PART 3

SYNTHESIS AND CONCLUSIONS

CHAPTER 18

TRACE FOSSIL ASSEMBLAGES (SUITES) IN INTERVALS IC TO IF AND THEIR DISTRIBUTION IN THE STUDY AREA.

TRACE FOSSIL ASSEMBLAGES (SUITES) IN INTERVALS IC TO IF AND THEIR DISTRIBUTION IN THE STUDY AREA

18.1. INTRODUCTION

The various trace fossil assemblages/suites (intervals, subintervals and levels) are defined in Chapter 4 of this volume. The present study deals only with a portion of the upper part of the Sydney Basin Permian and Triassic succession (compare Text-Fig. 1.7 with Text-Fig. 1.8). A comprehensive review of all of the ichnological sequences or episodes in the basin's history must take account of previous studies in the southern part of the basin: the first such study by Carey (1978) focused on the ichnology of the Lower Permian Snapper Point Formation (assigned to interval IB, the second interval, herein); the second such study, by McCarthy (1979), focused on the Lower Permian Wasp Head and Pebbley Beach Formations (assigned here to interval IA, the first interval). In the present study the stratigraphic succession of trace fossil intervals begins with interval IC (Bald Hill Claystone), followed by interval ID (Lower Newport Member), interval IE (Middle Newport Member), interval IF (Upper Newport Member), and interval IG (Hawkesbury Sandstone) (Webby, 1970) (see Chapter 4 for details). The present study was confined to this latter succession of rocks because these constitute the only part of the Sydney Basin succession exposed in the Sydney Northshore area (see Enclosures III.1).

Both the stratigraphic and geographic distribution of the trace fossil intervals and subintervals have been compiled for the Sydney Northshore area on the basis of the geographic control points documented in Enclosure III.2 and on the basis of the stratigraphic control documented in Enclosures III.3 and III.4. As indicated in Chapter 4 (Text-Figs. 4.1 & 4.2) and Chapter 5 (Text-Fig. 5.1), the stratigraphic and geographic distribution of trace fossils in the study area provides a record of the changing palaeoecology in time and space caused by local environmental changes. Stratigraphic variations of the ichnofaunas in terms of population density and taxonomic diversity within the logged sections along the length of the study area emphasise the influence of marine-dominated episodes or pulses (cf. Text-Fig. 5.2). Four major marine-dominated episodes can be defined laterally and temporally, both by population density and/or diversity of the ichnotaxa in the trace fossil intervals (Text-Figs. 4.1 - 4.3).

18.2. DISTRIBUTION OF TRACE FOSSIL INTERVALS

The distribution of trace fossils can be defined in several different ways: the first way is to study their distribution temporally (through time or stratigraphic sequence, cf. Text-Fig. 4.1); secondly, their distribution can be defined geographically (laterally or spatially, cf. Text-Fig. 4.2); and thirdly, their distribution can be defined palaeoecologically or environmentally (cf. Text-Fig. 5.1). These various distributions of trace fossils are either measured by their taxonomic diversity or on the basis of the population-density indices described in Text-Fig. 3.7 and Appendix II.1d. The population can be measured by the number of the individual ichnotaxa present or it can be measured by the percent of bioturbation (R = rare, 1 - 2%; U =

uncommon, <10%; C =common 10% - 40%; A = abundant, 40% - 60%; V = very abundant 60% to 90%; and BT = totally bioturbated, 90% - 100%).

18.2.1. Geographic distribution

In general the most obvious variation in the distribution of trace fossils in the study area is stratigraphic (Text-Fig. 4.1). The most diverse and populated trace fossil intervals are confined to the Bald Hill Claystone (interval IC), the Lower Newport Member (interval ID), and the Middle Newport Member (interval IE; see Enclosure III.1 and Text-Fig. 4.1). In the south of the study area (south of Long Reef Point (area 3)), and in the extreme north at Barrenjoey Head (area 1), the contact between the Upper Newport Member and the Hawkesbury Sandstone lies either close to or not far above sea level and consequently none of the underlying members of the Newport Formation (i.e., the Middle and Lower Members) are exposed (Enclosure III.1). Where the Upper Newport Member is exposed it consists of the topmost subintervals IF1 and/or IF2 of interval IF and the subintervals are characterized exclusively by the newly described steeply- inclined and branched ichnotaxon <u>Barrenjoeichnus mitchelli</u> (Text-Fig. 4.1). Exposures of these subintervals are confined to the southernmost part of the area at Shelly Beach and Blue Fish Point (area 20) and Cabbage Tree Bay (area 19), and to the extreme northernmost part of the area at Barrenjoey Head (area 1) and Palm Beach South (area 4b) (see Enclosure III.1 and Text-Fig. 4.3). In the southern part of the study area such as at Middle Head (area 22), South Head (area 23) and Dunbar Head (area

