# PART 1

## INTRODUCTION AND METHODOLOGY

# CHAPTER 1

# GENERAL INTRODUCTION

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## 1.1. PREAMBLE

The focus of this report is the palaeoichnology of the Lower and Middle Triassic rocks of the central eastern Sydney Basin exposed in the coastal clifflines, headlands, and wave-cut platforms of the metropolitan Sydney Northshore between Broken Bay in the north and Port Jackson in the south (Text-Figs. 1.1 & 1.2), and in particular on the rocks of the uppermost Narrabeen Group which contain the most abundant and taxonomically diverse ichnofauna of this succession. Historically, both the Narrabeen Group rocks and the overlying Hawkesbury Sandstone (which contains very few trace fossils) have been generally regarded as of fluvial or fluvio-lacustrine affinity on the basis of their predominant lithofacies characteristics, the absence of unequivocal marine body fossils, and the relative abundance throughout the succession of terrestrial plant fossils, mostly of allochthonous or hypautochthonous character. Although the presence of relatively abundant trace fossils in the uppermost part of the Narrabeen Group succession has long been known they have received almost no systematic study and hence their palaeoecological and, by extension, palaeoenvironmental significance has remained unexplored, notwithstanding suggestions as to their likely brackish-marine or shallow-marine affinity by several authors in recent decades (notably by Bunny & Herbert, 1971, and Retallack, 1975, 1976, & 1977b). Additional and more recent evidence that supports such shallow-marine, probably brackish, influence in at least one thin stratigraphic level within the upper Narrabeen

Group succession has been the discovery there of mytilid bivalve mollusc body fossils and acritachs (Grant-Mackie et al.,1985).

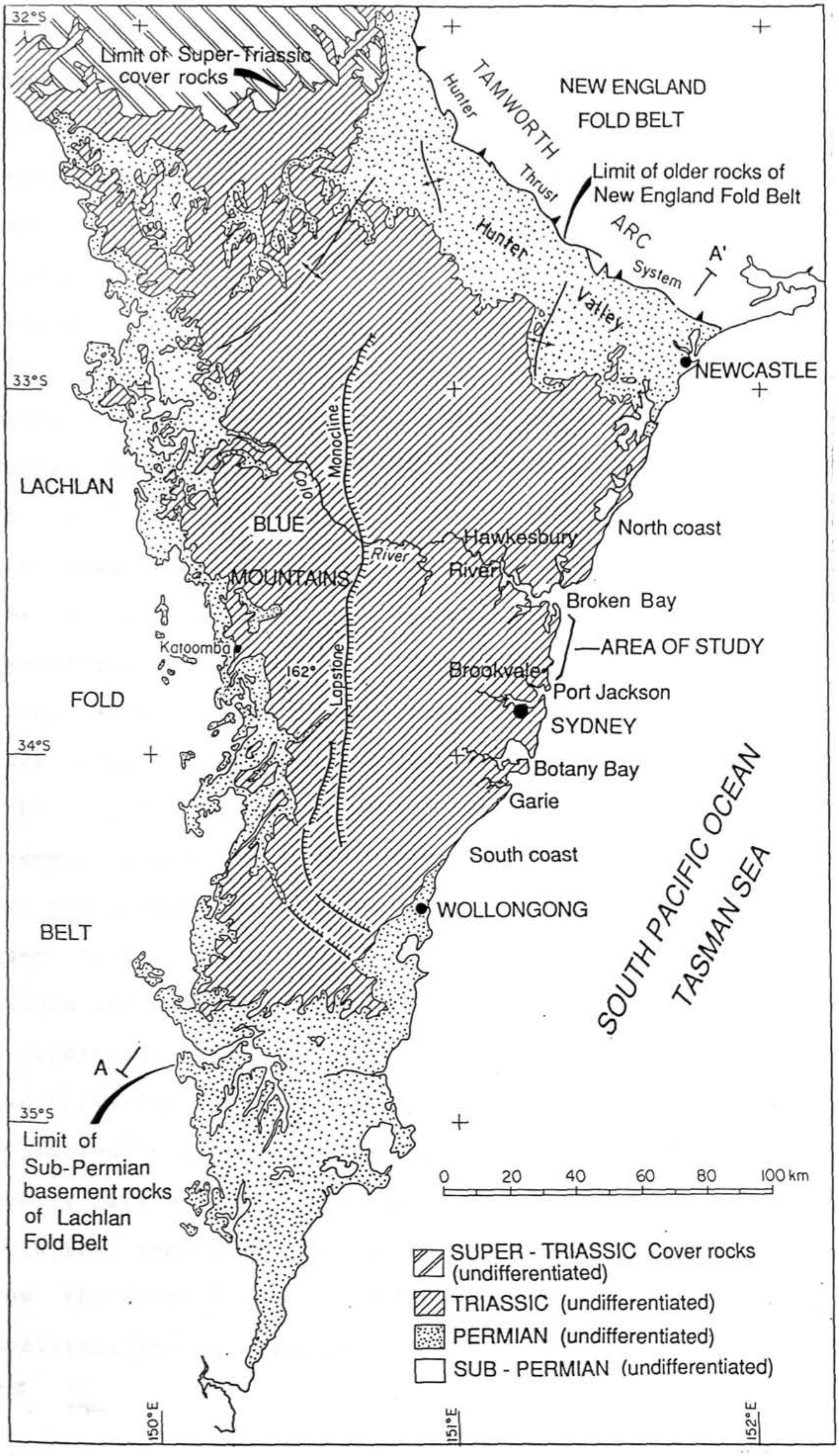
Accordingly, the aims of the present investigation were to document comprehensively the ichnofaunas of these rocks, and on the basis of the palaeoecological implications of these ichnofaunas, together with other relevant evidence, reassess the palaeoenvironmental affinities of these strata. Consequently, the major focus of this report is on the taxonomy of the trace fossils and associated biogenic structures, resolution where feasible of the likely producer organisms and their respective ethology, and interpretation of the likely palaeoecology of individual trace fossils and assemblages of trace fossils. This task became increasingly larger as the work progressed with the discovery that the diversity of the ichnofauna was considerably greater that initial reconnaissance had suggested and it includes a number of new and rather spectacular ichnotaxa of both invertebrate and vertebrate origin. In all, the ichnofauna of these rocks involves nearly 100 different ichnotaxa, including varietal categories, distributed among eight different stratigraphic zones or trace fossil assemblage intervals (Text-Fig. 4.1).

Because of the relatively large size of this report and its large taxonomic component, it is divided into 3 volumes (I - III), Volume I comprising the text, Volume II the plates, and Volume III the large-format enclosures (maps, cross-sections, etc.). For convenience of reference and by way of making Volume II sufficiently self-contained to be perused without reference to Volume I, certain appendixes that support both the text and the plates are located in both of these volumes. Such supporting information/data include, for example, the consolidated (cross-) index of specimen field and archival (Macquarie University (MU)) catalog numbers as well as the stratigraphic and geographic location of these specimens. Also, Volume I is divided into three parts: Part 1 (Chapters 1 to 5) covers introductory aspects, including methodology; Part 2 (Chapters 6 to 17) consists exclusively of systematic ichnotaxonomy; and Part 3 (Chapters 18 to 20) is concerned with the overall palaeoecological interpretations of the trace fossil assemblages and by extension the palaeoenvironmental and palaeogeographic reconstructions of their host strata.

The field work on which this report is based commenced in August 1985 and finished in June 1989, and proceeded on a full-time basis except for several significant delays caused by logistical and other unforseen (health) problems affecting my family.

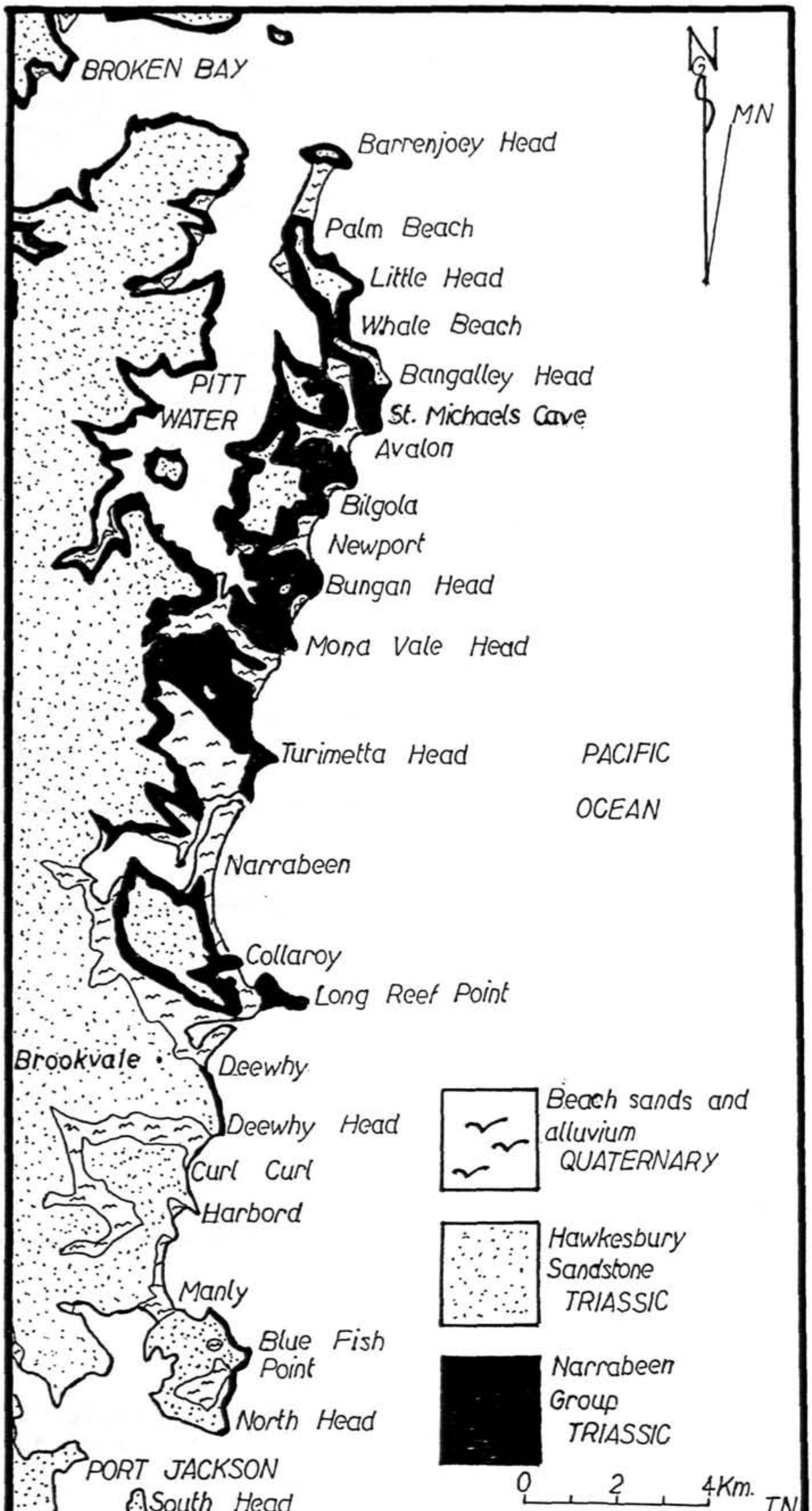
## 1.2. LOCATION AND EXTENT OF THE STUDY AREA

