CHAPTER 2.

METHODOLOGY

METHODOLOGY

2.1. GEOGRAPHIC DISTRIBUTION OF SUBAREAS WITHIN THE STUDY AREA

For reference purposes the area was subdivided into subareas which were numbered in chronological sequence (Appendix II.5). In general the place names numbered in this way as `areas' refer to prominent headlands and clifflines (Enclosures III.1 and III.2). Areas 1 to 26 (corresponding to the order in which the work progressed) occur on the 1:25,000 scale orthophotomaps `Broken Bay' (9130-I-N), `Mona Vale' (9130-I-S), and `Sydney Heads' (9130-II-N). Since the stratigraphic units containing the most diverse and abundant trace fossils occur in the central and northern parts of the Northshore, most of the work documented here relates to localities on the former two of the above orthophotomaps. Documentation of the geographic distribution of the various ichnotaxa also utilized this area-number-system or convention (Appendix I.3). For convenience, 100 field sample numbers were allocated to each of these areas (Appendix II.2)

2.2. FIELD LOGGING AND SAMPLING TECHNIQUES

At most localities of ichnological interest a detailed stratigraphic and sedimentological/ichnological log was measured at a scale of 1 to 10 in most cases (and larger in some) using various techniques and aids, including a jacob staff and abney level, metric tape, brunton compass (corrected for local magnetic declination 11.5°), strike and dip indicator (`dip frisbee') (cf. Text-Fig. 8.4), grain-size comparator, colour comparison chart, and a 1-metre-square metal-and-cord grid-frame (for population density studies etc.; Plate 69 Figs. m & n). Each log was entered onto an A3-sized logging data-sheet prepared especially for this project (Appendix I.1). A total of 27 such logs were measured in all within the Bald Hill Claystone and Newport Formation interval from Long Reef in the south to Barrenjoey Head in the north (as shown in Text-Fig. 1.2 and Enclosures III.1 & III.2). These detailed logs are called "sections" herein and are numbered using a code which differentiates them in terms of area number, locality number, and log number (cf. Appendixes II.2 & II.4), and are reproduced here at a scale of 1 to 10 (larger in some cases) as Enclosure III.4. These sections are supplemented by reproductions of Cowan's (1985) detailed sedimentological and stratigraphically more comprehensive logs (scale = 1:100) measured both at or in the vicinity of my own logs and in some areas where I have not measured a log myself. Details of the location of Cowan's logs are given in Enclosure III.2 and the logs themselves are reproduced here (with additional ichnological annotation) as Enclosures III.3.2 to III.3.23.

The format of the logging data-sheet (Appendix I.1) allowed for the separate recording of 10 different ichnotaxa in terms of their stratigraphic distribution as well as assessment of the percentage of bioturbation present at each stratigraphic level. Wherever possible, both colour slide and black-and-white photographs were taken of the trace fossils and other relevant sedimentological features and the stratigraphic and geographic locations of the photographs were recorded in a field notebook. The collection of representative samples or specimens of the various trace fossils was difficult and even impossible in many cases because of the large size of the rock sample that needed to be removed, the difficulty of extracting such samples from either solid outcrop or large loose slabs and blocks, and difficulties imposed by the coastal cliffline terrain, sea conditions and the distances over which the material had to be manually transported. The relatively short stratigraphic range and distinctive characteristics of the individual ichnotaxons or suites of ichnotaxa, in combination with distinctive lithological, sedimentological and macro-phytopalaeontological characteristics of the host sediment readily allowed the stratigraphic relocation and younging-direction of abundant large loose blocks of rock at the base of the cliffline in all localities, and hence permitted collection of trace fossil material from such loose blocks and slabs. However, in some cases a portable masonry saw, and/or sledge hammer and chisels were used to extract particular trace fossil specimens from solid outcrop or from large loose slabs or blocks.

A batch of 100 field sample numbers were allocated to each numbered field subarea as detailed in Appendixes II.2 and II.3, and the samples were numbered accordingly with these field numbers as the work progressed (Appendix I.3).

Special field-measuring and mapping techniques were necessary in documenting statistical and spatial distribution aspects of certain ichnotaxa. Such exercises involved population-density/spatial-distribution studies of some ichnogenera and the preferred orientation of one other characterized by subvertical to steeply-inclined burrows (i.e., <u>Barrenjoeichnus mitchelli</u> ichno. gen. sp. nov.). Dip angles and trend angles were measured on these burrows and plotted on a Schmidt-net for preferred orientation studies. These specialized techniques are described separately in various sections dealing with those particular ichnogenera.

Population-density studies were undertaking using two different methods (distance-to-nearest-neighbor and count-per-unit-square methods). These methods can only be applied to vertical cylindrical burrows (e.g., Skolithos in Chapter 8) and vertical U-shaped burrows (e.g., Diplocraterion in Chapter 7). Their application to population-density studies of branching vertical/ sub-vertical cylindrical burrows such as Barrenjoeichnus mitchelli and Ophiomorpha and Thalassinoides is limited. The population density of Ophiomorpha was studied by count-per-square metre, assuming one opening per burrow (counted as one dwelling for one animal) even though they are branched. The population densities of other horizontal or inclined burrows are described only semi-quantitatively (see Text-Fig. 3.7 and Appendix II.1d). Stratigraphic and geographic distribution charts of the various different ichnotaxa together with their semi-quantitatively-defined relative frequency are given respectively in Text-Figs. 4.1 & 4.2.

The depth of the burrows is in general inversely related with the water depth (cf. Text-Fig. 3.5): the deeper burrows occupied shallow-water areas and shallow burrows or traces characterize deeper-water areas. This relationship is tested in the case of the U-shaped spreite-bearing burrow Diplocraterion in Chapter 7. The width (length of limb) of U-shaped burrows is inversely related to the burrow depth (Legg, 1985, p.162 - 164), which in turn allows the burrow width to be used as an index of water depth. The width of the U-shaped diplocrateriid burrows were studied to this end.

The burrows of *Helikospirichnus veeversi* ichno. gen. sp. nov. have a regular pattern of radial arms arranged in helicoidal clockwise orientation. Angular measurement of these radial arms (in Chapter 13) is an important additional quantitative study and which may allow better understanding of similar rosette-shaped burrows. This burrow was previously assigned to *Subglockeria* by previous workers (e.g., Retallack, 1976, p.16, fig.15).

A one-metre-square grid made of metal and cord (Plate 69 Figs. m & n) was used for both spatial and angular measurements of the running-gait trackway of the small reptile *Moodieichnus* (Chapter 15; and are plotted in Text-Fig. 15.7).

Angular (angles of asymptotes) and distance measurements (wave length) were taken in wavy horizontal burrows classified as a new ichnogenus, *Colichnites howardi* (Chapter 17).

2.3. LABORATORY PROCEDURES

Routine laboratory procedures were employed in studying the trace fossils. In some cases studio photographs were taken to supplement or improve those taken in the field or to provide photographs of specimens not already photographed in the field. In some cases black-and-white prints had to be made from colour transparencies because the unavailability of adequate photographic equipment during some of the fieldwork precluded the field documentation of many specimens in both colour and black-and-white. All photographs, both colour and black-and-white, were systematically filed according to locality, date, film number, and ichnotaxon. In all, approximately 1200 colour photographs and approximately 1000 black-and-white photographs were taken. Overlay drawings and sketches were made of most of the studied samples from the detailed (close-up) photographs. This exercise was also helped by the use of a high-powered binocular-microscope and these overlay drawings and interpretative sketches enhanced understanding of the animal's behaviour.