24), the Newport Formation - Hawkesbury Sandstone contact lies below sea level and hence only the Hawkesbury Sandstone is exposed. In the abovementioned southern areas no trace fossil subintervals were recorded. However, the Hawkesbury sandstone has in general been designated as belonging to trace fossil interval IG on the basis of the occurrence of the ichnotaxon Brookvalichnus obliquus in a mudrock unit within this formation at Beacon Hill, Brookvale (Text-Figs. 1.1, & 4.1-4.3).

The most diverse and populated trace fossil subintervals are exposed in areas between South Palm Beach (area 4b) in the north and Long Reef Point (area 3) in the south. The best type localities for the various trace fossil intervals are as follows: interval IC - Turimetta Head (area 2, see details in Text-Fig. 1.3); interval ID - St. Michaels Cave (area 5, see details in Text-Fig. 1.4; and for the trace fossil intervals IE and IF - South Palm Beach and Barrenjoey Head respectively (areas 4b and 1 respectively; see details in Text-Fig. 1.5). Representive logged sections of each of these trace fossil intervals measured in these areas are shown in Enclosure III.1 and also in Enclosures III. 3 and III.4. The lateral distribution of these various trace fossil intervals and subintervals is summarized in Text-Fig. 4.3.

18.2.2. The trace fossil assemblage zones and their stratigraphic distribution

Trace fossil intervals were initially defined stratigraphically, i.e., corresponding to formations and/or members since the major variations in trace fossil distribution are vertical rather than lateral (see Text-Figs. 4.1 & 4.3 and see details in the text of Chapter 4). The established intervals and subintervals described here are (see Text-Fig. 4.1): interval IC (lowest interval exposed in the study area), Bald Hill Claystone, with five subintervals (IC1 to IC5); interval ID is mainly confined to the Lower Newport Member and the Garie Formation (where present), with six subintervals (ID1 to ID6); interval IE is mainly confined to the Middle Newport Member and has ten subintervals (IE1 to IE10); interval IF is confined to the Upper Newport Member and has two subintervals (IF1 to IF2); and interval IG (which is not subdivided into subintervals) comprises the Hawkesbury Sandstone in which the trace fossils occur only within shale lenses. As already mentioned in Chapter 4, the subintervals are defined and named after their typical index ichnotaxa or ichnotaxon. As so defined, these subintervals can also be regarded as zones or assemblages zones for ichnological studies. These zones are reiterated here as follows (in descending stratigraphic order):

(4) Rhizocorallium - Thalassinoides assemblage zone, subintervals IE9 - IE10;

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

(2) Skolithos - Diplocraterion assemblage zone, subintervals ID1 - ID2;

(1) Turimettichnus - Ophiomorpha assemblage zone, subintervals IC1 - IC4.

Additionally, although not previously differentiated or separately named as a trace fossil assemblage zone, subintervals IF.1 and IF.2 of the Upper Newport Member are dominated exclusively by vertical/subvertical branching and non-branching shafts of the new ichnotaxon Barrenjoechnus mitchelli (Text-Fig. 4.1; Plates 55 - 57; Plate 80; Figs. a & b).

Turimettichnus - Ophiomorpha assemblage zone (subintervals IC1 - IC4): The Turimettichnus - Ophiomorpha assemblage zone is the oldest trace fossil zone exposed in the study area and is confined to the Bald Hill Claystone. It is defined by the occurrence of the new ichnotaxa Turimettichnus conaghani, T. webbyi, and Pytiniichnus trifurcatum, in addition to Ophiomorpha nodosa, and Thalassinoides suevicus (see Text-Figs. 4.1 & 4.2) which indicate that it is of shallow-marine affinity, possibly brackish, but ranging locally into terrestrial alluvium with soil development (cf. Text-Figs. 3.5 & 5.1). In general, this shallow-marine trace fossil assemblage can be regarded as belonging to the Skolithos ichnofacies (Appendix I.8). This particular assemblage zone is best exposed at Turimetta Head (area 2), Bungan Head (area 13), and Bilgola Head (area 10). Where exposed at Long Reef Point (area 3) this assemblage zone is affected by palaeo-subaerial conditions (palaeo-weathering and some palaeo-erosion) and by lateral facies changes into a palaeosal-rich unit, manifested by the disappearance of Turimettichnus, Ophiomorpha and Thalassinoides and by the appearance of fossil roots and rootlets, and by the amphibian or reptilian burrow Pytiniichnus trifurcatum in the palaeosol strata (lithofacies FI; Plate 83, Fig. b). This assemblage zone is immediately followed stratigraphically by shoreline deposits characterized by ripples and the trackways of amphibians (both webbed and unwebbed), possibly of Paracyclotosaurus (Text-Fig. 4.1).