As with much of the Sydney Basin the metropolitan Sydney Northshore is a sandstone plateau area that lies between the major rias of Broken Bay (= estuary of the Hawkesbury River) in the north and Port Jackson (= estuary of the Parramatta River) in the south, and with its coastal perimeter terminating respectively in Barrenjoey Head in the north and North (Sydney) Head in the south (Text-Figs. 1.1 & 1.2). The present study area comprises the more immediate coastline of this area because it is here that the largest scale and best quality exposures of the Triassic rocks are to be found in clifflines, headlands and

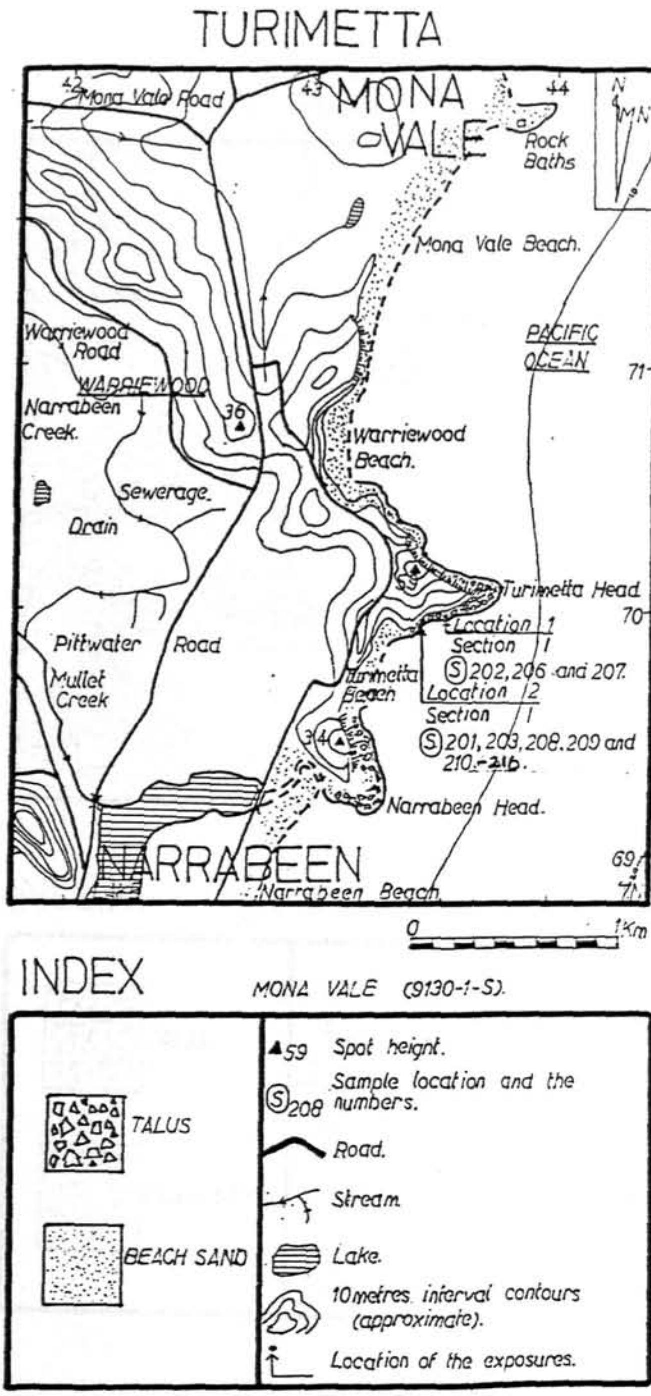



**TEXT-FIG. 1.1.** Geological map of the Sydney Basin, NSW, showing the locality of the study area along the metropolitan Sydney Northshore coastline between Broken Bay and Port Jackson. A - A' is the line of cross-section of the time-space plot in Text-Fig. 1.9.

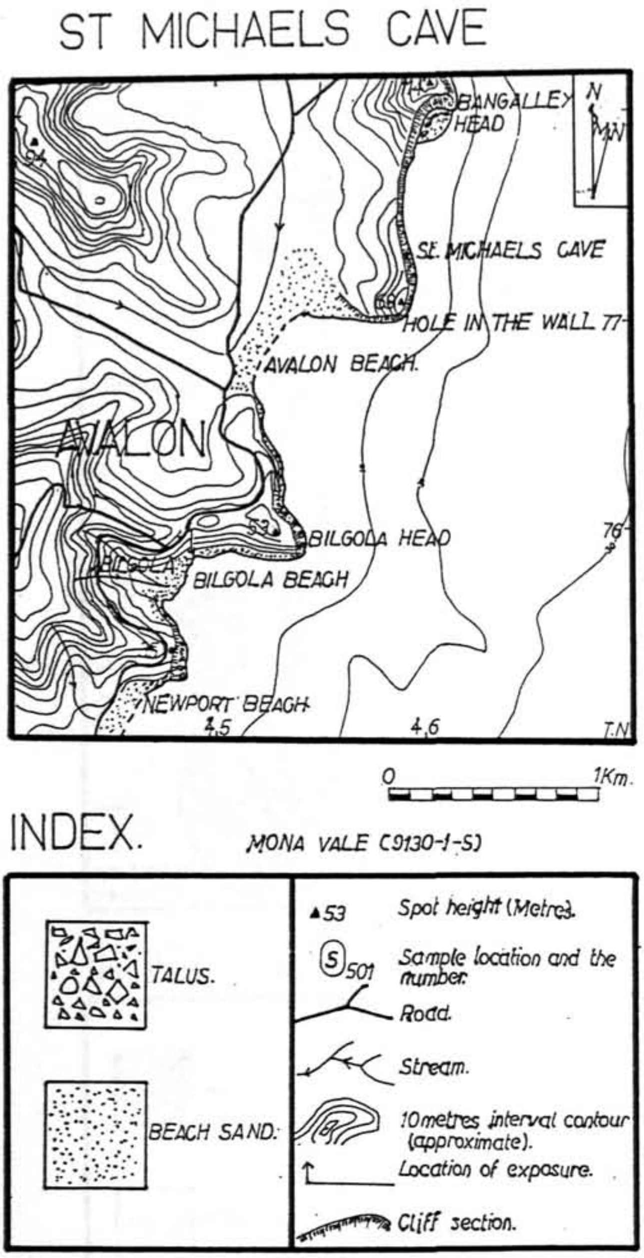
wave-cut platforms. However, some exposures in the immediate hinterland were also examined, especially within the plateau-forming Hawkesbury Sandstone whose exposure in the coastal cliff-lines is relatively inaccessible. Accordingly, the study area may be thought of as an elongate rectangular area some 30 km north-to-south (i.e., Barrenjoey to North Head) and some 2 km wide, bounded on the east by the coastline (Text-Fig. 1.2). Maximum elevations within this area approximate 150 m at the plateau surface but the height of individual coastal cliffines and headlands is commonly much less than this and usually not more than about 80 m (Text-Figs. 1.3, 1.4 & 1.5). All of this area is readily accessible by roads, the furthermost locality (Barrenjoey Head) being about 35 km and a 1 hour drive from the Sydney central business district. Access to the various head-lands, clifflines and wave-cut platforms from roads and streets is by foot but rarely involves distances of more than 1 km or so. However, in most cases such access involves negotiation of steep foot-tracks down the clifflines or scrambling and `rock-hopping' along rocky benches, boulder zones, or other kinds of broken terrain and in many places is constrained by tide, sea and weather conditions. For this and other logistical reasons, the manual transportation of large rock specimens from many of the field localities proved very difficult if not impossible and consequently many such rock samples containing trace fossils documented in this report were not collected. Text-Figs. 1.3, 1.4 and 1.5 show representative access and terrain details of some of the lacalities in the study area.