A large-format (23.5 cm x 14.5 cm) "sorter" card index file (Appendix I.2) was set up at the beginning of the project to provide a ready reference for all known ichnogenera based on the 1975 edition of the trace fossil and problematica volume of the Treatise of Invertebrate Paleontology (Part W, Hantzschel, 1975) and subsequent literature. This card-file was indexed on the basis of eight separate category systems including taxonomy, ethology, ichnofacies affinity, etc. (cf. Appendix I.2)

Other routine documentation of the trace fossils in the laboratory involved measurement of their various dimensions and preparing sketches and drawings. Linear measurements (not exceeding 15 cm) were made using a pair of Helix slide-clipper calipers. Measurements outside this range were made with a metal metric tape. Angular measurements on the trace fossils were made with a Helix circular protractor. Detailed study of fine-scaled features etc. was done using a maggy-lamp and/or a binocular-microscope. Drawings of trace fossil patterns were made wherever possible on a sheet of drawing plastic overlain onto a photograph of the trace fossil or trace fossil pattern. some samples/specimens were slabbed on the diamond saw to facilitate study of their internal structures.

2.4. SAMPLE CURATION AND REPOSITORY

All samples are held in the collections of the School of Earth Sciences at Macquarie University.

Once the samples were retrieved from the field to the University they were given a Macquarie University (MU.) serial catalog number as detailed in Appendixes I.3 and II.3. These appendixes also provide a cross-index of both the field numbers and the MU. catalog numbers. In the case where a sample has been broken or sawn into more than one piece, all pieces were given a single catalog number with subscripts \`a', \`b' and \`c', etc. Entry of each sample or specimen into the School of Earth Sciences collections involves the completion of relevant geographic and stratigraphic location information, and other data onto a catalog sheet bearing the unique catalog number of the specimens (cf. Appendixes I.3 & II.3).

Throughout this report individual specimens or samples will be referred to by specifying the field number and the MU. catalog number separated by a slash, thus: 306/MU.44367.

CHAPTER 3.

CLASSIFICATION OF ICHNOFACIES AND LITHOFACIES AS USED IN THE PRESENT STUDY

CLASSIFICATION OF ICHNOFACIES AND LITHOFACIES AS USED IN THE PRESENT STUDY

3.1. PREAMBLE

The definitions and classifications of trace fossils (biogenic sedimentary structures) and related problematica follow those of Hantzschel (1975), Frey & Seilacher (1980) and Frey & Pemberton (1984). These definitions as they apply to the `main-stream' varieties of trace fossils are summarized in Text-Figs. 3.1 and 3.2, and Table 3.1. The classification and nomenclature of trace fossil preservational aspect or mode follows that of Seilacher (1964), Webby (1969) and Hallam (1975) (cf. Text-Fig. 3.3) and that of toponomic aspect follows Martinsson (1970; cf. Text-Fig. 3.4 herein).

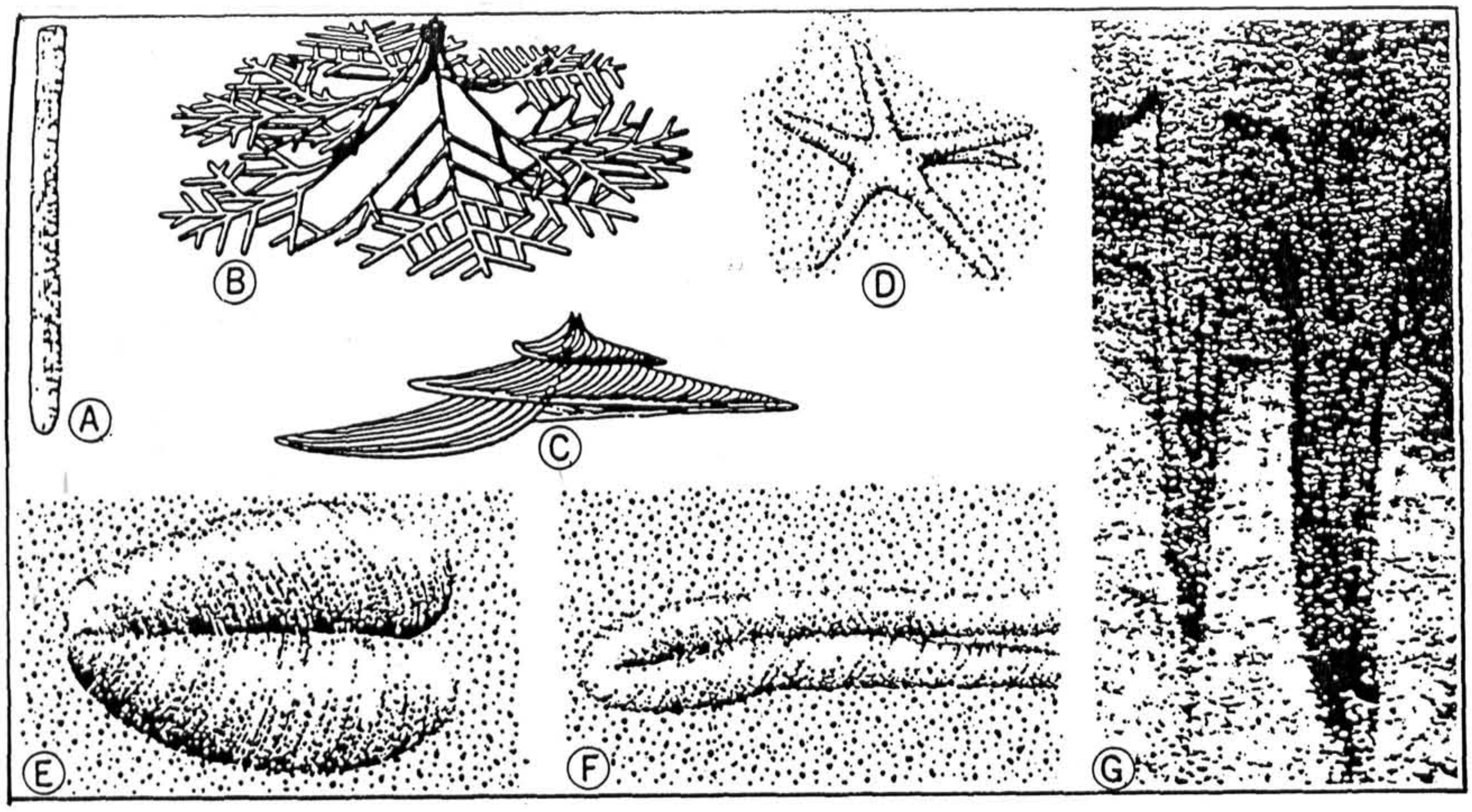
3.2. ICHNOFACIES DEFINITION AND CLASSIFICATION

The concept of and term "ichnofacies" was first introduced by Seilacher (1964) and is here defined as distinctive assemblages or suites of trace fossils that recur both geographically and throughout time as a function of biological response to recurrent environmental conditions. For example, as emphasized by Frey & Pemberton (1984, p.192): " Under equivalent climate, hydrogeographic, and sedimentologic regimes, for example, shoreface ichnofacies and ichnofacies everywhere exhibit a certain sameness, whether modern or ancient." Since Seilacher (1964) introduced this concept a general scheme of ichnofacies classification has evolved covering the whole spectrum of terrestrial through brackish-shoreline-marine, shallow-marine to deep-marine environments (Text-Fig. 3.5, Table 3.1). The ichnofacies

TEXT-FIG. 3.1. Major categories of behaviour represented by trace fossils.