The Turimettichnus - Ophiomorpha assemblage zone consists mainly of lithofacies FH and FI in the spectrum of lithofacies defined in Text-Fig. 3.6 and Appendix II.6, and rarely of lithofacies FE (e.g., in the Bald Hill Claystone exposed at Turimetta Head; Plate 78, Fig. a). This trace fossil assemblage zone is followed stratigaphically by the Skolithos - Diplocraterion assemblage zone.

Skolithos - Diplocraterion assemblage zone (subintervals ID1 & ID2): This trace fossil assemblage zone is mainly confined to the lower part of the Lower Newport Member and, where developed, the laterally equivalent Garie Formation (Text-Figs. 4.1 & 4.3). It is mainly exposed at Mona Vale (area 14), Bungan Head (area 13), Little Reef (area 12), Hole in the Wall (area 11), St. Michaels Cave (area 5), and Bangalley Head (area 8) (Text-Fig. 4.3). This particular assemblage zone is defined by two distinct kinds of vertically-orientated burrows: cylindrical Skolithos shafts and simple U-shaped Diplocraterion burrows (Text-Fig. 4.1). Although this particular assemblage zone has two distinct ichnogenera as described above, these two ichnogenera occur separately in some cases even though they occur in the same subinterval (as at Mona Vale, St. Michaels Cave and Bangalley Head. In contrast, at Little Reef and Bungan Head, Diplocraterion occurs in intimate association with Skolithos. Both the vertical/steeply-inclined cylindrical Skolithos burrows and the U-shaped Diplocraterion burrows can be attributed to very-shallow high-energy environments (cf. Text-Figs. 3.5 & 5.1). Rhizocorallium also occurs in this assemblage zone in two places in subinterval ID2 (St. Michaels Cave and Mona Vale) and its presence can be inferred to manifest calmer, lower-energy conditions (cf. Text-Figs. 3.5 & 5.1). However, the Rhizocorallium burrows in this assemblages zone have retrusive spreite indicating that the burrows were formed under conditions of bed-accretion and hence suggesting that the area was not entirely free from sensible sediment influx. This conclusion is also indicated by the presence of bivalve mollusc escape-structures (Adeiaichnus ichno. gen. nov.) in the underlying subinterval (i.e., ID1; cf. Text-Fig. 4.1). The association of Turimettichnus conaghani var. C (i.e., the variety lacking a wall-layer) and the running-gait trackways of small amphibians or reptiles are recorded in the same subinterval (i.e., ID1) can be attributed to their formation along a strandline during a marine-influenced episode which produced a coastal lagoon or estuarine environment. This trace fossil assemblage is interpreted to belong to the Skolithos ichnofacies (Appendix I.8). The assemblage zone mainly comprises lithofacies FD and FE (Plate 69). These lithofacies comprise beds of medium thickness (about 10 cm); most of the beds comprise massive sandy units (fine sandstone to very fine sandstone) with an upward fining pattern. These sandy beds are normally interbedded with greenish-grey siltstone or claystone which is normally extensively bioturbated. This assemblage zone is followed by a non-marine interval (consisting of trace fossil subintervals ID.3 and ID.4) which is relatively barren of ichnofossils (Text.Fig. 4.1).