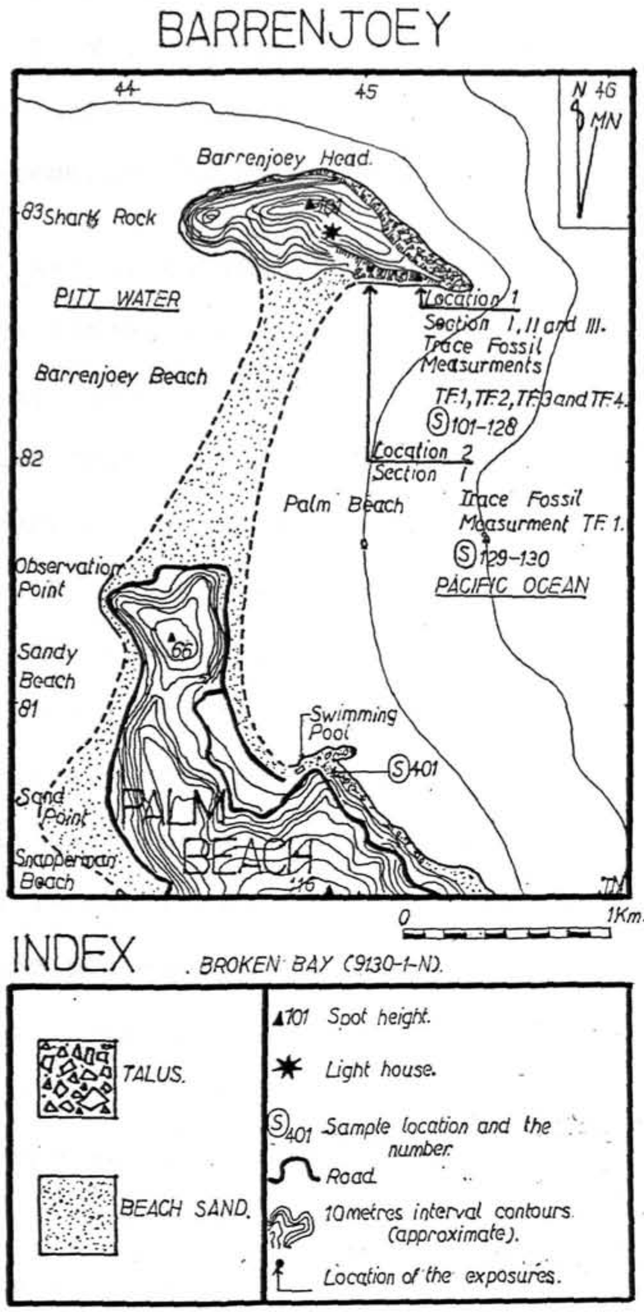

**TEXT-FIG. 1.2.** Geology of the study area. The detailed study area comprises the coastline between Broken Bay and Port Jackson.




**TEXT-FIG.** 1.3. Detailed locality map of the Turimetta Head area (area 2) with locations of the logged sections and collected samples.




**TEXT-FIG. 1.4.** Detailed locality map of the St. Michaels Cave area (area 5) with locations of the logged sections and collected samples.




TEXT-FIG. 1.5. Detailed locality map of the Barrenjoey Head area (area 1) with locations of the logged sections and collected samples.

The study area is covered by three (topographic and cadastral) orthophotomaps at 1:25,000 scale. From north to south these are Broken Bay (9130-I-N), Mona Vale (9130-I-S), and Sydney Heads (9130-II-N). Geological map coverage is by the 1:100,000 scale Sydney sheet (map sheet 9130; compiled by Herbert & West, 1983) with accompanying notes (Herbert, 1983a).

## 1.3. GEOLOGY AND GEOLOGICAL CONTEXT OF THE STUDY AREA

The Sydney Northshore area lies just north of the NW - SE - trending regional synclinal axis of the Sydney Basin which intersects the coastline in the vicinity of Botany Bay (Text-Fig. 1.1). As such, the study area lies within the southernmost part of the basin's northern limb so that strata in the area dip regionally at very shallow angles towards the southwest and stratigraphically lower strata become exposed along the coastal transect progressively towards the north (Text-Fig. 1.1). Thus, where the regional basin axis intersects the coastline, i.e., between Sydney Heads in the north and Garie Head in the south (Text-Fig. 1.1), only the plateau- and cliff-forming Hawkesbury Sandstone is exposed; but rocks of the underlying Narrabeen Group reappear progressively above sea-level to the north and south of these places and progressively dominate the coastal cliffline exposures in both directions beyond these points. At its formally defined type section at Clifton, on the Illawarra escarpment near Stanwell Park, the Narrabeen Group is 253 m thick (Hanlon et al., 1954; Herbert, 1983b, p.9). The youngest preserved Triassic unit in the Sydney Basin, the mudrock-dominant Wianamatta Group (Text-Fig. 1.8), is recessive and is nowhere preserved in the immediate vicinity of the coastline. Throughout the entire basin the Narrabeen Group is underlain by a coal measure succession of Late Permian age which is given different stratigraphic names in different parts of the basin (Text-Fig. 1.8). The coal measures are underlain in turn by marine sediments of Early Permian age (i.e., Shoalhaven/Maitland Groups).

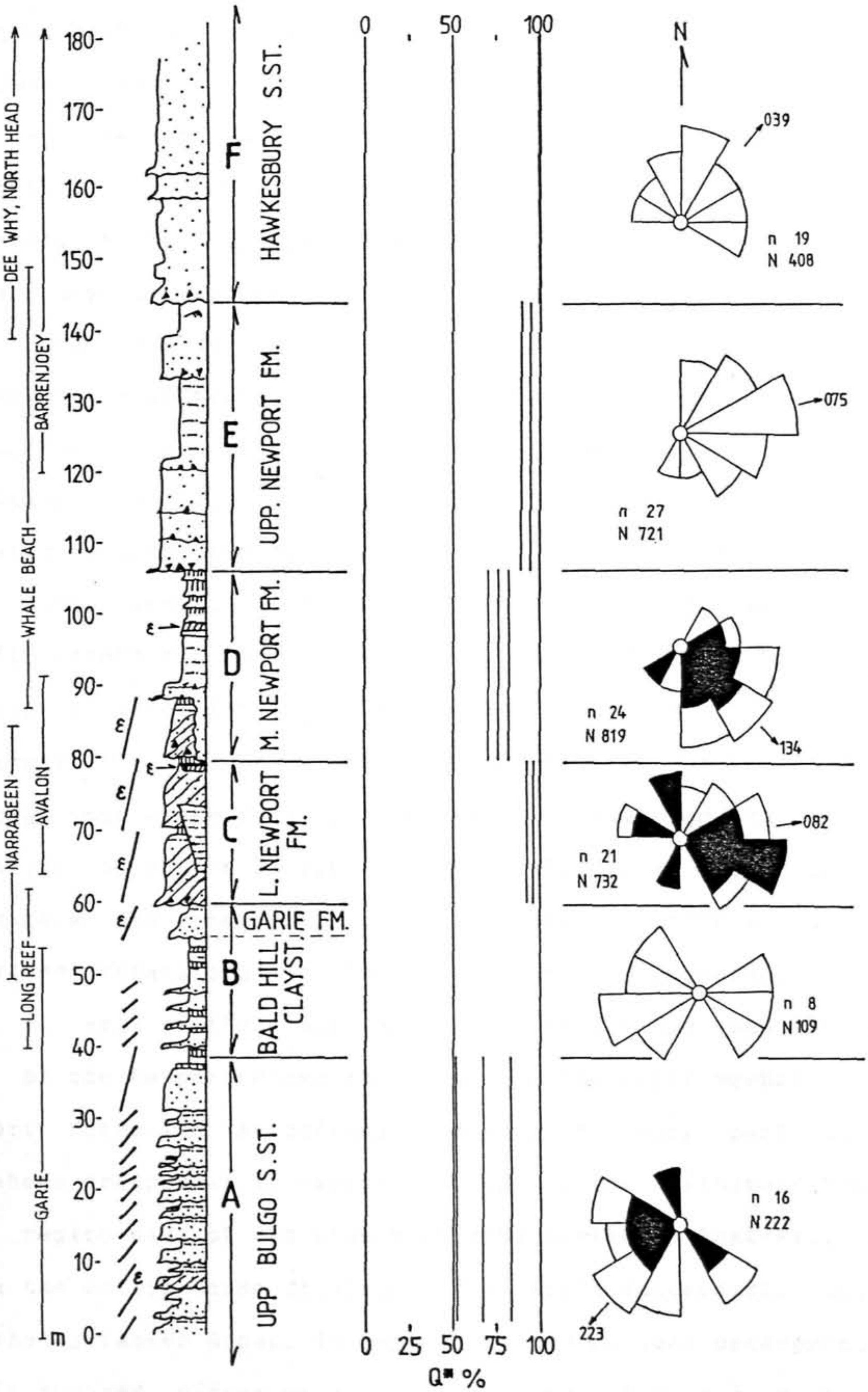
The Narrabeen Group thins regionally towards the south-west from a maximum preserved thickness of 700 m in the Broken Bay area and undergoes related facies changes to the south and west so that different stratigraphic nomenclatures are necessary in different parts of the basin (Text-Fig. 1.8). The evolution of these different nomenclatures and the stratigraphic relationships of their component formations are reviewed and summarized by Mc Elroy et al. (in Packham, 1969, p. 388-407), Goldbery & Holland (1973), Mayne et al. (1974) and Herbert (1970, 1983b).

