RIDGE.
BAR
MHW
MLW
WAVE BASE.
180m.
4000m
PALAEO-ENVIRONMENTS.
ENVIRONMENTAL CODE.
SERIAL NUMBER
RECORDED TRACE FOSSILS AND OTHER FOSSILS FROM THE STUDY AREA
PALAEOSOLS.
CHANNEL DEPOSITS & POINT BARS.
RIVER BANK, FLOOD PLAIN, SWAMP & MARSH.
LAGOON, ESTUARY, TIDAL CHANNEL, TIDAL FLAT & POINT BARS.
BACK BEACH & BERM.
FORE SHORE & TIDAL BA.
SHOREFACE.
NEAR SHORE
OFFSHORE SHELF.
BATHYAL SLOPE
ABYSS.
A B C D E F G H I J K
Agrichnium sp.
Asteriacites sp?
Barrenjoeichnus mitchelli ichno. gen. sp. nov.
Beaconites antarcticus.
Bifungites.
Brookvalichnus obliquus.
Chondrites spp.
Type. A (horizontal, angular).
var. 1 (dense, uniform size).
var. 2 (non-uniform size).
var. 3 (regular, uniform size).
Type. B (oblique, radial).
Type. C (oblique, asymmetrical).
var. 1 (widely spaced).
Colichnites howardi ichno. gen. sp. nov.
Collapse-structures.
Decapod crustacean fossil.
Diplocraterion parallelum.
D. yoyo.
D. polyupsilon.
D. polyupsilon var. polyupsilon.
D. polyupsilon var. corophioides.
Escape-structures.
Type. A (bivalves).
Adeiaichnus ichno. gen. nov.
var. 1 (normal escape)
A. kykleomotatus ichno. sp. nov.
var. 2 (rapid escape)
A. alyxis ichno. sp. nov.
Type. B (crustacean/fish)
Hannibalichnus amplius ichno. gen. sp. nov.
Flask-shaped structures (produced by bivalve)
Fuersichnus communis?
Imbrichnus sp.
J-shaped structures.
L-shaped structures.
Microfossils.
A. Palynoflora (spores and pollen).
B. Acritarchs.
Ophiomorpha nodosa.
Type. A (individual, vertical).
Type. B (networks, horizontal).
Type. C (Type A with turn-around).
Palaeophycus alternatus.
P. striatus.
P. sulcatus.
P. tubularis.
Pelecypod (body fossil).
Category A. Para-autochthonous.
Category B. Autochthonous.
Pelecypodichnus (=Lockeia).
Pellets.
Type. A (faecal).
Type. B (feeding).
Type. C (excavation).
Type. D (Fe ooids).
Phycodes bischoffi ichno. sp. nov.
Planolites beverlyensis.
P. montanus.
Plant remains.
Large leaf impressions.
Small plant? stems
Tree trunk (carbonised).
Pytiniichnus trifurcatum.
Resting traces.
Rusophycus?
Rusophycus-like traces
Resting trace-like structures.
Rhizocorallium jenense.
R. jenense var. jenense.
R. jenense var. retrosus.
Rhizocorallium irregulare.
R. irregulare var. irregulare.
R. irregulare var. birfucatum.
R. irregulare var. nexus.
Rhizocorallium uliarense.
R. uliarense var. planuspirus.
Ring-structures.
Type. A (rings without column).
Type. B (rings with column).
Type. C (numerous rings with column).
Type. D (Large ringed-structure).
Roots and rootlets penetration structures.
Rhizoliths.
Type A. Root-mould.
Type B. Root-tubules.
Type C. Root-cast.
Type D. Rhizoconcretion.
Roots and rootlets
Petrification structures (Type E).
Scalarituba sp.
Scoyenia gracilis.
Scribbling grazing traces.
Skolithos verticalis.
S. linearis.
S. monocraterion
S. tigillites.
S. annulatus.
Skolithos sp.
Spongeliomorpha (Type C).
Star-shaped traces.
Helikospirichnus veeversi ichno. gen. sp. nov.
Straight horizontal filled burrows.
Stuffed burrows.
Thalassinoides suevicus (Type A).
T. paradoxicus (Type B).
Thalassinid Turn-around.
Type. A (for an individual animal).
var. 1 (cylindrical).
var. 2 (Y- or V- shaped).
Type. B (for a colony of animal).
var. 1 (irregular-shaped).
var. 2 (Y-shaped).
Track marks.
Type. A1 (large amphibia with unwebbed-feet).
Type. A2 (Large amphibian with webbed-feet).
Type. B (small amphibian), Moodieichnus
Species 1. M. didactylus.
Var. 1 M. didactylus var. permiansis.
Var. 2 M. didactylus var. triassicus.
Species 2. M. tridactylus ichno. sp. nov.
Turimettichnus conaghani.
1. T. conaghani var. A.
2. T. conaghani var. B.
3. T. conaghani var. C.
T. webbyi.
Unclassified structures.
1. Small bean-shaped structures.
2. Networks systems.
ENVIRONMENTAL CODE.
A B C D E F G H I J K