- **A.** Dwelling-structure Skolithos, a vertical shaft.
- **B.** Feeding-structure Chondrites, a record of repeated, systematic probes within the substrate.
- **C.** Grazing-trace Zoophycos, a spiral spreite-bearing structure reflecting systematic mining of sediment.
- **D.** Resting-trace Asteriacites, a rosette-shaped resting-trace; the bifurcation of one arm indicates animal movement.
- **E.** Resting-trace Rusophycus, characterized by two lobes corresponding to inward movements by two rows of arthropod legs.
- **F.** Crawling-trace Cruziana, intergradational with Rusophycus.
- **G.** Escape-structures of anemone-like animal consisting of nested, funnel-like laminae.

(Adapted from Frey & Seilacher, 1980).



(1) **DOMICHNIA (dwelling-structures)** (e.g., Fig. Ⓐ Skolithos)

More or less permanent domiciles are made mainly by endobenthic suspension feeders and certain predators and scavengers. Dwelling structures may aproach the size of the tracemaker - a virtual external mold, as with most pholad borers - or they may consists of tubes, simple shaft (Fig. A), or an integrated system of shafts and tunnels. Because of their relative permanence, burrow walls ordinarily are enforced by coats of mucus, agglutinated sediment (including muddy pellets daubed into the walls) or organic tubes of varied composition, all constituting distinctive burrow linings. These wall characteristics help distinguish dwelling structures from feeding structures. Most such domiciles are passively filled with sediment after the demise of the animal.

(2) **FODINICHNIA (feeding-structures)** (e.g., Fig. Ⓑ Chondrites)

Unlike the "strip mining" plan of most grazing traces, feeding structures typically represent extensive subsurface foragings by deposit-feeding organisms. Elaborate, three-dimensional patterns often result (Fig. B). Most are produced by endobenthic animals, although a few epibenthic may feed inside the sediment by means of an extensible proboscis or equavalent organ. Endobenthos both feed and dwell within the excavation, yet feeding activities are the main raison d'ēre. Nevertheless, certain types of feeding probes are later converted to permanent domiciles or some deposit feeders simultaneously pass fine sediemnt through their gut and coarser sediment around their body, producing meniscate backfills or other fills may be structureless (Frey & Seilacher, 1980).

(3) **PASICHNIA (grazing-traces)** (e.g., Fig. Ⓒ Zoophycos)

Grazing behaviour, although exhibited by both epibenthic and endobenthic organisms, tends to be most advantageous in exploiting surficial or relatively shaoolw subsurface sediemnts. The organisms are deposit feeders. Most grazing traces are compact, more or less planar structures, and they record efficient utilization of feeding space (Fig. C). Typical patterns include coiled or looped meanders, finely dichotomous branches, and closely repetitive or radial traces. Most individual feeding probes avoid contact with previously made probes, the older ones already having been mined and depleted of nutrients. In addition to sediemntary grazing traces, algal grazers such as chitons and limpets rasp hard surface along rocky coast, leaving telltale scrapings or sculpting as records of their activity.

(4) **CUBICHNIA (resting-traces)** (e.g., Figs. Ⓓ Asteriacites, and E. Rusophycus)

These biogenic structures are formed primarily by mobile epibenthic or endobenthic organisms, although nektobenthic animals may be involved. Most resting traces are made by animals trying to avoid detection by intruders, concealing themselves from their prey, or undergoing a period of inactivity. The trace may record various secondary movements, or may intergrade with crawling traces (Figs. E & F). In many cases the ventral morphology of the tracemaker is recorded in considerable detail (Fig. D). With rapid substrate aggradation, the trace may be repeated vertically; such traces are transitional with escape-structures.

(5) **REPICHNIA (Crawling-traces)** (e.g., Fig. Ⓕ Cruziana)

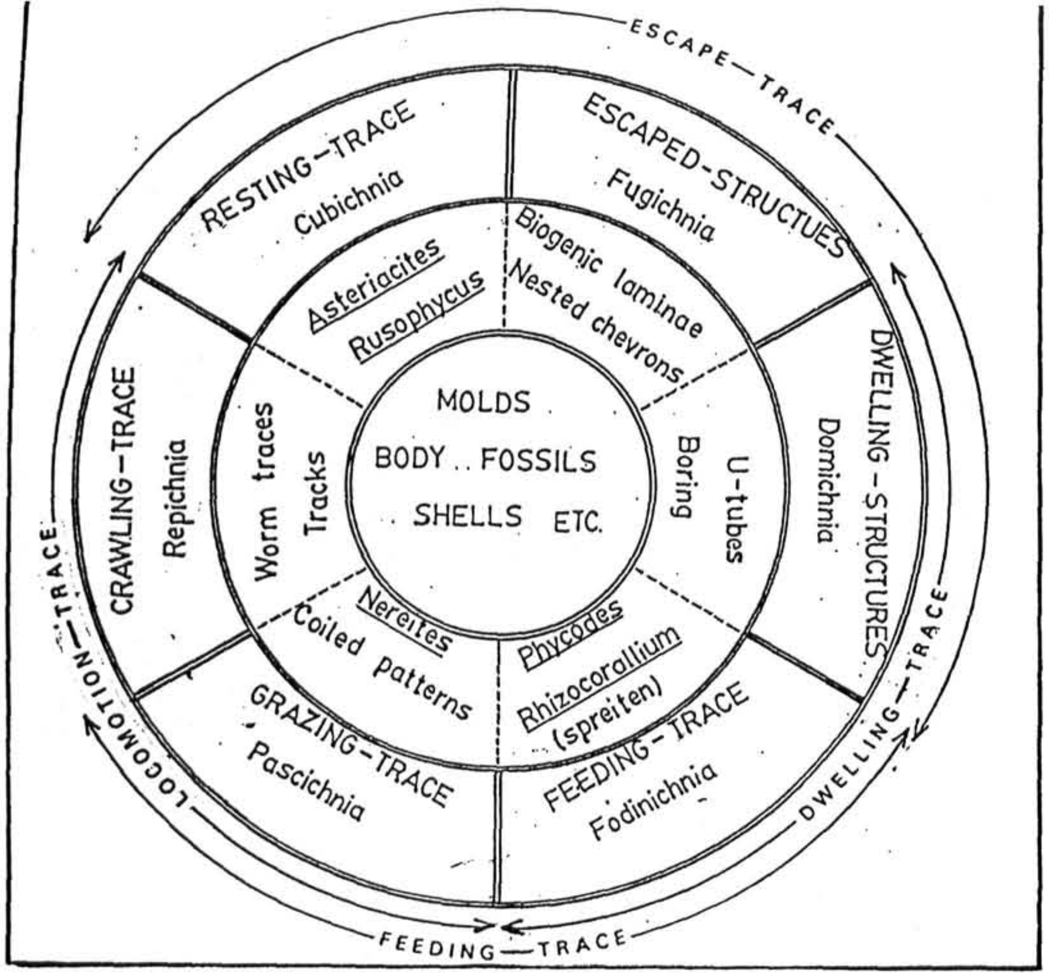
Such traces, made both upon and within the substrate, are direct record of locomotion. Travel by the animals may involve flight from intruders, forays in search of food, actual food gathering, or such miscellaneous activities as migrating or rutting. Many subsurface crawling traces follow interfaces between sedimentary layers; on the outcrop, these might be difficult to distinguish from surficial crawling traces. The traces ranges in fabrication from simple or ornamented, continuous grooves and ridges (Fig. F) to trackways consisting of individual podial imprints. In general, both crawling and resting traces are better preserved as sole cast on the overlying bed than as surficial features on the host bed.