Helikospirichnus veeversi assemblage zone (subintervals ID5, ID6 & IE.1): This assemblage zone is mainly confined to the upper part of Lower Newport Member (i.e., subintervals ID5 -ID6) and to the lowermost part of the Middle Newport Member (subinterval IE.1). The assemblage is exposed mainly in the areas of Bilgola Head (area 10a), Hole in the Wall (area 11), St. Michaels Cave (area 5), Bangalley Head (area 8), and Careel Head (area 9) (Text-Fig. 4.3). The assemblage is particularly defined by the common occurrence of the new ichnogenus Helikospirichnus which is associated with different types of escape-structures (described in Chapter 14) and similar V-shaped collapse-structures (also manifesting animal escape). The assemblage is also characterized by the common occurrence of sinuous trails of the new ichnogenerus Colichnites. This assemblage is best explained as of shallow brackish-marine environmental affinity responding additionally to bed-load substrate accretion which caused the burial and attempted escape of many infaunal organisms in the sediment (Plates 40-44). Some episodes of substrate erosion also characterized the deposition of these subintervals as indicated by evidence of attempted downward-escape movements in the case of some bivalve mollusc burrows. This trace fossil assemblage can be interpreted as belonging to the Skolithos ichnofacies (Appendix I.8). This assemblage zone comprises mainly lithofacies FF (i.e., beds of well-laminated fine sandstone interbedded with thin mudrock laminations a few mm to a cm thick (cf. Text-Fig. 3.6). This assemblage zone is followed stratigraphically by a non-marine interval relatively barren of ichnofossils (i.e., subintervals

IE.2 - IE.8).

Rhizocorallium - Thalassinoides assemblage zone (subintervals IE.9 & IE.10): This trace fossil assemblage zone is mainly confined to the uppermost part of the Middle Newport Member and terminates at the contact of this member with Upper Newport Member (Text-Figs. 4.1 & 4.3). The assemblage is especially defined by two distinct ichnogenera, Rhizocorallium and Thalassinoides, the latter with several types of turn-arounds. The new ichnotaxon Barrenjoeichnus mitchelli is also present within this assemblage zone in silty sandstone (Text-Fig. 4.1). The assemblage zone is mainly confined to the northern part of the study area where the Middle and Upper Newport Members are exposed (Enclosure III.1). The best exposure is at South Palm Beach from where the assemblage zone extends south to Careel Head (area 9) and Little Head (area 7). As previously documented in Chapter 7 this assemblage zone contains several varieties of Rhizocorallium, including forms produced both by suspension-feeders (R.jenense) and deposit-feeders (R. bifurcatum and R. uliarense). The new ichnospecies Spongeliomorpha kalia, which also occurs in this assemblage zone, probably manifests the deposit-feeding activities of a crustacean which evidently lived in close association with the producer of Rhizocorallium. This trace fossil assemblage can be interpreted as belonging to the Skolithos ichnofacies (Appendix I.8). The assemblage zone is extensively bioturbated, especially in the massive sandstone units which alternate between greenish-grey siltstone which is burrowed by the new ichnogenus Barrenjoeichnus. As previously mentioned in Chapter 7, preomission, omission, and postomission surfaces occur within this assemblages zone, and their environmental significance is explained in Text-Fig. 7.13. It is likely that the environmental affinity of this ichnofaunal assemblage is similar to the other taxonomically diverse assemblages already described: that is, that it manifests a brackish shellow-marine protected setting such as a coastal lagoon or estuary. This assemblage zone comprises lithofacies FD and FE (cf. Text-Fig. 3.6). These lithofacies comprise fine to very fine parallel-laminated, sandstone in moderately thin beds which are interbedded with grey silty units containing steeply-inclined branched and unbranched burrows of Barrenjoeichnus and unbranched cylindrical burrows of Skolithos. The assemblage zone is followed stratigraphically by fluvial deposits of lithofacies FA of the Upper Newport Member.

Subintervals IF1 and IF2: These subintervals comprise the Upper Newport Member, the mudrock lithofacies of which (i.e., lithofacies FE & FG) are commonly dominated by a single ichnotaxon, Barrenjoeichnus mitchelli (Text-Fig. 4.1; Plates 55-57; Plate 80, Figs. a & b). Inasmuch as no other trace fossils occur in associated with Barrenjoeichnus mitchelli in these subunits (in contrast to the situation in the underlying Rhizocorallium - Thalassinoides assemblage zone), and because the marine/non-marine environmental affinities of B. mitchelli remain unclear, these subintervals have not been elevated into a named assemblage zone as in the case of underlying units. Although the ichnofacies affinity of this monotypic trace fossil assemblage is presently unclear, it is tentatively assigned to the Skolithos ichnofacies (Appendix I.8).