TEXT-FIG. 5.1.

remaining environments that do have relevance to this study include both non-marine and shallow-marine ones, including most importantly (as will be demonstrated in Parts 2 and 3 of this volume) brackish-marine shoreline environments.

5.3. GENERAL DEFINITION OF THE DEPOSITIONAL ENVIRONMENTS

In the classification detailed in Text-Fig. 5.1 and Table 5.1, there are eleven major depositional environments; three are of non-marine, six are shallow-marine and two of them are deep-marine to very deep-marine. The palaeoenvironments of the study area are exclusively of non-marine and very shallow-marine affinity (Text-Fig. 3.5 & 5.1). These environments are coded or abbreviated as environments A to K with prefix E (for environment), and thus become EA, EB, EC, etc. These depositional environments can be subdivided into several sub-environments (cf. Table 5.1).

Palaeosols (environment EA) are fossil soil horizons. Fluvial channels (EB) comprises the in-channel domains of rivers and streams. This environment has been subdivided into channel-floors, channel-bars (river-bars) and point-bars. Bars are simply made up of a ridge-like accumulations of sand, gravel, or other alluvial material formed in the channel, along the banks, or at the mouth of a stream where a decrease in velocity induces deposition. Fluvial overbank (EC) or flood-plain deposits (vertical-accretion deposits) mainly consist of fine-grained sediment (silt and clay) deposited from suspension on a flood-plain by flood-waters. The deposits are generally thicker near the river channels and thin toward the valley slopes.