(6) **FUGICHNIA (Escape-structures)** (e.g., Fig. Ⓖ Adiaichnus)

Such traces ordinarily are made by organisms that dwell at specific depths within the substrate; they therefore must attempt to maintain constant spatial relationship ith respect to the substrate surface, despite episodic intervals of deposition or erosion. Among vertical burrows, a common record of upward migration of nested, funnel-like laminae (Fig. G). Many escape structures are precise indicators of substrate aggradation or degradation. However, escape structures must not confused with certain type of physical collapse-features (Frey et al., 1978, figs. 7e & 9). Even escape-structures represent modification of pre-exiting structures they are absolute regards as different ethological phenonmenon and must be considered differently, from the pre-existing structures.

TEXT-FIG. 3.1.

TEXT-FIG. 3.2. Ethological classification of trace fossils with representative characteristic morphology and some examples from the study area. (Diagram is partly adapted from Frey & Seilacher, 1980.)

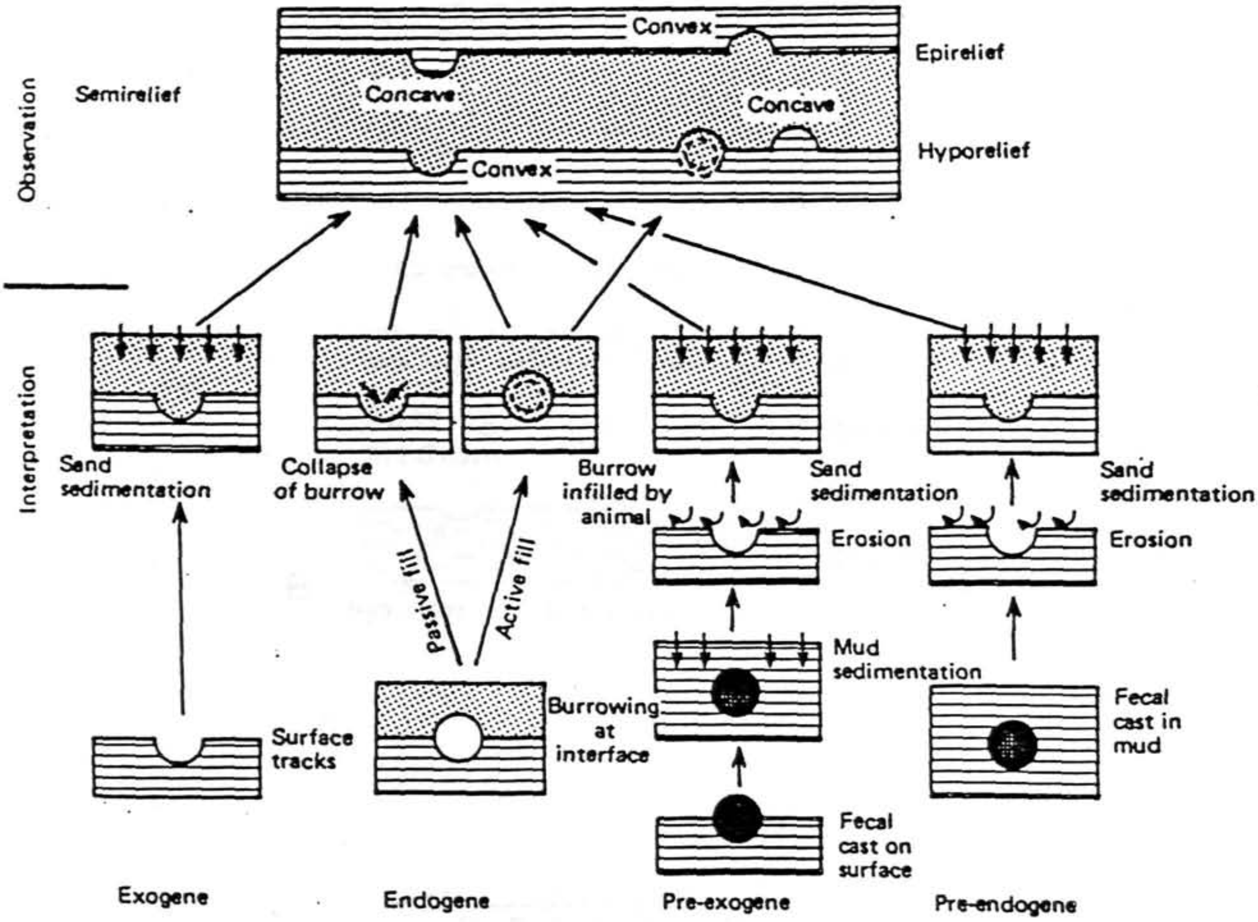


ETHOLOGICAL CLASSIFICATION	DEFINITION OF BEHAVIOUR	CHARACTERISTIC MORPHOLGY	SOME EXAMPLES FROM THE STUDY AREA
(1) DOMICHNIA (Dwelling-structures)	Burrows, borings, or dwelling tubes providing more or less permanent domiciles, mostly for hemisessiles suspension feeders or, in some cases, carnivores. Emphasis is on habitation. Second ary activities may be discernible.	Simple, bifurcated or U-shaped structures perpendicular or inclined at various angles to bedding, or branched burrow or boring systems having vertical and horizontal components; burrow walls typically lined. Complete form may be preserved	Diplocraterion Ophiomorpha Pytiniichnus Turimettichnus
(2) FODINICHNIA (Feeding-structures)	More or less temporary burrows constructed by deposit feeders; the structures also may provide shelter for the organisms. Emphasis is on feeding behaviour analogous to 'underground mining'. some tend to be gradational with dwelling structures.	Single, branched or unbranched, cylindrical to sinuous shafts or U-shaped burrows, or complex, parallel to concentric burrow repetitions (spreiten structures); walls not commonly lined, unless by mucus. oriented at various angles with respect to bedding; complete from may be preserved.	Chondrites Helikospirichnus Phycodes
(3) PASICHNIA (Grazing-traces)	Grooves, patterned pits, and furrows, many of them discontinuous, made by mobile deposit feeders or algal grazers at or under the substrate surface. Emphasis is upon feeding behaviour analogous to 'strip mining'.	Branched or unbranched, nonoverlapping, curved to tightly coiled patterns or delicately constructured spreiten dominate; patterns generally reflect maximum utilization of food resources; complete form may be preserved. Over-all structure tends to be planar, locally may be trochospiral.	Rhizocorallium irregulare, R. uliarense
(4) CUBICHNIA (Resting-traces)	Shallow depression made by the animals that settle onto or dig into the substrate surface. Emphasis is on reclusion. May include shallow, ephemeral domiciles.	Trough-like relief, recording to some extent the lateroventral morphology of the animal; ideally, structures are isolated, but may intergrade with crawling-traces or escape-structures.	Asteriacites Pelecypodichnus Rusophycus
(5) REPICHNIA (Crawling-traces)	Trackways and epistratal trails made by organisms travelling from one place to another. Emphasis is upon locomotion. Secondary activities may be involved.	Linear or sinuous over-all structures, some branched; foot-prints or continuous grooves, commonly annulated; complete form may be preserved, or may appear as cleavage reliefs.	Colichnites Moodieichnus (vertebrate trackway)
(6) FUGICHNIA (Escape-structures)	Lebensspuren of various kinds modofied or made anew by animals in derect response to substrate degradation or aggradation. Emphasis is upon readjustment, or equilibrium between relative substrate position and the configuration of contained traces. intergradational with other behavioural catagories.	Vertically repetitive resting traces; biogenic laminae either en echelon or as nested funnel or chevrons; U-in-U spreiten burrows; and others structures reflecting displacement of animals upward or downward with respect to the original substrate surface. Complete form may be preserved, especially in aggraded substrates.	Adiaichnus Diplocraterion yoyo D. polyupsilon Hanniballichnus amplius