Along the coastal transect of the basin the Narrabeen Group is subdivided into two subgroups, the lower one being the Clifton Subgroup and the upper one the Gosford Subgroup (called the Terrigal (formerly Gosford) Formation in the area north of Broken Bay; Text-Fig. 1.8). In the Sydney Northshore area only the uppermost formation of the Clifton Subgroup is effectively exposed, i.e. the Bald Hill Claystone. The lowermost formation of the Gosford Subgroup, i.e. the Garie Formation, is thin and discontinuously developed there, and the section is dominated by the overlying, approximately 90 m thick, Newport Formation which (following Cowan, 1985) is divisible into Lower, Middle, and Upper Members (Text-Fig. 1.8). Where the Gosford Subgroup reappears from below sea-level on the southern limb of the basin at

Garie Head, it is markedly thinner than it is in the Sydney Northshore area, and whereas the Garie Formation is distinctive and has a laterally persistent development in this southern part of the basin, the Newport Formation consists mostly of mudrocks and cannot be subdivided into members as in the north (Cowan, 1985). Text-Fig. 1.6 (from Cowan, 1985) shows a composite stratigraphic section of the uppermost Narrabeen Group succession and overlying Hawkesbury Sandstone based on the coastal exposures of the Sydney Northshore and Garie Head areas, commencing stratigraphically in the top part of the Bulgo Sandstone. This diagram also illustrates the upsequence petrographic discontinuities through the succession which formed the initial basis for its stratigraphic subdivision into separate intervals, i.e., intervals A to F, by Cowan (1985), as well as the individual thickness of each of these intervals and their gross lithofacies and palaeocurrent characteristics which, as can be seen in the diagram, differ distinctly one from the other. Text-Fig. 1.7 summarizes the relationship of Cowan's intervals A to F with conventional stratigraphy of the central eastern part of the basin.

In the Sydney Northshore area the most abundant and taxonomically diverse trace fossils occur in the Bald Hill Claystone, Garie Formation and Newport Formation (Text-Fig. 1.8), i.e., within intervals B, C, D, and E of Cowan (1985) and Text-Figs. 1.6 & 1.7, trace fossils being rare in both the underlying Bulgo Sandstone (known in the Northshore area from subsurface cores drilled by the Sydney Metropolatan Water, Sewage and Drainage Board; trace fossils are also rare in this unit at and

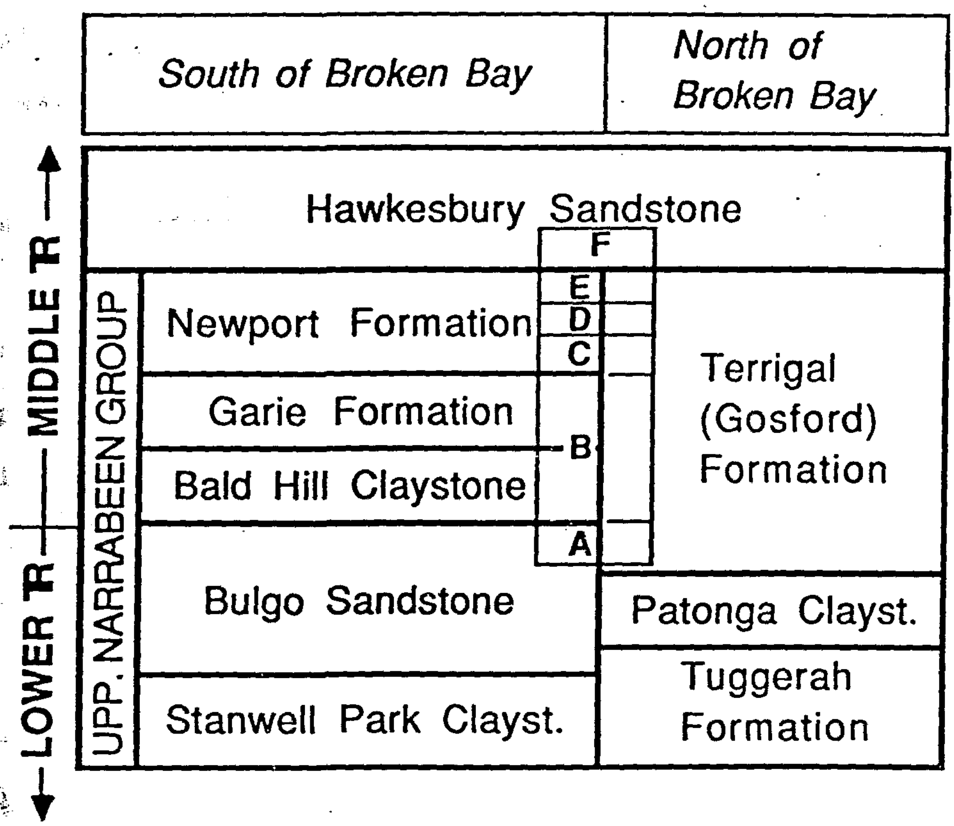
**TEXT-FIG. 1.6.** Composite section of the uppermost Lower and lower Middle Triassic succession of the central-eastern Sydney Basin based on the coastal exposures in the Sydney Northshore and Garie Head areas as indicated by the locality details given at left (from Cowan, 1985, fig. 2.1). Stratigraphic names on the right side of the column are all conventional except for the threefold-member subdivision of the Newport Formation which was introduced by Cowan initially on the basis of petrologic data involving the parameter Q*% (middle column of diagram; Q*% = detrital megaquartz content expressed as a percentage of detrital megaquartz plus volcanic rock-fragments plus sedimentary chert fragments). The present study retains this threefold subdivision of the Newport Formation into Lower, Middle and Upper Members and demonstrates that their boundaries also coincide with ichnofaunal changes (cf. Text-Fig. 4.1). Palaeocurrent data in the rose diagrams are as follows: black = small-scale palaeoflow structures (ripple-marks and ripple cross-lamination, i.e., rank 6 structures of Miall, 1974); white = large-scale palaeoflow structures (crossbeds; i.e., rank 5 structures of Miall, 1974). Grand vector mean of palaeocurrent data in each interval/formation is computed on the basis of pooled sample vector means; N = total number of palaeocurrent readings in the n samples. $\Sigma$ = sets of epsilon cross-strata. Stratigraphic intervals A to F are those of Cowan (1985) and are argued by him to be genetically distinct in terms of their petrographic composition, lithofacies characteristics, and temporal relationships.


DEE WHY, NORTH HEAD
BARRENJOEY
WHALE BEACH
NARRABEEN
AVALON
LONG REEF
GARIE
m
0-
10-
20-
30-
40-
50-
60-
70-
80-
90-
100-
110-
120-
130-
140-
150-
160-
170-
180-
ε
F
HAWKESBURY S.ST.
E
UPP. NEWPORT FM.
D
M. NEWPORT FM.
C
L. NEWPORT FM.
GARIE FM.
B
BALD HILL CLAYST.
A
UPP BULGO S.ST.
0
25
50
75
100
Q* %
N
039
n 19
N 408
075
n 27
N 721
n 24
N 819
134
082
n 21
N 732
n 8
N 109
n 16
N 222
223

TEXT-FIG.1.6.