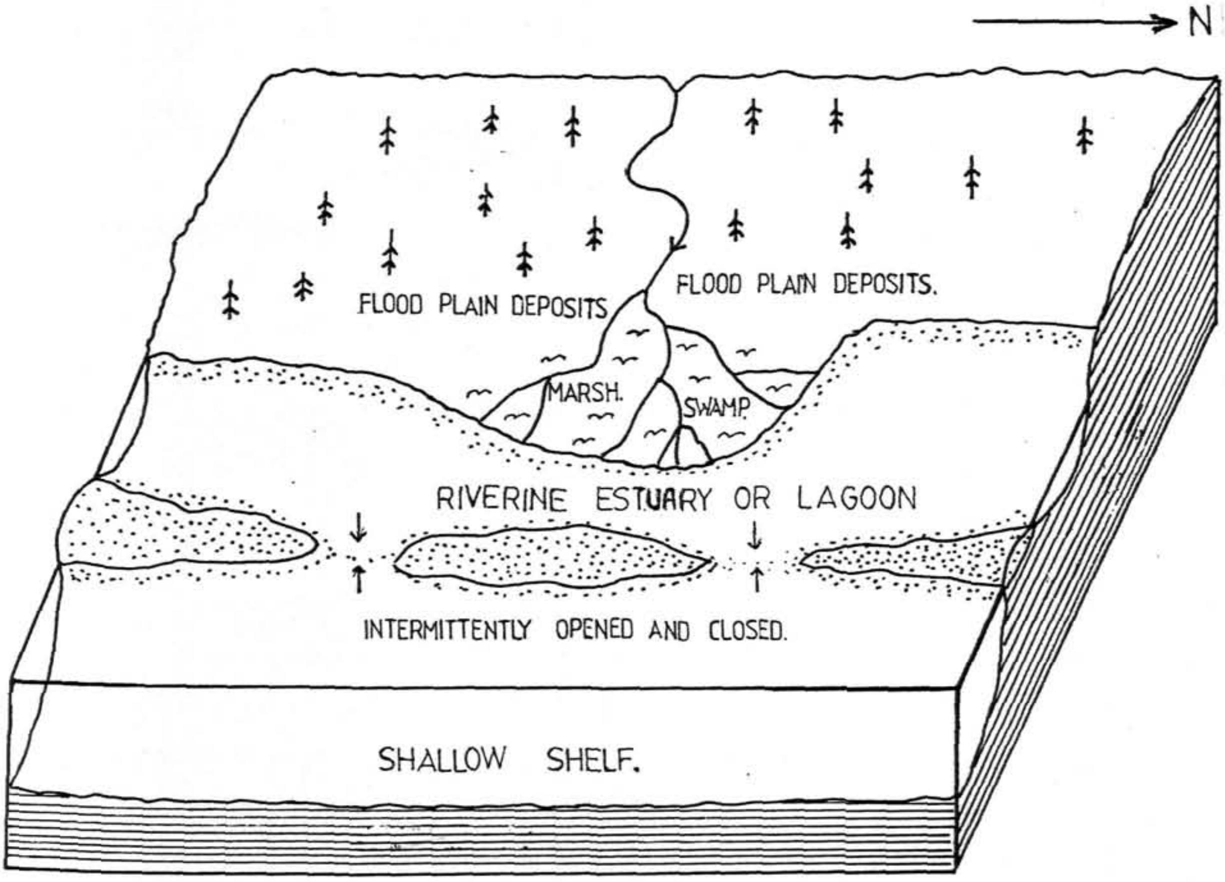
There are six major shallow-marine depositional environments, ranging from very shallow (intertidal) to offshore shelf (normally about 180 m to 200 m in depth). The backshore environment (ED) is a narrow shore zone, lying between the high-water line (high-tide) and the coastline. Its surface is essentially subhorizontal or slopes landward, and it is divided from the foreshore by the crest of the most seaward berm or barrier island environment (EE). The barrier island environment (EE) is a long, low, and narrow wave-built sandy island representing a broad barrier-beach that is emergent above high tide level and is orientated parallel to the shore. The barrier-island environment (EE) is commonly occupied by vegetated aeolian dunes and swampy depressions extending lagoonward from the beach. The foreshore environment (EF) is a seaward-sloping zone of the shore or beach, lying between the crest of the most seaward berm of the backshore environment (EE), which is also the upper limit of the high-tide level, and the low-water mark or low-tide. This foreshore zone is regularly covered and uncovered by the rise and fall of the tides, and hence can be simply defined as the zone lying between the tide levels (high-tide and low-tide). This zone is sometimes referred to as the shore or beachface. The shoreface environment (FG) is a narrow, rather steeply-sloping zone seaward from the low-water shoreline. This area is permanently covered by water, and is characteristized by the constant movement of beach and shoreface sands and gravels with changing conditions. Sandbars (shoreface terrace or wave-built terrace; environment (EG) are commonly or sporadically developed in this area. The zone is delineated seawards by the more nearly horizontal surface of the offshore zone. The offshore environment (EH & EI) is comparatively distant from the shore and is a flat-lying zone of variable width extending from the breaker (wave) zone to the seaward edge of the continental shelf beyond which substantial movement of the bottom sediments is limited. The offshore environment can be further subdivided into a nearshore shelf environment (EH) and offshore shelf environment (EI).

The third major category of depositional environments encompasses the deep-marine realm and comprises the bathyal slope environment (EJ) and the abyssal plain environment (EK). These deep-marine environments are not represented in the study area but are included in the classification (cf. Text-Fig. 5.1 & Table 5.1) for completion of the spectrum of environments.