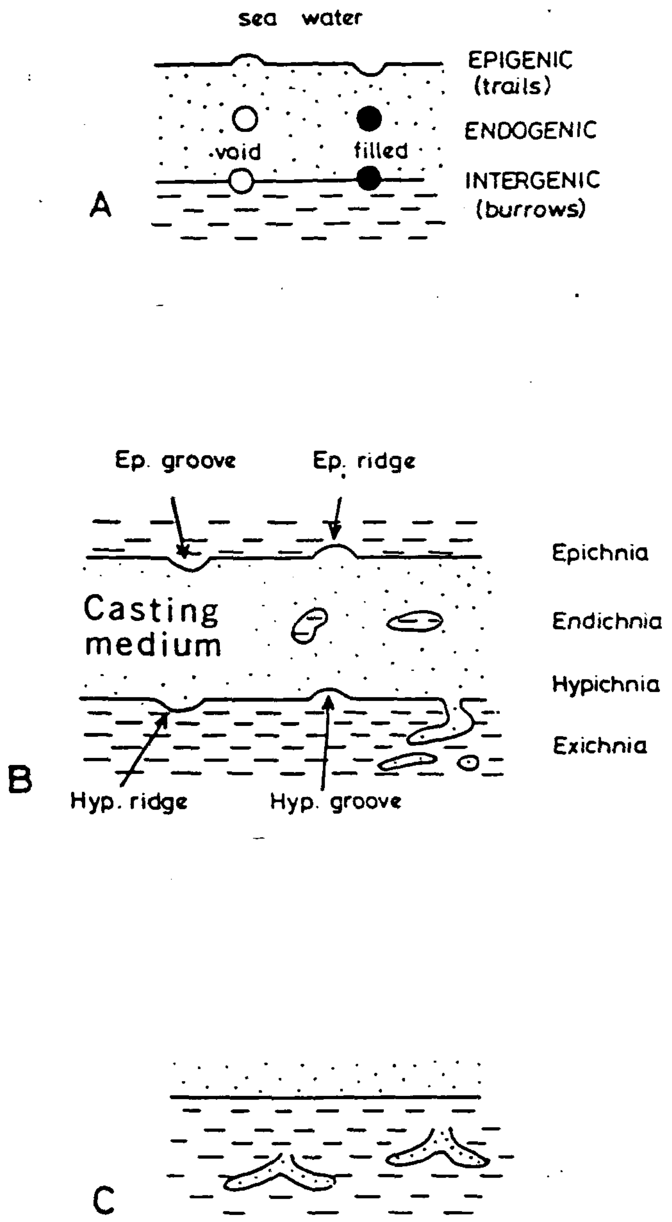
TEXT-FIG. 3.2.

classification detailed in Text-Fig. 3.5 and Table 3.1 contains two terrestrial ichnofacies (i.e., Scoyenia and Teredolites), three strandline ichnofacies (i.e., Trypanites, Glossifungites and Skolithos), one shallow-marine ichnofacies (i.e., Cruziana), and two deep-marine ichnofacies (i.e., Zoophycos and Nereites). With the exception of the terrestrial ichnofacies these facies are reproduced here without modification from Pemberton & Frey (1984, fig. 5 and table 2). The terrestrial ichnofacies however are modified from Pemberton & Frey inmuchas the Teredolites (or `woodground') ichnofacies is placed together with the Scoyenia ichnofacies rather than the Trypanites (hardgrounds) ichnofacies to emphasize the predominantly fully terrestrial origin of the wood substrate. This is done with the realization that drifted (and foundered) woodground substrate can occur anywhere throughout the whole spectrum of shoreline and marine environments, but the primary source of the wood is within the terrestrial environment. It is intended too that the Scoyenia and Teredolites ichnofacies should be applied separately as appropriate to any given situation. Of the spectrum of ichnofacies depicted in Text-Fig. 3.5 only the terrestrial, shoreline and shallow-marine ones apply to the Triassic strata of the study area because these strata lack any evidence of moderately-deep or deep-marine affinities, including trace and body fossil evidence (e.g. Packham, 1976; and Retallack 1976, 1977). More than 100 different ichnotaxa are presently known in these strata (Text-Fig. 4.1) and their environmental affinities range from terrestrial (fluvio-lacustrine) through protected brackish-shoreline possibly to shallow-marine and whose ichnofacies affinities are referable variously to Scoyenia, ?Teredolites, Glossifungites and Skolithos (Table 3.1). One of the Glossifungites ichnofacies developments in these rocks is particularly well-defined and noteworthy, especially because such firmground ichnofacies are rarely described outside of carbonate substrates. Some of the ichnotaxa in these strata are ichnofacies-independent (e.g., Helikospirichnus veeversi ichno. gen. sp. nov. (= rosette-shaped burrows), Phycodes, Asteriacites, and Rhizocorallium irregulare) and normally can be expected to occur in deeper-marine settings.

The trace fossils presently known from the study area **are** tabulated in Table 3.2, together with their **inferred** ethology (cf. Text-Figs. 3.1 & 3.2), trophic or feeding groups and probable producer(s). In general domichnia (dwelling) burrows are dominant in sandy substrates, fodinichnia (feeding), cubichnia (resting) and repichnia (crawling) traces are dominant in muddy substrates, and fugichnia (escape-burrows) are more dominant in mixed substrates (cf. Text-Figs. 3.1 & 3.2). In general,under the preservational classification full-relief forms (both endichnia or exichnia) are dominant in sandy substrates and half-relief (positive/negative and epi-/hypo-relief) forms are dominant in muddy substrates (cf. Text-Figs. 3.3 & 3.4). The distribution of the studed trace fossils relative to the various lithofacies is illustrated in Text-Fig. 3.6; and ichnofabric indices related to infaunal population-density defined by degree of bioturbation (applied in Text-Figs. 4.1, 4.2, 5.1, & 3.6) are detailed in Text-Fig. 3.7.