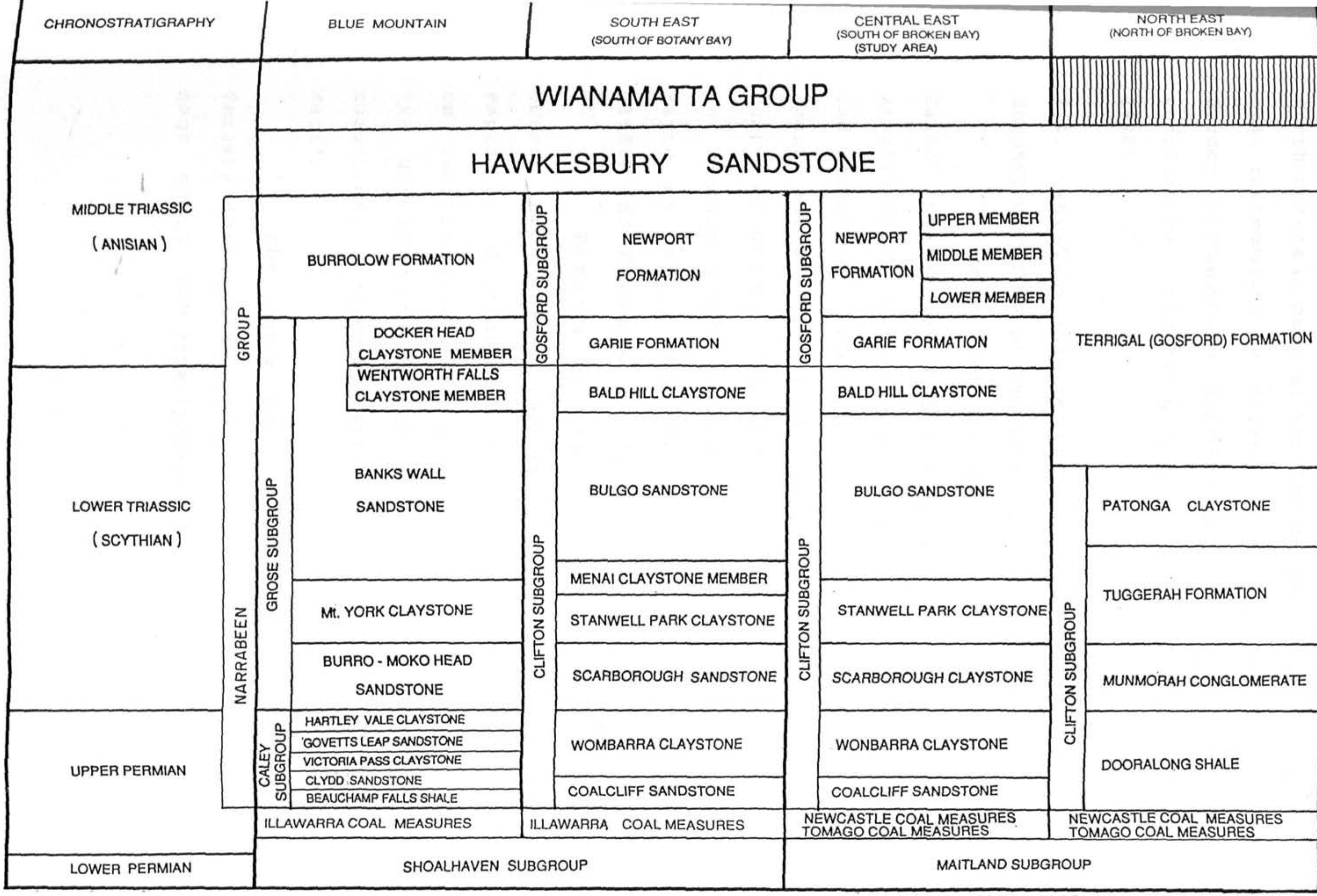
south of Garie Head on the southern limb of the basin) and overlying Hawkesbury Sandstone (i.e., intervals A and F respectively of Cowan, 1985, and Text-Figs. 1.6 & 1.7). In this area the Bald Hill - Garie - Newport succession is approximately 105 m thick (Text-Fig. 1.6) and its component lithofacies elements (i.e., intervals B to E in Text-Fig. 1.6) are distinctive. North of Broken Bay the approximate equivalent of the 105 m thick Bald Hill - Garie - Newport succession of the Sydney Northshore is equivalent (according to petrographic-based correlations by Cowan 1985, fig. 5.1) to the upper 130 m of the 260 m thick Terrigal Formation (cf. Text-Figs. 1.7 & 1.8). Moreover, the distinctive lithofacies-defined stratigraphy that characterizes the Narrabeen succession south of Broken Bay (cf. Text-Fig. 1.6) is less readily recognized in the Terrigal Formation north of Broken Bay because of lateral facies changes that accompany the increased thickness of the time-equivalent strata in this direction. Although some trace fossils have been recorded from the Terrigal Formation by McDonnell (1972, 1974, 1983), their ichnotaxonomic affinities and stratigraphic relationships relative to those in equivalent strata south of Broken Bay remain unexplored.

West of the coastline that faces the open sea the upper part of the Newport Formation (probably the Upper Member of the Newport Formation as defined herein) is the only part of the Narrabeen Group that is exposed throughout the Northshore hinterland region east of the Blue Mountains plateau (Text-Fig. 1.1) where the entire Permo-Triassic Sydney Basin succession, including the Narrabeen Group, is exposed in the plateau escarpment and deeply-incised canyon walls (cf. Goldbery, 1972, and Bembrick,




**TEXT-FIG. 1.7.** Stratigraphic nomenclature and correlation of the Lower to Middle Triassic succession exposed in the study area and north of Broken Bay. Intervals A to F (cf. Text-Fig. 1.6) correspond to those of Cowan (1985).

1980). This immediate hinterland exposure of the upper Newport Formation is confined to the very lowermost part of the sandstone plateau escarpment that bounds the Hawkesbury River estuary at Broken Bay and its various inlets and tributaries (cf. Sydney 1:100,000 geological sheet), and is not exposed at all to the south in Port Jackson. As is the case with almost all stratigraphic units in the Sydney Basin, the Triassic formations that are exposed in the Sydney Northshore area thin gradually towards the west and south so that their correlative units in the Blue Mountains (Text-Fig. 1.8) are thinner than in the east. In the Blue Mountains region the correlative units of the Bald Hill Claystone, Garie Formation, and Newport Formation on the coast are respectively: the Wentworth Falls Claystone Member of the Banks Wall Sandstone, the Docker Head Claystone Member of the Banks Wall Sandstone, and the Burralow Formation (Text-Fig. 1.8). Each of these units is very much thinner in the Blue Mountains than in the eastern coastal area and the Burralow Formation is relatively more sandy there, so much so in the western Blue Mountains that it is said to become indistinguishable from the overlying Hawkesbury Sandstone (Bunny & Herbert, 1971, p.63; Bembrick, 1980). The stratigraphy and sedimentology of these units in the Blue Mountains is poorly Known, Particularly so in respect of the Burralow Formation, the concept and definition of which has been revised a number of times since its original definition by Crook (1957 ; e.g., compare Goldbery & Holland, 1973, table 1 with Bembrick, 1980, fig.8.2). Unpublished work on the exposed Triassic succession by Royce and Conaghan (cf. Royce, 1979) in the Blue Moun-




TEXT-FIG. 1.8. Comparative stratigraphic nomenclature of the Triassic System in different parts of the Sydney Basin and nomenclature of the underlying Permian System. Source: Herbert, 1970 & 1983a; Ward, 1972a & b; Loughnan et al., 1964; Bembrick, 1980; Uren, 1980; McDonnell, 1983; and Cowan, 1985.

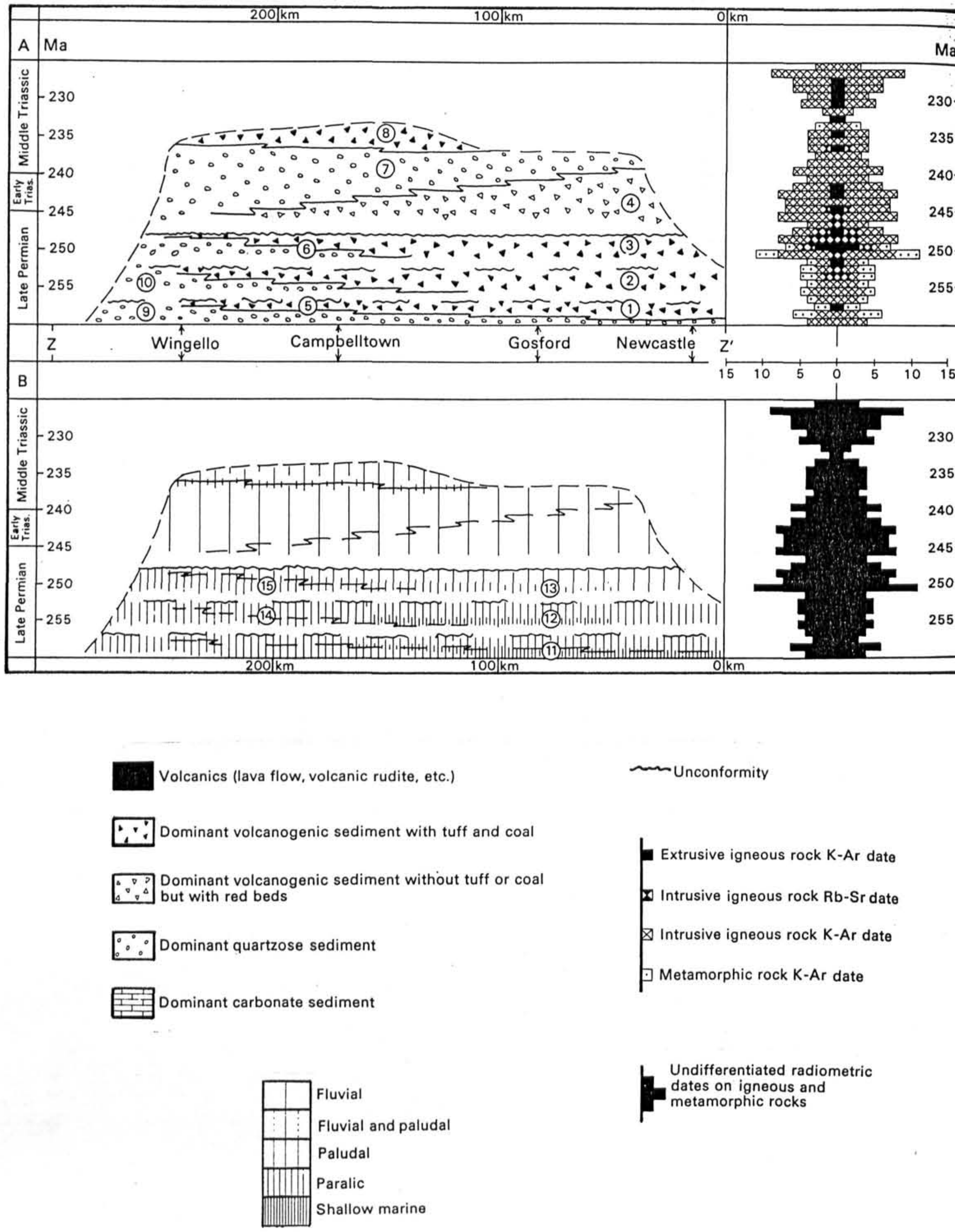
tains and by Gregory and Conaghan (cf. Gregory, 1990) in the north-central part of the Sydney Basin suggests that the abundant and taxonomically diverse ichnofauna that characterizes the Sydney Northshore Narrabeen Group rocks does not occur in the correlative strata in these areas (P. J. Conaghan, pers. comm., 1990).