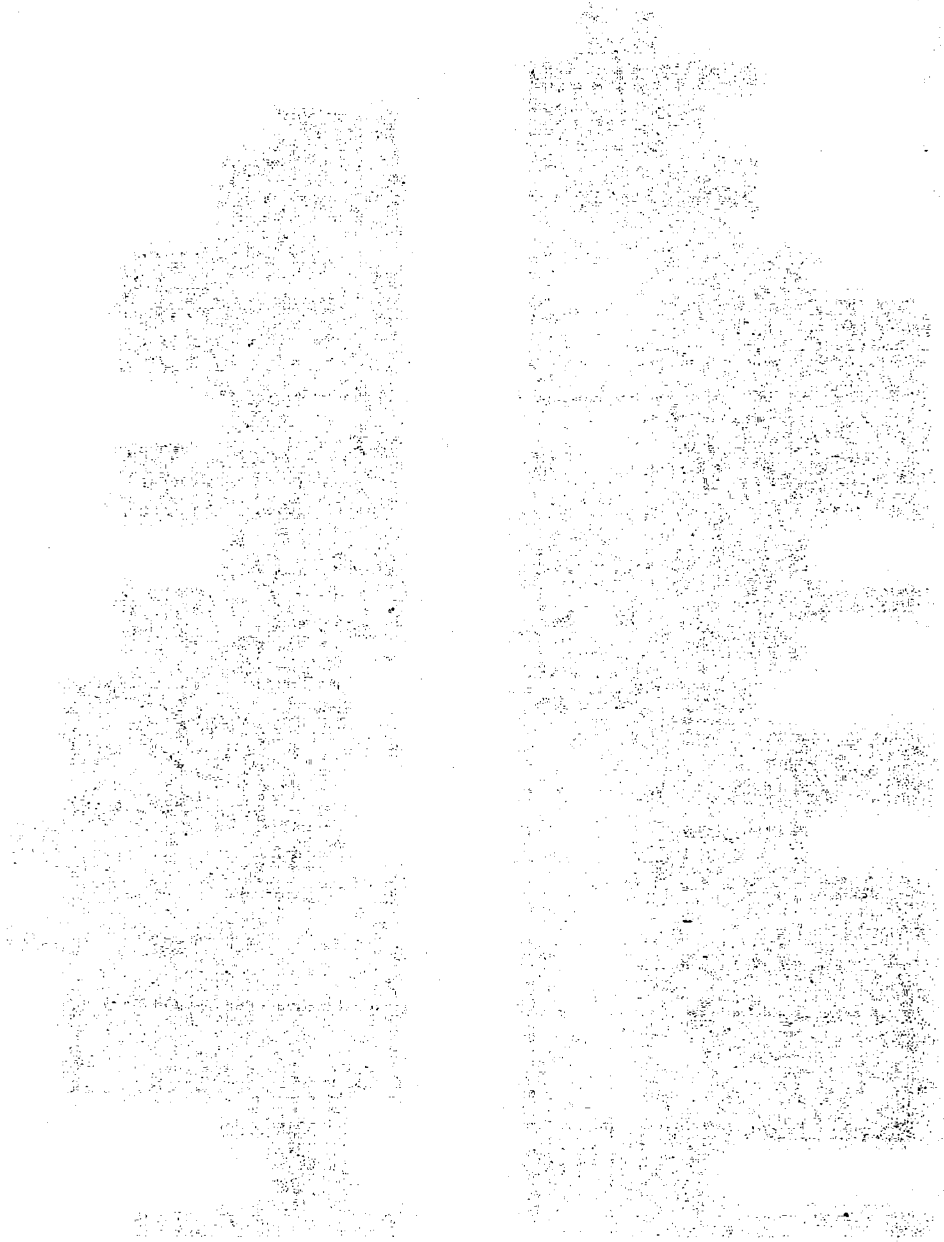
The distribution of trace fossil assemblages in these environments (cf. Text-Fig. 5.1) will be discussed in more detail in the last part of this volume (Part 3, Chapter 19).

5.4. SUMMARY OVERVIEW OF THE STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF PALAEOENVIRONMENTS IN THE STUDY AREA