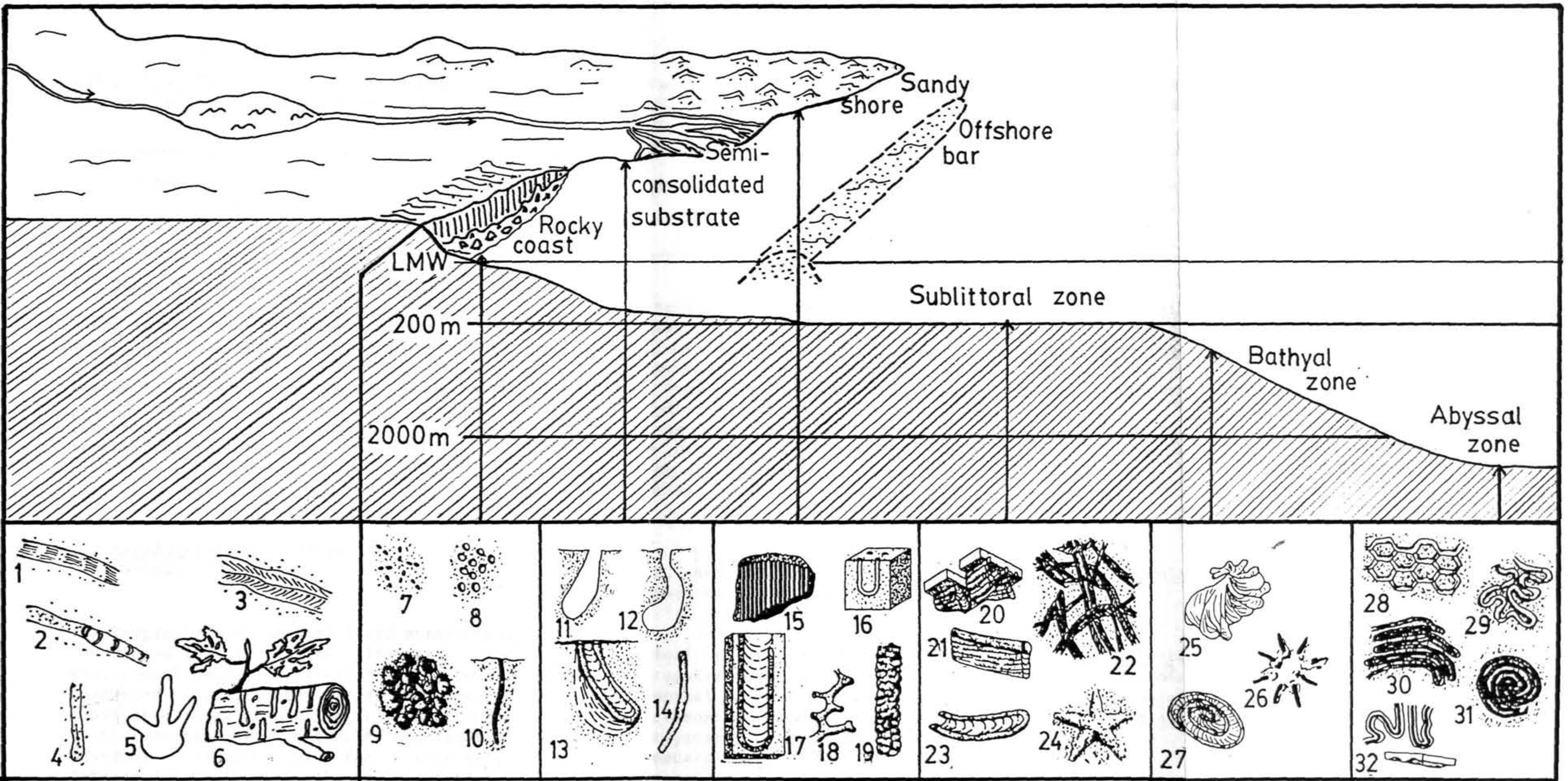


TEXT-FIG. 3.3. Toponomic (preservational) classification of ichnofossils. (Adapted from Seilacher, 1964; Webby, 1969; Chamberlain, 1971; and Hallam, 1975.)



TEXT-FIG. 3.4. Alternative toponomic classifications of trace fossils: A. By Chamberlain (1971); B. By Martinsson (1965, 1970); C. By Simpson (1957).

TEXT-FIG. 3.5. Recurring ichnofacies set in a representative, but not exclusive, suite of environmental gradients. Local physical, chemical and biological factors ultimately determine sites which trace fossils occur in and are mentioned at the bottom of the figure. Typical trace fossils (numbered) at these sites are listed in Table 3.1. (The figure is adapted and modified from Crimes, 1975; Frey & Seilacher, 1980; and Frey & Pemberton, 1984)



ENVIRONMENTS	Fluvial, lacustrine & subaereal	Rocky coast	Semi-consolidated substrate	Sandy shore	Sublittoral zone	Bathyal zone	Abyssal zone
ICHNOFACIES	SCOYENIA 1 & TEREDOLITES 2	TRYPANITES 3	GLOSSIFUNGITES 4	SKOLITHOS 5	CRUZIANA 6	ZOOPHYCOS 7	NEREITES 8

Environmental framework	Terrestrial Brackish Shallow–marine Deep–marine
Dominant lithology	Fluvial deposits & red-beds Littoral sands Well-sorted silts & sands Impure shales, silts & sands Pelagic mud & turbidites
Sedimentary features	Fluvial cross-bedding Oscillation ripples Poor bedding & lamination Load cast convolutions
Burrow depth & attitude	Vertical burrows, horizontal tracks & trails Deep vertical burrows Trails very shallow (near surface) & horizontal
Dominant ethology group	Dwelling – burrows Burrows of suspension-feeders Burrows of deposit-feeders
	Domichnia Domichnia — Cubichnia — Fodinichnia Fodinichnia Pasichnia Agrichnia

TEXT-FIG. 3.5.

TABLE 3.1. Tabulation of typical trace fossil suites included in the recurring ichnofacies. Tabulation is modified from Seilacher (1967), Crimes (1975), Frey & Seilacher (1980), Frey et al., (1984), Frey & Pemberton (1984), and Pemberton & Frey (1984).

Ichnofacies and typical benthic environment.	**Characteristic forms.**	**Typical trace fossil suites in ichnofacies (cf. Text-Fig. 3.1).**
(1) Scoyenia ichnofacies: Moist to wet, pliable, argillaceous to sandy sediments at low-energy sites; either very shollowly submersed lacustrine or fluviatile deposits periodically becoming emergent, or water-side subaerial deposits periodically becoming submergent; intermediate between aquatic and nonaquatic terrestrial environments.	Small horizontal, lined, back-filled feeding burrows; curved to tortuous, unlined feeding burrows; sinuous crawling traces; vertical, cylindrical to iregular shafts; tracks and trails. Invertebrates mostly deposits feeders or predators; vertebrates are grovelers, predators, herbivores. Invertebrate diversity very low, yet some traces may be abundant. Vertebrate tracks may be diverse and abundant around water bodies.	(1) Scoyenia; (2) Ancorichnus; (3) Cruziana; (4) Skolithos; (5) vertebrate trackway.
(2) Teredolites ichnofacies: Woodground.	Vertical, and horizontal borings in wood and impression of feeding on leaves.	(6) Teredolites.
(3) Trypanites ichnofacies (hard substrate): consolidated marine littoral and sublittoral ommission surfaces (rocky coast, beachrock, hardgrounds, reefs) or organic substrates (beds of shell,bones). Bioerosion is as important as, and indeed accelerates, physical erosion of the substrate. Intergradational with the Glossifungites ichnofacies; somewhat intergradational with the Teredolites ichnofacies.	Cylindrical to vase-, tear-, or U-shaped to irregular domiciles of endolithos, orientated normal to substrate surfaces, or shallow anastomosing systems of borings (sponges, bryozoans); excavated mainly by suspension feeders or `passive' carnivores. Rasping and gnawings of agal graziers, etc. (chitons, limpets, and echiniods). Diversity generally low, although borings or scrapings of given kinds may be abundant.	(7) Caulostrepis; (8) Echinoid borings; (9) Entobia; (10) Trypanites.
(4) Glossifungites ichnofacies (firm substrates): Firm but unlithified marine littoral and sublittoral omission surfaces, especially semiconsolidated carbonate firmgrounds, or stable, coherent parrtially dewatered muddy substrates either in protected, moderate-energy setting or in areas of somewhat higher energy where clastic, semiconsolidated substrates offer resistance to erosion. Final sedimentary record typically consists of a mixture of relict and palimpsest features.	Vertical cylindrical, U-, tear-shaped borings or boring-like structures, or sparsely to densely ramified dwelling burrows; protrusive spreiten in some, developed mostly through growth of animals. Fan-shaped Rhizocorallium Diplocraterion. Many intertidal species (e.g., crabs) leave the burrows to feed; other are mainly suspension feeders. Diversity typically low, but given kinds of structures may be abundant.	(11) Gastrochaenolites; (12) Related ichnogenera of Gastrochaenolites; (13) Diplocraterion; (14) Psilonichnus.