## 1.4. PREVIOUS WORK AND RECENT CONCEPTS REGARDING ENVIRONMENTAL RECONSTRUCTIONS OF THE TRIASSIC SUCCESSION OF THE SYDNEY BASIN

Early work on the Triassic succession of the Sydney Basin including descriptions and correlation of the various stratigraphic units, evolution of the stratigraphic nomenclature, and concepts regarding the depositional palaeoenvironments of these units have been variously discussed and reviewed by a number of workers, in particular: Osborne (1948); various authors in Packham (1969, p.388-423; p.439-444), Herbert (1970, 1983b), Mayne et al. (1974), Herbert & Helby (1980), Bradley et al. (1985) and Bowman et al.(1986).

Because of its immediate proximity to and ease of access from Sydney and because of the superb quality of the exposure, a great deal of both the earlier and more recent work on the Triassic System in the Sydney Basin, and particularly on the Narrabeen Group, has been focused on the outcrops along the coastline, called by Conaghan et al. (1982) the "coastal transect".

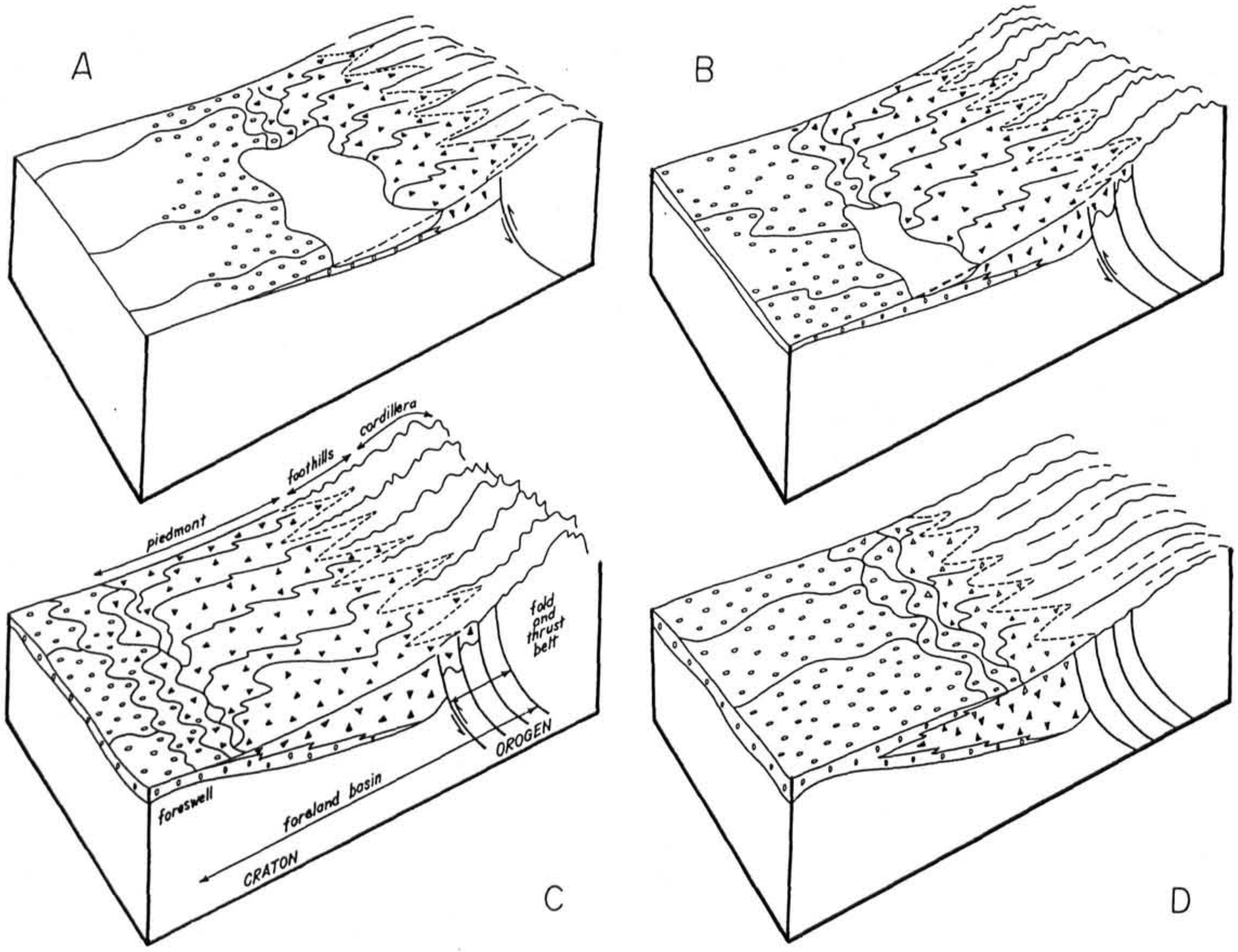
The early work, prior to about the 1970s, was very largely descriptive and laid much of the foundation of our knowledge about the stratigraphy, mineralogy and palaeontology of these rocks but was not equipped with the multifaceted conceptual tools of modern sedimentology and the actualistic approach of modern facies analysis to deal rigorously with the problems of environmental reconstruction. Consequently, many different depositional environments were variously suggested by these earlier workers (see reviews by Osborne, 1948, and McDonnell 1972). For the Narrabeen Group these included lacustrine, fluvio-deltaic, and (for the redbeds such as the Bald Hill Claystone), interdistributory bay and shallow-marine. For the Hawkesbury Sandstone the range included shallow-marine, littoral, estuarine, fluvial, lacustrine and aeolian. For the Wianamatta Group, the upsequance pattern of body fossils, lithology and sedimentary structures allowed a more straight-forward interpretation and suggested a change from lacustrine at the base, followed by shallow, probably brackish-marine, followed by littoral/paralic and fluvial environments (Lovering et al. (in Packham, 1969, p. 443-444)), an overall interpretation that has not been greatly revised subsequently, even though some aspects of the stratigraphy of the Wianamatta Group have been revised (Herbert, 1980b). More recent work, beginning in the late 1960s - early 1970s, has seen more tightly constrained environmental reconstructions proposed for the Narrabeen Group and the Hawkesbury Sandstone, as well as for their overall tectonic context within the basin. Thus, the Narrabeen Group - Hawkesbury Sandstone succession is argued by Conaghan et al. (1982) and Jones et al. (1984) to manifest the upper, retreating phase of a piedmont clastic wedge which records a first-order Late Permian - Early Triassic tectonic pulse in the Tamworth Mountain Arc of the New England Fold Belt in the north




TEXT-FIG. 1.9. Time-space transect of the Sydney Basin along line A - A' in Text-Fig. 1.1. A, rock composition; B, environmental wetness. Stratigraphic units are 1, lower Tomago Coal Measures; 2, upper Tomago Coal Measures; 3, Newcastle Coal Measures; 4, Narrabeen Group excluding upper Gosford Formation; 5, Cumberland Subgroup; 6, Sydney Subgroup; 7, Hawkesbury Sandstone and upper Gosford Formation; 8, Wianamatta Group; 9, Nowra Sandstone; 10, Berry Formation; 11, Mulbring Formation; 12, Kulnura Marine Tongue; 13, Dempsey Formation; 14, upper Erins Vale Formation; 15, upper Wilton Formation. Stratigraphic data from Brakel (1982), Conaghan et al. (1982), and Herbert & Helby (1980). (From Jones et al. (1984), figs. 164 & 166.)

and northeast (Text-Fig. 1.9). This piedmont clastic wedge of volcanogenic labile sediment begins with the southward advance of the Late Permian coal measures into a shallow sea at about 257 Ma, coeval with volcanic activity in the Tamworth Mountain Arc, culminates at about 247 Ma with the most southward advance of the clastic wedge into the southern and southwestern part of the basin (i.e., Newcastle and upper Illawarra Coal Measures), and then retreats progressively throughout the Early Triassic (i.e., during deposition of the Narrabeen Group) till ca. 240 Ma when the craton-sourced quartzose Hawkesbury Sandstone over-runs the foredeep from the southwest (Text-Fig. 1.9). This compositionally cyclic pattern of foreland basin infill was generalized by Jones et al. (1984) into a foreland basin model, reproduced schematically here in Text-Fig. 1.10. As developed by Conaghan et al. (1982) and Jones et al. (1984) for the Sydney Basin, this model was constrained by various environmental analysis of the Late Permian coal measures (viewed as predominantly fluvio-lacustrine and deltaic; Parbury 1976; Conaghan, 1982; Cameron et al., 1982; McDonnell, 1983), the Narrabeen Group (viewed as predominantly fluvial, including alluvial fan environments in the extreme northern part of the basin (Ward, 1972; McDonnell, 1972, 1974, 1983), and the Hawkesbury Sandstone (viewed as of fluvial origin (Standard (in Packham, 1969, p. 407-417)), and more particularly of low-sinuosity fluvial origin (Conaghan & Jones, 1975; Conaghan, 1980).