__Interval IG__: This comprises the Middle Triassic Hawkesbury Sandstone which is dominated by thick sandstone lithosomes (cf. Conaghan & Jones, 1975; Conaghan, 1980), called lithofacies FA.1 and FA.2 herein (cf. Text-Fig. 3.6, Appendix II.6). Mudrock units ranging from a few centimetres to a maximum recorded thickness of 35m occur sporadically within this formation but are relatively rare. The only trace fossil presently described from the Hawkesbury Sandstone is __Brookvalichnus obliquus__ Webby (1970) from the Beacon Hill quarry at Brookvale (area 26; Enclosure III.2d; Plate 72, Figs. c & d). This trace fossil has been redescribed here from the same locality for completeness but neither this nor any other kinds of trace fossils were found in the Hawkesbury sandstone at other localities within the study area. However, amphibian trackways, probably produced by __Paracyclotosaurus davidi__ Watson (1958) have been described from the depositional surface of crossbed-set foresets (Fletcher 1948; Sherwin, 1969) in the Hawkesbury sandstone from the Sydney metropolitan area. All lines of evidence from the Hawkesbury sandstone, including its body fossils, indicate its environmental affinities are non-marine and were fluvio-lacustrine (Conaghan & Jones, 1975; Conaghan, 1980). Trace fossils in the Hawkesbury Sandstone can be regarded as belonging to the __Scoyenia__ ichnofacies (Appendix I.8).

Other trace fossil assemblage zones of non-marine affinity (subintervals IC4 & 5, ID3 & 4, IE2 - 8): These unnamed assemblage zones contain fewer trace fossils both in number and in kind compared to the various assemblage zones of inferred marine affinity. Among the more common ichnotaxa that occur in one or more of these subintervals are: __Barrenjoeichnus mitchelli__, __Pyti-__

niichnus trifurcatum, Skolithos spp., Planolites spp., Palaeophycus spp., Thalassinoides sp., Phycodes bischoffi, vertebrate trackways, ring-structures and pellets, as well as various root-penetration and root-petrification structures (cf. Text-Fig. 5.1). These trace fossil assemblages can be tentatively assigned to the Scoyenia and Teredolites ichnofacies (Appendix 1.8).

CHAPTER 19

INTERPRETATION OF THE PALAEOENVIRONMENTAL AFFINITIES OF THE TRACE FOSSIL ZONES AND DEPOSITIONAL SETTING OF THE STUDY AREA

INTERPRETATION OF THE PALAEOENVIRONMENTAL AFFINITIES OF THE TRACE FOSSIL ZONES AND DEPOSITIONAL SETTING OF THE STUDY AREA

19.1. INTRODUCTION

Interpretation of the palaeoenvironmental affinities of the various trace fossil zones is based on the palaeoecological constraints provided by the mostly palaeoenvironmentally equivocal, and with the exception of the abundant plant fossils, mostly rare body fossils, but in particular on the palaeoecological constraints provided by the trace fossils themselves. The general overall spectrum of non-marine (i.e., terrestrial, both aquatic and non-aquatic), brackish-marine, shallow-marine, and deep-marine environments is tabulated in Table 5.1. This spectrum of depositional environments is based on and related to the environmental distribution of different trace fossils and particular trace fossil assemblages shown in Text-Fig. 5.1 and the recurring ichnofacies illustrated in Text-Fig. 3.5.

19.2. ENVIRONMENTAL AND ICHNOFACIES CLASSIFICATIONS

All major depositional environments and subenvironments are tabulated in the classification of Appendix II.7. The definition of individual subenvironments is given in Chapter 5. The spectrum of environments described in this classification covers all habitats from terrestrial ones to very deep-marine ones. On the basis of the trace fossils encountered in the present study and the known distribution of body fossils in these strata, the environmental spectrum represented in these strata includes non-aquatic terrestrial habitats (manifested by palaeosols), fluvial environments, and brackish to shallow-marine environments. No trace fossils or body fossils of deeper-marine affinity are recorded from the study area.