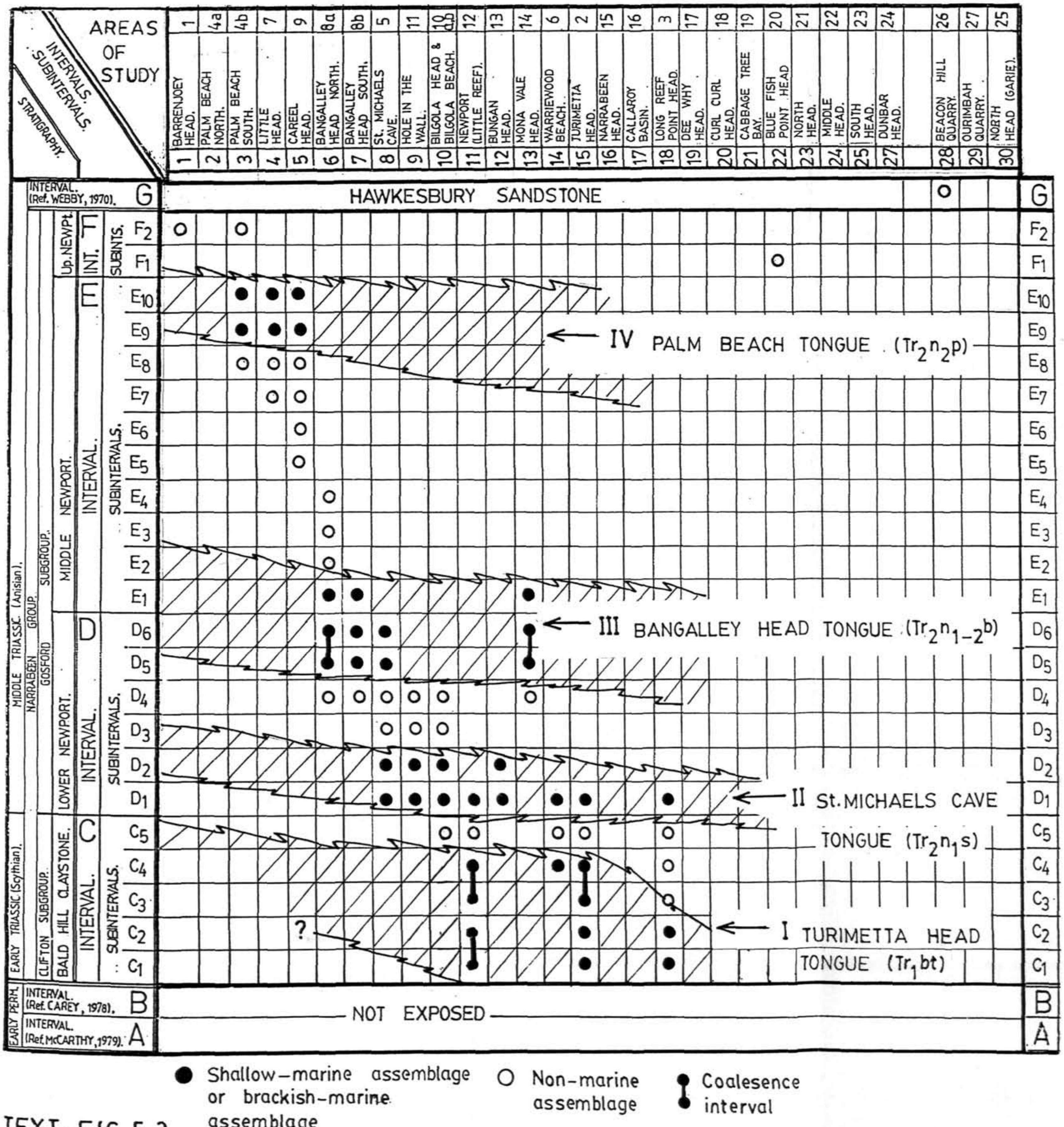
As already mentioned in Chapter 1, Retallack's (1977b) palaeoenvironmental reconstruction of the Sydney Northshore area for the latest Early and early Middle Triassic envisaged the presence of a coastal lagoon, intermittently open to the sea in the south and hence subject to brackish-marine characteristics, and into which streams debouched from the west or northwest (Text-Fig. 1.11). This interpretation was based in very large part on phyto-sociological and functional palaeobiological evi-



TEXT-FIG. 5.2. Block diagram palaeoenvironmental reconstruction of the study area during deposition of the Newport Formation. The overall study area is interpreted to represent a fluvially-dominated coastal estuary or lagoon (termed here the "Newport Lagoon") that was intermittently open to the sea across some kind of protecting barrier or bar located either to the east or south-east. The periods when this lagoon was open to the sea coincide with the marine-influenced episodes defined in the sedimentary record by abundant diverse trace fossils. Contrastingly, the periods when the lagoon was closed to the sea by the barrier are defined in the sedimentary record by fluvially-dominated deposits with rare and low-diversity trace fossils.