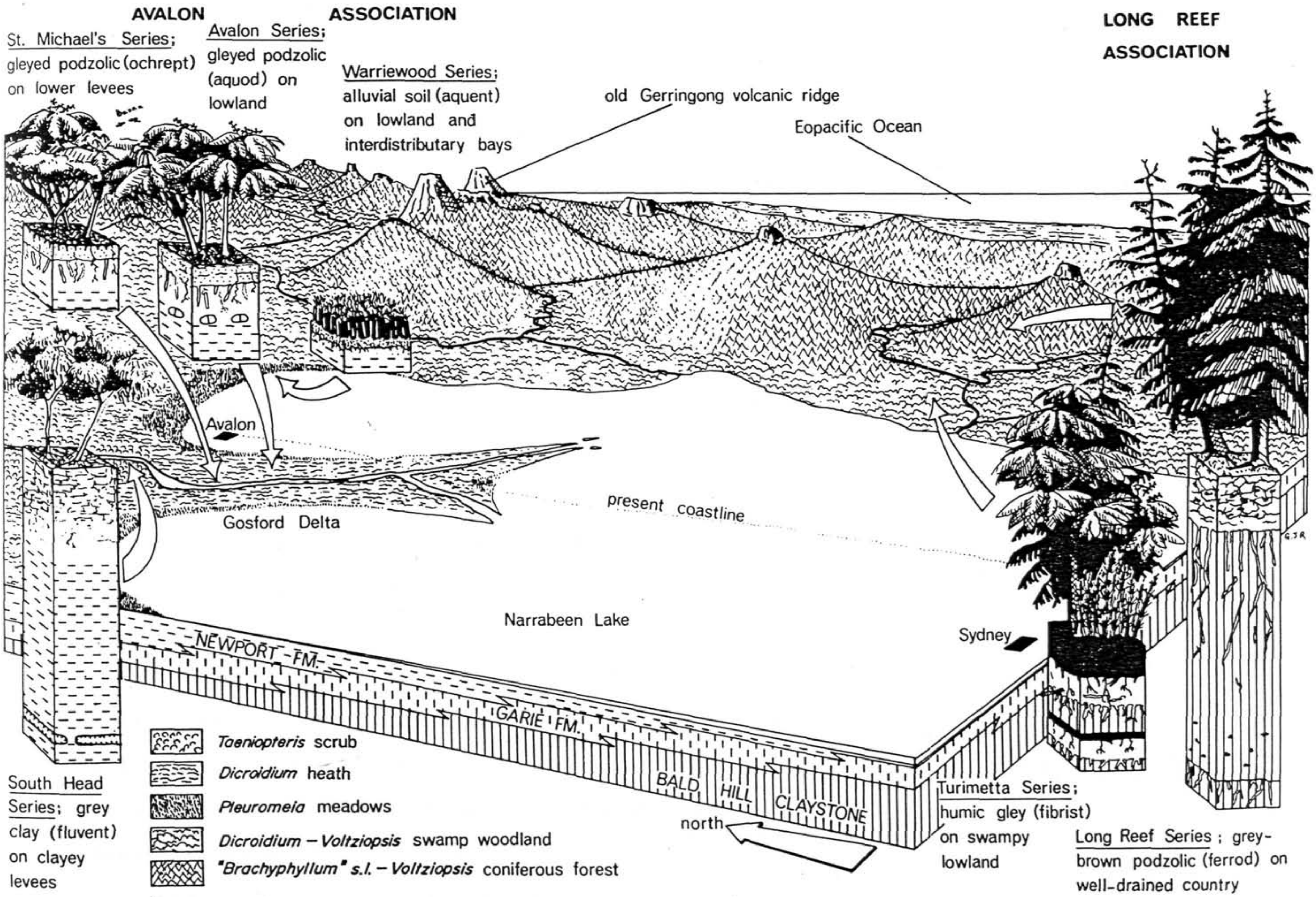
In this wider palaeographic context, the Early Triassic retreat of the Narrabeen piedmont clastic wedge can be seen to




TEXT-FIG. 1.10. Model of a foreland basin developing through a single cycle. Lettering on C identifies topographic and tectonic elements common to all block diagrams. Sediment symbols as for Text-Fig. 1.9. The figure portrays four instants in the course of a foreland basin cycle on a scale of about 5 to 25 ma. Onset of uplift-cum-volcanism initiates growth of a mountain range and of piedmont alluvial fans, which begin to prograde into a concomitantly sagging and flooding foreland basin (A). With continuing uplift and outward expansion of the orogen, involving thrusting and folding of proximal outwash, the piedmont advances cratonwards into a contracting marine or lacustrine moat, pushing back the limits of craton-derived sediment (B). Ultimately marine and/or lacustrine conditions are eliminated from the foreland basin as the piedmont of a now mature cordillera spans most or all of the width of the basin to the limiting foreswell (C). With the decline of tectonism, the cordillera begins to settle, and the foreland basin rises gently, resulting in a falling water-table and an interval of non-deposition or mild erosion across the foreland while streams from the cordillera readjust to reduced gradients. Tuff and coal, which manifest the concurrent volcanism and high ground-water levels of the prograding piedmont, are no longer formed, and redbeds make their appearance as the piedmont begins to retreat. Without regeneration through uplift and volcanism, the orogen dwindles in height and extent through continued erosion and settling, and the piedmont shrinks, allowing a compensatory advance of cratonic quartz sands (D). (From Jones et al. (1984), fig. 167, and p.259.)

culminate in an episode of starved bedload alluviation throughout much of the basin as manifested by the development of the Bald Hill Claystone - Wentworth Falls Claystone redbed unit at the top of the Clifton Subgroup, a point first emphasized by Bunny & Herbert (1971). Mineralogical studies of the Bald Hill Claystone by Loughnan (1963) and Loughnan et al. (1964) suggested to them that its predominant kaolinite-haematite mineralogy, together with its predominant fabric comprising "coarse bedded claystones, clay-siltstones and clay-breccias" (Loughnan, 1963, p.182), indicated that it consisted of a transported pre-existing lateritic soil. Moreover the quartz-deficient nature of the Bald Hill Claystone (cf. Loughnan, 1963) suggested to them that such lateritic soils might need to be sought on mafic igneous rocks such as comprise the geographically neighbouring Upper Permian Gerringong Volcanics in the area to the east and south, an idea subsequently taken up by Ward (1972, 1980), Goldbery & Holland (1973), Retallack (1973, 1977a & b, 1980) and Herbert (1980a). Further, Bunny & Herbert (1971), working primarily with subsurface drill-core from the southern part of the basin (south of Botany Bay) recognized a soil horizon at the top of the Bald Hill Claystone and other soil horizons at various stratigraphic levels within the overlying Newport Formation. On the basis of the characteristic graded-bedded oolitic/pisolitic and brecciated clay-pellet textures of the intervening Garie Formation they (and also Herbert, 1980a, p.46-48) interpreted the Garie Formation to represent the redeposited products of the soil horizon in the top of the Bald Hill Claystone and suggested that such redeposition was caused by a transgressing shallow-marine shoreline through the erosional retreat of micro-clifflines analogous to a modern example of such a phenomenon on tidal flats of the China Sea (cf. Nossin, 1961; see also Herbert, 1980a, p.46-48). Bunny and Herbert (1971) also argued on the basis of sporadic burrows and rootlets/soil horizons in the lower part of the Newport Formation that the same gentle marine transgression manifested by the Garie Formation also sporadically influenced the lower part of the Newport Formation. They saw no evidence for such marine influence in the top part of the Newport Formation and hence argued that whereas the Garie Formation and lower part of the Newport Formation are trangressive, the upper part of the Newport Formation and the overlying Hawkesbury Sandstone are regressive. Moreover, they argued that the quartzose sandstone bodies of the Newport Formation are of deltaic origin and pass up gradationally into the quartzose fluvial Hawkesbury Sandstone. Because of this they argued that, following the time-break/ diastem recorded at the top of the Bald Hill Claystone, subsequent deposition of the Gosford Subgroup sediments (i.e., Garie Formation and Newport Formation) belong more properly with the Hawkesbury Sandstone phase of sedimentation rather than with the Clifton Subgroup phase of deposition. Further support for this idea was subsequently provided by Retallack (1973, 1975, 1976, 1977a, b & c, 1980) who recognized palaeosols throughout the Bald Hill Claystone and at various levels in the overlying Newport Formation in the Sydney Northshore area and, for the first time, a geographically sporadically developed lithofacies in this area at the top of the Bald Hill Claystone referable to the Garie Formation.

Retallack brought a number of modern palaeoecological, pedological and sedimentological approaches to bear in attempting to reconstruct the depositional environments of these rocks. However, he focused in particular on the phyto-sociological aspects of the fossils present and not on the trace fossils, though he did document and comment briefly on some of the trace fossils (Retallack 1976, 1977a & b). In brief, Retallack's environmental reconstruction of the Bald Hill Claystone - Newport Formation succession in the Sydney Northshore area was similar to that of Bunny & Herbert's (1971) for the southern part of the basin (for example, see Retallack, 1977b, fig. 10, reproduced here as Text-Fig. 1.11; and Retallack 1977c, fig. 2). He saw the red-brown palaeosol-bearing sediments of the Bald Hill Claystone as having formed in well-drained interfluves between streams transporting volcanogenic sandy sediment from the Gerringong Volcanic Ridge to the east of the present coastline and, with progressively increasing rise of the ground-water level consequent upon the expansion of the "Narrabeen Lake" (Text-Fig. 1.11), the formation of the drab-coloured clayey sediments of the Garie Formation. Retallack saw the Newport Formation sediments as having been deposited in a series of quartz-rich fluvio-deltaic lobes that entered from the northwest and west a freshwater to brackish-water coastal lagoon or lake (i.e., his "Narrabeen Lake", cf. Text. 1.11) that was "intermittently open to the sea in the south" (Retallack, 1977b, p.31). Botanical evidence for the possible brackish nature of the lagoonal water is seen in the facies-discordant development of a Pleuromeia - Cyclostrobus lycopod horizon in the Garie Formation and in the base of the