The trace fossil distribution illustrated in Text-Fig. 5.1 shows the typical fluvial-dominated shallow brackish-marine environments with palaeosol development in adjacent terrestrial non-aquatic areas. Trace fossils characteristic of the offshore zone (beyond the offshore shelf) and deeper-marine parts of the environmental spectrum are not represented in the study area. The ichnotaxonomic composition of several of the trace fossil assemblages (discussed in Chapter 18) is consistent with a brackish- to shallow-marine origin representative in general of the Skolithos ichnofacies (cf. Text-Figs. 3.5 & 5.1; Appendix I.8). Some strata in the uppermost Narrabeen Group succession, exemplified by trace fossil interval IC in the Bald Hill Claystone at Long Reef Point (area 3) consist of palaeosols with vertebrate burrows (Pytiniichnus trifurcatum), plant roots and rootlets and other plant remains, and evidently indicate an essentially terrestrial non-aquatic habitat representative of the Scoyenia and Teredolites ichnofacies (cf. Text-Figs. 5.3 & 5.1; Appendix I.8). The bathymetric distribution of many of the trace fossils shown in Text-Fig. 5.1 extends beyond the offshore shelf into deeper-marine habitats because such distributions are based on previous records of the environmental ranges of the particular trace fossils. This deeper-water range of occurrence of such trace fossils is shown by dotted lines in that figure (e.g., Planolites, Palaeophycus and Skolithos). In Text-Fig. 5.1 the interpreted environmental ranges of particular trace fossils in rocks of the study area are shown by solid lines, as distinct from their environmental ranges known from elsewhere and which are shown by the dotted lines as described above. The overall interpretation of the palaeoenvironmental affinities of the study area indicates an origin involving a fluvially-dominated coastal plain that was subject to intermittent inundation by brackish to shallow-marine water which converted the area into a coastal lagoon or estuary (Text-Fig. 5.2). Detailed study of the population density of the ichnogenus Ophiomorpha and depth/width ratio data of the ichnogenus Diplocraterion (Text-Fig. 9.6) together with burrow-width versus bed-thickness data for the latter ichnotaxon (Text-Fig. 7.10) also support an interpretation of a protected very shallow-marine environment. The non-biogenic sedimentary structures (e.g., ripple-marks and cross-stratification; cf. Plates 40-44, Plate 69 Figs. g & h, Plate 77 Fig. a) associated with many of these trace fossils are consistent with such an interpretation.

19.3. INTERPRETATION OF THE MARINE-INFLUENCED EPISODES

According to the environmental distribution of trace fossils illustrated in Text-Fig. 5.1, the strata of the study area record a fluvially-dominated (cf. Text-Fig. 5.2) brackish coastal lagoon or estuary, strata representing the terrestrial/fluvial habitats on the one hand and the brackish marine habitats on the other being intercalated cyclically (cf. Text-Fig. 5.3). The presence of these marine-influenced episodes against a background of non-marine sedimentation is manifested most dramatically by the alternating stratigraphic pattern of high-diversity and low-diversity/barren trace fossil zones in Text-Fig. 4.1. A synthesis of the stratigraphic and geographic distribution of this alternating pattern can be made by integrating the data in Text-Fig. 4.1 (i.e., stratigraphic distribution chart of the trace fossils) and in Text-Fig. 4.2 (i.e., geographic distribution chart of the trace fossils). The resulting distribution is shown in Text-Fig. 4.3. In this figure the trace fossil subintervals are located on the vertical axis according to their stratigraphic positions and the various subareas of the study area are located on the horizontal axis in their actual geographic order from north to south.

The figure summarizes both the stratigraphic and north-south geographic extent of the four shallow- to brackish-marine trace fossil assemblages that occur in the study area (see also Text-Fig. 5.3). The first marine-influenced episode involves the uppermost part of Bald Hill Claystone and extends throughout subintervals IC1 - IC4; the second marine-influenced episode involves the lowermost part of the Lower Newport Member (and Garie Formation where present) and is confined to subintervals ID1 and ID2; the third marine-influenced episode involves the uppermost part of the Lower Newport Member and the lower part of the Middle Newport Member and is confined to subintervals ID5, ID6 and IE1; the fourth and last marine-influenced episode involves the uppermost part of the Middle Newport Member and is confined to subintervals of IE9 and IE10.

The north-south geographic extent of each of these marine-influenced depositional episodes encompasses the preserved north-south limits of the exposed host strata in each case (cf.