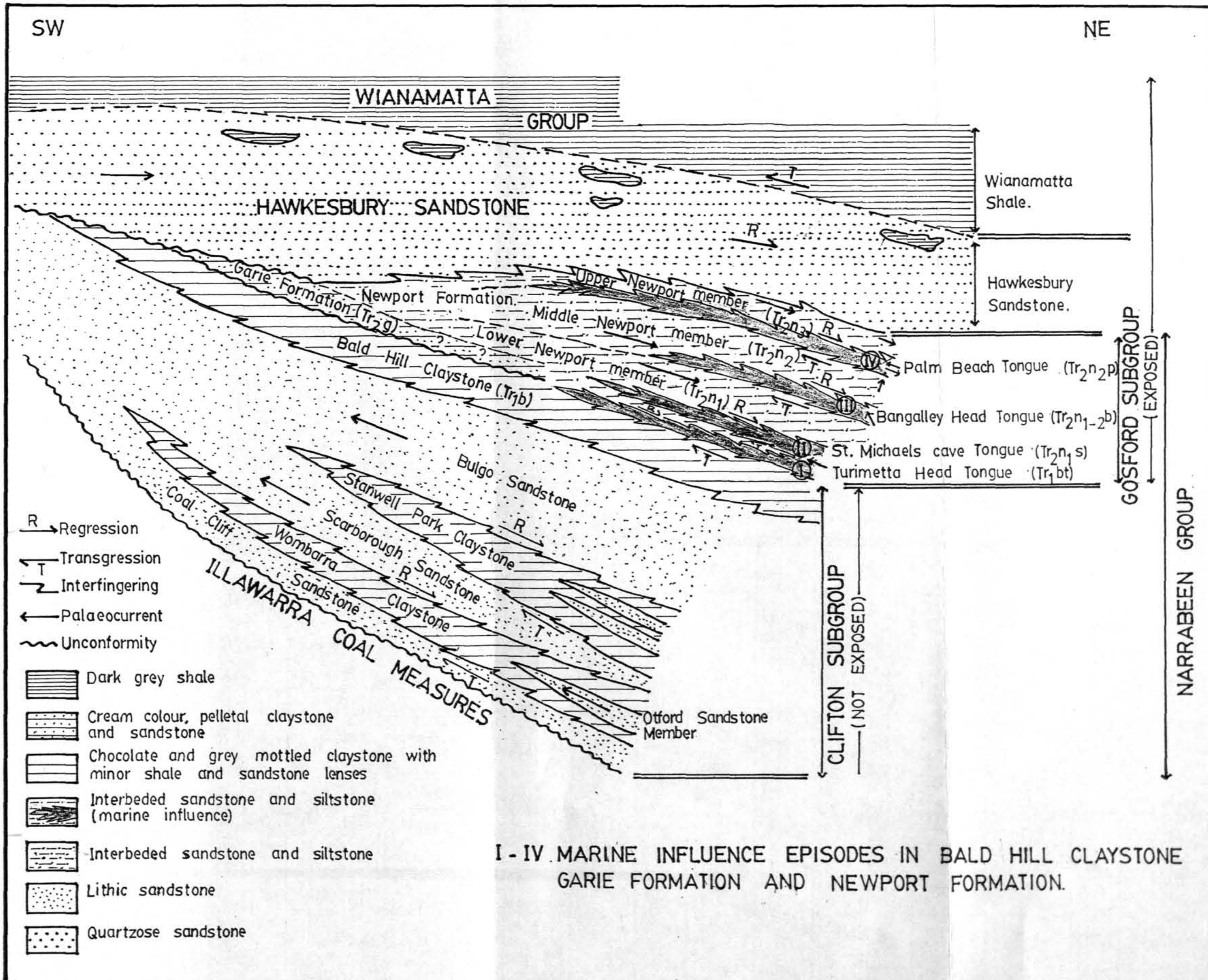


TEXT-FIG. 5.3. Stratigraphic distribution versus geographic distribution (cf. Text-Fig. 4.3) of trace fossils of the study area with interpreted marine-influenced episodes. These episodes correspond to: (1) trace fossil subintervals IC1 - IC5 of the Bald Hill Claystone, mainly exposed at Turimetta Head (Turimetta Head Tongue); (2) trace fossil subintervals ID1 & ID2 of the lower part of Lower Newport Member, mainly exposed at St. Michaels Cave (St. Michaels Cave Tongue; (3) trace fossil subintervals ID5, ID6 & IE1 of the upper part of the Lower Newport Member and lower part of Middle Newport Member, mainly exposed at Bangalley Head (Bangalley Head Tongue; and (4) trace fossil subintervals IE9 & IE10 of the upper part of Middle Newport Member, mainly exposed at Palm Beach (Palm Beach Tongue). (For further explanation see Text-Fig. 4.3.)