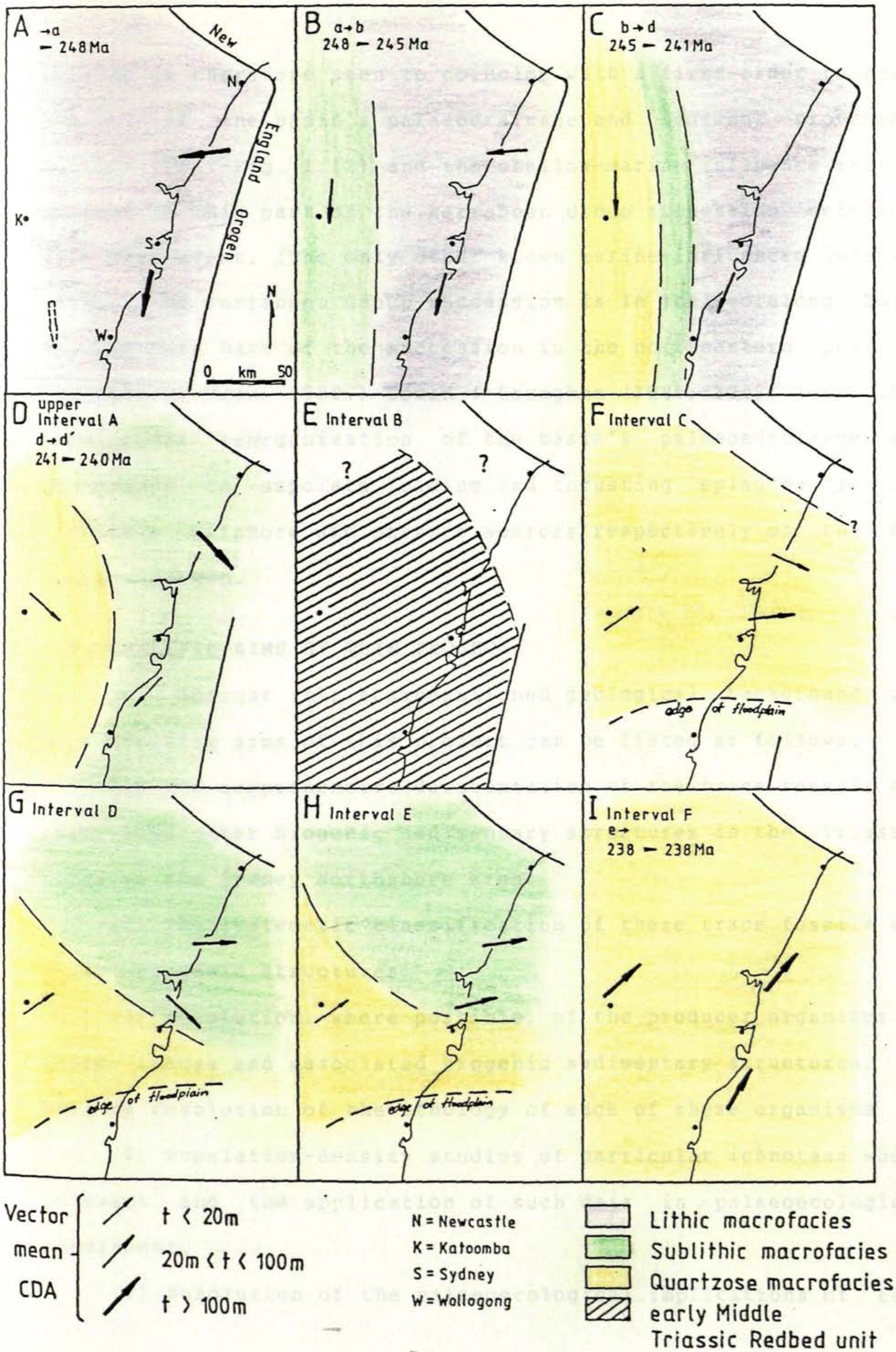



TEXT-FIG. 1.11. Reconstructed soils, vegetation, and topography of the Sydney Northshore area during deposition of Lower Newport Formation. (From Retallack (1977b), fig. 10.)

overlying Newport Formation (Retallack, 1977b, fig. 9) and on the basis that this lycopod is reconstructed as a faculative halophyte, "like many modern coastal plants adapted to highly variable salinities of tidal-flat shorelines" (Retallack, 1975, p.12).

The last and most recent major contribution to our knowledge of the Triassic rocks of the present study area is that of Cowan (1985). As already mentioned, Cowan successfully subdivided the Newport Formation into lower, middle, and upper units (cf. Text-Figs. 1.6 & 1.7; his intervals C, D, and E respectively). Although this subdivision has not yet been formalized through publication, these three subunits of the Newport Formation can be regarded as members of the formation and are treated herein as such. Cowan's work focused in particular on the fluvial sedimentology of the Triassic Northshore succession and its implication for Conaghan et al's (1982) "dynamic fluvial [basin-fill] model". His study showed that the Gosford Subgroup sedimentation did indeed differ in pattern and style compared to that of the Clifton Subgroup, at least in the central and southern parts of the basin where there is a laterally continuous development of the Bald Hill Claystone - Wentworth Falls Claystone, manifesting the lull in clastic bedload alluviation that evidently affected the basin at the end of `Clifton Subgroup time'. Unlike several earlier workers (e.g., Bunny & Herbert, 1971; McDonnell, 1972, 1983; Conaghan et al., 1982) who regarded the upper Newport Formation/Terrigal Formation as the distal time-equivalent of the more proximal Hawkesbury Sandstone, Cowan argued that the fluvial styles evident in these two stratigraphic units are incompatible and that the Hawkesbury Sandstone represent a new and separate phase of deposition following a hiatus which closed Narrabeen Group deposition. He also showed that whereas prior to deposition of the Bald Hill Claystone the eastern parts of the basin received volcanogenic labile and sublabile sediment transported by southerly-flowing trunk/axial streams, subsequent to accumulation of the Bald Hill Claystone - Garie Formation, sediment in the Gosford Subgroup (Newport Formation and upper part of the Terrigal Formation) was predominantly quartzose, was confined mainly to the central, northern and western parts of the basin and was transported by stream systems which varied episodically in their hydrological character (as manifested by the different fluvial styles evident in Cowan's intervals C, D, and E - see Text-Fig. 1.6) and flow direction (Text-Fig. 1.12), the latter being variously and episodically southeasterly, easterly, and northeasterly (cf. Text-Figs. 1.6 & 1.12). Of the three members of the Newport Formation, the Middle Member (i,e., interval D in Text-Fig. 1.6) is the only one that contains volcanogenic labile components in significance proportions suggesting that it was sourced in part from the New England Orogen to the north and northeast rather than wholly by the craton to the southwest as indicated by the two other members of the Newport Formation as well as by the overlying Hawkesbury Sandstone whose palaeoflow pattern is uniformly towards the northeast (Text-Figs. 1.6 & 1.12). These same upsequence compositional and palaeocurrent patterns have recently been found to occur in the exposed Triassic succession of the central-northern part of the basin also (Gregory, 1990).

The Garie Formation - Newport Formation depositional




TEXT-FIG. 1.12. Late Permian to Mid Triassic development of the Sydney Basin (from Cowan 1985, fig. 6.2). The frames are constructed from a time-space transect of the basin (Cowan's fig. 6.1). Intervals A to F (frames D to I) correspond with intervals A to F in Text-Fig. 1.6.

episode is therefore seen to coincide with a first-order reorganization of the basin's palaeodrainage and sediment provenance pattern (Text-Fig. 1.12) and the shallow-marine influence that is evident in this part of the Narrabeen Group succession coincides with this event. (The only other known marine-influenced interval within the Narrabeen Group succession is in the Dooralong Shale at the vary base of the succession in the northeastern part of the basin; Uren, 1980.) Cowan & Conaghan (1988, 1989) link this first-order reorganization of the basin's palaeoedrainage and provenance to separate folding and thrusting episodes in the presently offshore and onshore sectors respectively of the New England Orogen.

## 1.5. SPECIFIC AIMS OF THIS PROJECT

Against the abovementioned geological background the more specific aims of this project can be listed as follows.

(1) The comprehensive documentation of the trace fossils and associated other biogenic sedimentary structures in the Triassic rocks of the Sydney Northshore area.

(2) The systematic classification of these trace fossils and other biogenic structures.

(3) Resolution, where possible, of the producer organisms of these traces and associated biogenic sedimentary structures, as well as resolution of the ethology of each of these organisms.

(4) Population-density studies of particular ichnotaxa where relevant and the application of such data in palaeoecological assessment.

(5) Resolution of the palaeoecological implications of each

of the different ichnotaxa and assemblages of ichnotaxa and the application of these constraints in reconstructing the palaeoenvironments of the host strata.

**(6)** Stratigraphic zonation of the Northshore Triassic succession on the basis of upsequence changes in the ichnotaxonomic composition, diversity and relative abundances in the trace fossil assemblages.

**(7)** Resolution of the presence and number of marine-influence depositional episodes in the uppermost Narrabeen Group succession on the basis of the ichnological evidence, such marine-influenced episodes having been suggested by previous workers mainly on general lithofacies and palaeobotanical evidence and on the basis of only very casual reference to the ichnological evidence.

(8) Documentation of the stratigraphic thickness and exposed geographic extent of these marine-influenced intervals and the degree of lateral ichnofacies variation within them.

(9) Comparison of the upsequence stratigraphic zonation of the Northshore Triassic succession with Cowan's (1985) petrological- and lithofacies-based subdivision of it.

(10) Reconstruction of the changing palaeogeography in late Early and early Middle Triassic time in the Sydney Northshore area on the basis of the above palaeoecological and environmental constraints.