Text-Fig. 4.3) and is of the order of at least 20 km (extrapolated to more than this in Text-Fig. 5.3). A type locality was chosen for each of these marine-influenced depositional eposides and they have been named accordingly as follows (cf. Text-Fig. 5.3):

(4) Palm Beach Tongue (Tr2n2p)

(3) Bangalley Head Tongue (Tr2n1-2b)

(2) St. Michaels Cave Tongue (Tr2n1s)

(1) Turimetta Head Tongue (Tr1bt)

19.3.1. Turimetta Head Tongue (subintervals IC1-IC4)

This marine tongue is best developed in the locality of Turimetta Head (area 2). The thickness of the tongue in the type area is about 2 m to 3 m and it extends laterally both to the north and south. The exposed thickness of this tongue at Long Reef Point (area 3) is less than elsewhere because it passes upwards there into palaeosol strata (Plate 81 Fig. b). The mudrock lithology of this tongue is very distinctive because of its purplish or reddish colour and commonly abundant pellets. The most predominant lithofacies present are FH and FI (cf. Text-Fig. 3.6 and Appendix II. 6; Plate 86 Figs. b, c & d. In ichnofaunal terms this marine tongue is characterized by the new ichnotaxa _Turimettichnus conaghani_ var. A, and _T. webbyi_, as well as _Ophiomorpha nodosa_ and _Thalassinoides_ (Text-Fig. 4.1).

This marine tongue passes upwards into subintervals IC4 and IC5 at Long Reef and into subinterval IC5 at Turimetta Head and at Little Reef (cf. Text-Fig. 5.3). These overlying subintervals contain distinctive palaeosols at Long Reef

Point (Retallack, 1977a, b) but less certainly so at the other latter two localities (cf. Retallack, 1977b, Fig. 9). Subinterval IC5 contains sporadic Ophiomorpha nodosa, Thalassinoides, pellets, Planolites, rootlet zones and vertebrate trackways, suggestive of an aquatic, perhaps marginal or non-marine situation; but subinterval IC4 also contains the amphibian/reptilian burrow Pytiniichnus trifurcatum within palaeosol strata indicating a habitat of more prolonged emergence.

Inasmuch as subintervals IC4 and IC5 separate the Turimetta Head and St. Michaels Cave marine tongues, it is possible that, given the limited and sporadic geographic extent of exposure of subinterval IC5 (i.e., Long Reef Point in the south to Bilgola Head in the north, a distance of about 11 kms), that the exposed sediments of this subinterval may have accumulated in a complex of ephemeral low-lying islands and associated semi-aquatic environments during a continuation of brackish-marine conditions in surrounding areas. Should this have been the case, then there may well have been a more-or-less continued presence of the "Newport Lagoon" (cf. Text-Fig. 5.2) in the Northshore region throughout the period of accumulation of this subinterval; in other words, that only one marine-influenced episode is manifested by what are here regarded and named as two separate marine tonues. However, there is a conspicuous contrast in the ichnofaunas present in each of these two marine tongues (cf. Text-Fig. 4.1), suggesting that they may well manifest discrete events.

19.3.2 St. Michaels Cave Tongue (subintervals ID1 and ID2)

This marine tongue is best known at the locality of St. Michaels Cave (area 5). Its thickness there is about 3 m to 4 m and it extends laterally both to adjacent subareas on the north and the south. But the tongue itself seems to thin out laterally from the St. Michaels Cave area in both directions. The main lithologies comprising this tongue are conspicuously well-bedded grey to greenish-grey fine and very fine sandstones (i.e., lithofacies FD and FE cf. Text-Fig. 3.6 and Appendix II.6; see also Plate 69 Figs. o & p, Plate 84 Fig. c). Ichnotaxonomically, the tongue is defined by the trace fossils Skolithos, Rhizocorallium, the small reptilian trackway Moodieichnus, and Turimettichnus conaghani var. C (Text-Fig. 4.1). The tongue is overlain by sediments of subintervals ID3 and ID4 which are either rarely populated or are barren of trace fossils (Text-Fig. 4.1) and the few types that do occur constitute a non-marine assemblage.

19.3.3. Bangalley Head Tongue (subintervals ID5, ID6 & IE1)

This marine tongue is best known at the localities of Bangalley Head (area 8), St. MIchaels Cave (area 5), and Mona Vale Head (area 13) (Text-Fig. 5.3). The thickness of the tongue as exposed in the type area (Bangalley Head) is about 2 m to 3 m. The tongue thins out laterally toward the south (in Mona Vale Head). The main lithology comprising this tongue is conspicuously bedded purplish to purplish-grey sandstone containing darker coloured silt or clay laminae (i.e., mainly lithofacies FD and FE; Plate 78 Fig. e). The tongue is not exposed beyond Bangalley Head to the north. The tongue is especially well defined by the trace fossils Helikospirichnus, Chondrites (branching feeding-burrows), Colichnites (sinuous bedding-parallel traces), escape-structures/collapse-structures, and many bedding-parallel traces of Planolites, Palaeophycus, Scalarituba, and scribbling grazing-traces (Text-Fig. 4.1). The tongue is overlain by non-marine fluvial sediments comprising subintervals IE2-IE8 which are either barren or contain rare trace fossils of non-marine affinity (Text-Figs. 4.1 & 5.3).