TABLE 3.1. (Continued).

Ichnofacies and typical benthic environment.	Characteristic forms.	Typical trace fossil suites in ichnofacies (cf. Text-Fig. 3.1).
(5) Skolithos ichnofacies (shifting substrates): Lower littoral to infralittoral, moderate to relatively high-energy conditions; slightly mudy to clean, well-sorted, shifting sediments; subject to abrupt erosion or deposition. (Higher energy increases physical reworking and obliterates biogenic sediemntary structures. leaving a preserved record of physical stratification.)	Vertical, cylindrical or U-shaped dwelling burrows; protrusive and retrusive spreiten in some, developed mainly in response to substrate aggradation or degradation (escape or equilibrium structures); forms of Ophiomorpha consisting predominantly of vertical or steeply inclined shafts. Animals chiefly suspension-feeders. Diversity is low yet given kinds of burrows may be abundant.	(15) Skolithos; (16) Arenicolites; (17) Diplocraterion; (18) Thalassinoides; (19) Ophiomorpha.
(6) Cruziana ichnofacies: Infralittoral to shallow circalittoral substrates; below daily waves base but not strom waves base, to somewhat quiter offshore-type condi-tions; moderate to relatively low energy; well-sorted silts and sands; to interbedded muddy and clean sands, moderately to intensely bioturbated: negligible to appreciable, although not necessarily rapid, sedimentation. A very common type of depositional environment, including estuaries, bays, lagoons, and tidal flats, as well as continental shelves or epeiric slopes.	Abundant crawling traces, both epi- and intrastratal; inclined U-shaped burrows having mostly protrusive spreiten (feeding swaths; soft-sediment Rhizocorallium); forms of Ophiomorpha and Thalassinoides consisting of irregularly inclined to horizontal components; scattered vertical cylindrical burrows. Animals include mobile carnivores and both suspension and deposits feeders. Diversity and abundance generally high.	(20) Phycodes; (21) Teichichnus; (22) Crossopodia; (23) Rhizocorallium; (24) Asteriacites.
(7) Zoopyhcos ichnofacies: Circalittoral to bathyal, quiet-water conditions; nearly thixotropic muds or muddy sands rich in organic matter but somewhat dificient in oxygen, below storm wave base to fairly deep water, in areas free of turbitidy flows or significant bottom currents. Watery surficial sediments are difficult to exploit by epibenthos, resulting in both diversity and abundance and poor preservation of epistratal traces. Where relict or palimpsest substrates are present especially is swept by shelf-edge or deeper water contour currents, this ichnofacies may be omitted in the transition from infralittoral to abyssal environments.	Relative simple to moderately complex efficiently executed grazing traces and shallow feeding structures; spreiten typically planar to gently inclined, distributed in delicate sheets, ribbons, or spirals ('flattened' forms of Zoophycos or, inpelitic sediments Phycosiphon). Animals virtually all deposit-feeders. Low diversity; given structures may be abundant.	(25) Zoophycos; (26) Lorenzinia; (27) Zoophycos.

TABLE 3.1. (Continue).

Ichnofacies and typical benthic environment.	**Characteristic forms.**	**Typical trace fossil suites in ichnofacies (cf. Text-Fig. 3.1).**
(8) Nereites ichnofacies: Bathyal to abyssal, mostly quiet but oxygenated waters, in places interrupted by down-canyon currents or turbitidy currents (flysch deposits); or highly stable, very slowly accreting substrates. In flysch-like deposits, pelagic muds typically are bounded above and below by turbidites. In more distal regions, the records is mainly one of continuous deposition and bioturbation. (The stable deep-sea floor is not universally bioturbated, however, at least not equally intensively at every site).	Complex grazing-traces and patterned feeding/dwelling-structures, reflecting highly organised, efficient behavior; spreiten structures typically nearly planar, although Zoophycos forms are spiraled, multilobed, or otherwise very complex. Numerous crawling-grazing traces and sinuous fecal casting (Neonereites, Helminthoida, and Cosmorhaphe), mostly intrastratal, Animals chiefly deposit-feeders or 'Scavengers' although many may have 'farmed' microbe cultures within their more or less permanent, open domiciles (Paleondictyon). Diversity and abundance significant in flysh deposits, less so in more distal regions.	(28) Paleodictyon; (29) Cosmorhaphe; (30) Helminthoida; (31) Spirorhaphe; (32) Taphrhelminthopis.

TABLE 3.2. List of trace fossils present in the study area with interpretation in terms of their ethology, trophic level and also their possible producer(s). (Body fossils and plant fossils are also listed here for completion).

STUDIED TRACE FOSSILS AND BODY FOSSILS.	**ETHOLOGY**	**TROPHIC GROUP (feeding group)**	**PRODUCER(S)**
Agrichnium sp	Agrichnia/pasichnia	Suspension/deposit	?
Arenicolites sp	Fodichnia	Deposit	Worms.
Asteriacites sp?	Cubichnia	Suspension	Starfish.
Barrenjoeichnus mitchelli ichno. gen. sp. nov	Fodichnia/domichnia	Suspension/deposit	Worms.
Beaconites antarcticus	Domichnia/fodichnia	Deposit	Crustacean/lung-fish.
Bifungites	Domichnia	Deposit/suspension	Worms.
Brookvalichnus obliquus	Domichnia/fodichnia?	Suspension?/deposit	Worm/insect larva.
Chondrites spp	Fodinichnia	Deposit	Worms.
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	Repichnia	Deposit?	Worms.
Collapse-structures.			
Decapod crustacean fossil.			
Diplocraterion parallelum	Domichnia	Suspension	Worms/crustacean.
D. yoyo	"	"	"
D. polyupsilon	"	"	"
D. polyupsilon var. *polyupsilon*	"	"	"
D. polyupsilon var. *corophioides*	"	"	"
Escape-structures	Fugichnia	Suspension	Bivalve & crustacean/ fish.
Type. A. (bivalves)			
Adeiaichnus ichno. gen. nov	"	"	Bivalve (mollusc).
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	"	Deposit/suspension	Crustacean/fish.
Flask-shaped structures (produced by bivalve)	Domichnia/fugichnia	Suspension	Bivalve (mollusc).
Fuersichnus communis?	Fodinichnia	Deposit	Worms.
Imbrichnus sp	Repichnia	Suspension	Bivalve (mollusc).
J-shaped structures	Domichnia	Suspension	Crustacean/bivalve?
L-shaped structures	"	"	"
Microfossils.			
A. Palynoflora (spores and pollen).			
B. Acritarchs.			
Ophiomorpha nodosa	Domichnia	Suspension/deposit	Crustacean.
Type. A (individual, vertical)	"	"	"
Type. B (networks, horizontal)	"	"	"
Type. C (Type A with turn-around)	"	"	"