AREAS OF STUDY
INTERVALS. SUBINTERVALS.
STRATIGRAPHY.
BARRENJOEY HEAD.
PALM BEACH NORTH.
PALM BEACH SOUTH.
LITTLE HEAD.
CAREEL HEAD.
BANGALLEY HEAD NORTH.
BANGALLEY HEAD SOUTH.
St. MICHAELS CAVE.
HOLE IN THE WALL.
BILGOLA HEAD & BILGOLA BEACH.
NEWPORT (LITTLE REEF).
BUNGAN HEAD.
MONA VALE HEAD.
WARRIEWOOD BEACH.
TURIMETTA HEAD.
NARRABEEN HEAD.
CALLAROY BASIN.
LONG REEF POINT HEAD.
DEE WHY HEAD.
CURL CURL HEAD.
CABBAGE TREE BAY.
BLUE FISH POINT HEAD
NORTH HEAD.
MIDDLE HEAD.
SOUTH HEAD.
DUNBAR HEAD.
BEACON HILL QUARRY.
OURIMBAH QUARRY.
NORTH HEAD (GARIE).
INTERVAL. (Ref. WEBBY, 1970). G
HAWKESBURY SANDSTONE
Up. NEWPt. INT. F SUBINTS. F2 F1
E10 E9 E8 E7 E6 E5 E4 E3 E2 E1
MIDDLE NEWPORT. INTERVAL. SUBINTERVALS.
IV PALM BEACH TONGUE (Tr_2n_2p)
III BANGALLEY HEAD TONGUE ($Tr_2n_{1-2}b$)
D D6 D5 D4 D3 D2 D1
LOWER NEWPORT. INTERVAL. SUBINTERVALS.
MIDDLE TRIASSIC (Anisian). NARRABEEN GROUP. GOSFORD SUBGROUP.
II St. MICHAELS CAVE TONGUE (Tr_2n_1s)
C C5 C4 C3 C2 C1
BALD HILL CLAYSTONE. INTERVAL. SUBINTERVALS.
EARLY TRIASSIC (Scythian). CLIFTON SUBGROUP.
I TURIMETTA HEAD TONGUE (Tr_1bt)
EARLY PERM. INTERVAL. (Ref. CAREY, 1978). B
NOT EXPOSED
INTERVAL. (Ref. McCARTHY, 1979). A
● Shallow-marine assemblage or brackish-marine assemblage
○ Non-marine assemblage
Coalescence interval

TEXT-FIG. 5.3.

TEXT-FIG. 5.4. Diagrammatic stratigraphic cross-section of the Triassic sediments exposed in the Sydney coastal area and the zones of marine influence in the Bald Hill Claystone, Garie Formation and Newport Formation. Extrapolation of the marine tongues inland to the southwest and west is speculative but is consistent with the views of Bunny & Herbert (1971).



I - IV MARINE INFLUENCE EPISODES IN BALD HILL CLAYSTONE GARIE FORMATION AND NEWPORT FORMATION.

TEXT-FIG.5.4.

dence of the plant fossils in these rocks but without any major consideration of their ichnofaunas. The comprehensive study of these ichnofaunas in Part 2 of this volume confirms Retallack's palaeoenvironmental reconstruction but has resolved the temporal history of this palaeo-lagoon and, within the limitations of the geographic extent of the outcrop, its north-south extent in the Northshore area in greater detail than Retallack's work allowed (Text-Figs. 4.1 - 4.3). As will be demonstrated in Parts 2 and 3 of this volume, the ichnospecies composition of the more heavily populated and taxonomically more diverse of the trace fossil assemblage zones documented in Text-Fig. 4.1 indicates a brackish shallow-marine affinity (cf. Text-Figs. 4.3, 5.1 & 5.2) and permits the identification of four separate marine-influenced episodes or marine tongues that are intercalated with non-marine, fluvial strata (Text-Figs. 5.3 & 5.4). Although the pattern depicted in Text-Figs. 5.3 and 5.4 are largely interpretative and rest in large part on the descriptive ichnotaxonomic information and resulting ichnofacies inferences and conclusions contained in Part 2 of this volume, these figures are presented here at the outset ahead of Part 2 in order to provide the reader with a better conceptual overview of the non-marine - marine stratigraphic framework of the uppermost Narrabeen Group succession in this part of the Sydney Basin. The synthesis in Part 3 of this volume will return to these summary diagrams.