19.3.4. Palm Beach Tongue (subintervals IE9 & IE10)

This marine tongue is best known at the localities of South Palm Beach (area 4b), Little Head (area 4) and Careel Head (area 5) (Text-Fig. 5.3), that is, only in the northern part of the study area. The thickness of the tongue at the type area (South Palm Beach) is about 2 m to 3 m thick. This thickness seems to be uniform throughout the area of outcrop but laterally there is a decrease in both the abundance and diversity of the contained ichnofauna towards the southern locations (i.e., Little Head and Careel Head; Text-Fig. 4.2). The main lithology comprising this tongue is strongly laminated medium- to thin-bedded, grey, fine to very fine sandstone (lithofacies FD & FF) interbedded with greenish-grey siltstone (lithofacies FG) containing abundant burrows of the new ichnotaxon Barrenjoeichnus mitchelli. The ichnofossils that characterize this tongue are: the bedding-parallel U-shaped burrow Rhizocorallium, Spongeliomorpha, and Thalassinoides, with and without turn-arounds. The tongue exhibits several small-scale depositional episodes as manifested by the colonisation history of these trace fossils (Text-Fig. 7.13). The tongue is overlain by subintervals IF1 and IF2 comprising fluvial deposits with palaeosols and subvertical/vertical shafts of Barrenjoeichnus mitchelli, best exposed in the adjacent Barrenjoey Head (area 1) to the north (Text-Figs. 4.3 & 5.3).

19.4. DEPOSITIONAL SETTING OF THE STUDY AREA

The four marine tongues defined by the above-described four ichnotaxonomically diverse trace fossil assemblages are consistent with the notion of shallow-marine influence within the uppermost Narrabeen Group as earlier suggested by Bunny & Herbert (1971) and Retallack (1977a, b & c), and as reconstructed palaeogeographically here in terms of the recurrent presence of a protected brackish shallow-marine coastal lagoon or estuary (Text-Fig. 5.2; see also Text-Fig. 1.11). Although there is presently little subsurface information concerning the inland extent of these marine tongues, a speculative and schematic cross-section of the central-eastern part of the basin is shown in Text-Fig. 5.4 to illustrate their possible extent and their stratigraphic relationships to the enclosing strata.

As earlier also envisaged by Retallack (1977a & c) the reconstructed coastal lagoon or estuary was evidently barred by a protecting barrier system of some kind in the east and/or southeast of the study area, and in the east this barrier evidently took the form of an upland ridge of mafic Upper Permian volcanic rocks, the "Gerringong Volcanic Ridge" of Ward (1972, 1980). Retallack (1977b; cf. Text-Fig. 1.11 herein) and Herbert (1980a, figs. 2.20 & 2.21). As earlier explained in Chapter 1, these and earlier workers (in particular Loughnan, 1963, and

Loughnan et al., 1964) interpreted the rather unique kaolinite- and haematite-rich and quartz-deficient mineralogy of the Bald Hill Claystone in terms of its sediments having been shed westwards from this ridge after its rocks had been deeply weathered and lateritized. In terms of Jones et al's (1984, 1987) reconstruction of the eastern Sydney Basin, this Geringong Volcanic Ridge constituted a remnant part of the presently offshore sector of the New England Fold Belt (cf. Jones et al. 1984, fig. 162; 1987, figs. 1A & 5; see also Text-Fig. 1.12 herein) that trended in a southerly direction approximately parallel to the present coastline. Whether a subsidiary barrier of constructional sedimentary origin also existed offshore the line of the present coastline, either to the east on to the south/southeast is unclear, but is in any case depicted in the schematic reconstruction of Text-Fig. 5.2. However, the protecting physiographic influence of the Gerringong Volcanic Ridge on the east may well have precluded the constructional development of a linear sandy barrier ridge or bar to the east (i.e., unlike the scenario depicted in Text-Fig. 5.2). Equally unclear, in terms of the evidence available, is what the mechanism was for triggering each of the short-lived marine transgressions represented by the four marine tongues.