TABLE 3.2. (Continued)

STUDIED TRACE FOSSILS AND BODY FOSSILS.	ETHOLOGY	TROPHIC GROUP (feeding group)	PRODUCER(S)
Palaeophycus alternatus	Domichnia	Carnivore	Worms.
P. striatus	"	"	"
P. sulcatus	Domichnia	Carnivore	Worms.
P. tubularis	"	"	"
Pelecypod (body fossil).			
Catagory A. Para-autchothonous.			
Catagory B. Autchothonous.			
Pelecypodichnus (=Lockeia)	Cubichnia	Suspension	Bivalve (mollusc).
Pellets.			
Type. A (faecal)	Excretion		Worms/crustacean.
Type. B (feeding)	Fodinichnia	Deposit	Crustacean.
Type. C (excavation)	Excavation	Deposit	Crustacean.
Type. D (Fe ooids).			
Phycodes bischoffi ichno. sp. nov	Fodinichnia	Deposit	Worms.
Planolites beverlyensis	Fodinichnia	Deposit	Worms.
P. montanus	"	"	"
Plant remains.			
Large leaf impressions.			
Small plant? stems			
Tree trunk (carbonised).			
Pytiniichnus trifurcatum ichno. gen. sp. nov	Domichnia	Carnivorous/herbivorous	Reptile/amphibian.
Resting traces.			
Rusophycus?	Cubichnia	Deposit/suspension	Arthropod.
Resting trace-like structures	"	"	"
Rhizocorallium jenense	Domichnia	Suspension	Crustaceans/worms?
R. jenense var. jenense	"	"	"
R. Jenense var. retrosus	"	"	"
Rhizocorallium irregulare	Fodinichnia/domichnia	Deposit	"
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)	Domichnia/fodinichnia	Suspension/deposit	Worms.
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	Fodinichnia	Deposit	Plants.
Type B. Root-tubules	"	"	"
Type C. Root-cast	"	"	"
Type D. Rhizoconcretion	"	"	"
Roots and rootlets petrifaction structures (Type E).			
Scalarituba sp	Fodinichnia/domichnia	Deposit	Worms.
Scoyenia gracilis	Domichnia/fodinichnia	Deposit	Worms?

TABLE 3.2. (Continued).

STUDIED TRACE FOSSILS AND BODY FOSSILS.	ETHOLOGY	TROPHIC GROUP (feeding group)	PRODUCER(S)
Scribbling grazing traces	Pasichnia	Deposit	Worms?
Skolithos verticalis	Domichnia	Suspension	Worms.
S. linearis	"	"	"
S. monocraterion	"	"	"
S. tigillites	"	"	"
S. annulatus	"	"	"
Skolithos sp.	"	"	"
Spongeliomorpha (Type C)	Domichnia	Deposit	Crustaceans.
Star-shaped traces.			
Helikospirichnus veeversi ichno. gen. sp. nov	Fodinichnia	Deposit	Worms/Bivalves.
Straight horizontal filled burrows	Fodinichnia	Depsoit	Worms?
Stuffed burrows	Domichnia	Suspension	?
Thalassinoides suevicus (Type A)	Domichnia	Deposit	Crustaceans.
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 (with unweb-feet)	Repichnia	Carnivore/Herbivore	Amphibian.
Type. A2 (with web-feet)	"	"	"
Type. B (small reptile), *Moodieichnus*	Repichnia	Herbivore/carnivore	Reptile.
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 ichno. gen. sp. nov	Domichnia	Suspension/deposit	Crustacean.
1. *T. conaghani* var. A	"	"	"
2. *T. conaghani* var. B	"	"	"
3. *T. conaghani* var. C	"	"	"
T. webbyi ichno. gen. sp. nov	Domichnia	"	?
Unclassified structures.			
1. Small bean-shaped structures	Cubichnia	Suspension?	Bivalve?
2. Networks systems	Dwelling	Deposit	Crustacean?

3.3. LITHOFACIES CLASSIFICATION

The grain-size scale and grain-size terminology used here is that of the Wentworth-Udden scheme. The sedimentary rock types that occur in the area range from mudrock through sandstone to pebbly sandstone, granule conglomerate and intraformational mudstone-breccia; but mudrock and sandstone are the predominant rock types. The term "mudrock" is used throughout this report as an unbrella term for (non-fissile) mudstones and (fissile) shales regardless as to their detailed clay/silt/mud textural characteristics. The terms mudstone, siltstone and claystone are used in the sense of Folk (1980, p.28). Scale connotations in the use of cross-stratification terms follow that of Allen (1968, 1970a) and Conaghan (1980) and the various textural and genetic flow-regime cannotations that apply to bedding terms (e.g., parallel-lamination/stratification; flat/horizontal-lamination/stratification, etc.) follow those of Harmes & Fohnestock (1965) and Simons et al. (1965), and Conaghan (1980).

The Bald Hill Claystone consists mainly of red mudrock with palaeosols and with minor interbeds of clay-pellet (including oolites and pisolites) sandstone of probable intraformational origin (Plate 86 Figs. c & d). The latter lithology also predominates in the Garie Formation. The overlying Newport Formation is conspicuously heterolithic (Plate 80 Figs. a - c) comprising an alternation of sandstone and mudrock in various bed thicknesses and exhibiting a variety of sedimentary structures (Text-Fig. 1.6). The uppermost formation in the study area, the Hawkesbury Sandstone, comprises predominantly medium to very coarse quartzose sandstone and minor intervals of mudrock (Plate 57 Fig. e).

The most detailed recent lithofacies descriptions and classification of the rocks in these formations are those of Retallack (1973 & 1977) and Cowan (1985). Retallack's work focused particularly on some of the unusual beds and bedsets in the Bald Hill Claystone and the Newport Formation and which he interpreted genetically as types of palaeosol, this interpretation having been reached on the basis of a range of evidence, including certain pedologic inferences. Cowan (1985) on the other hand classified the lithofacies of these rocks, using a hierarchial scheme, into mesofacies and macrofacies, following in large part McDonnell's (1983) similar classification of the correlative

formations north of Broken Bay. Cowan defined three mesofacies, coded S1, M1 and E1, to accommodate sandstone, mudstone and heterolithic epsilon cross-bedded lithosomes respectively (Enclosure III.3) and further subdivided these into 12 microfacies coded with the lower-case letter "r" (for rudite), "s" (for sandstone), and "m" (for mudrock), each with subscript numerals to differentiate the separate microfacies within rocks of these lithological groups. These various microfacies and mesofacies are defined in terms of this coding system on the segments of Cowan's (1985) stratigraphic logs that are also reproduced here as Enclosure III.3. However, no attempt to use Cowan's lithofacies scheme as a basis for the present work was attempted and a simpler lithofacies classification was formulated (Text-Fig. 3.6 and Appendix II.6). There are several reasons why Cowan's lithofacies scheme was not employed in the present project. Firstly, given that the main concentration of the trace fossils is restricted to relatively thin stratigraphic intervals and to a relatively narrow range of Cowan's microfacies, the focus of my work was more particularly only on parts of the complete stratigraphic section investigated by Cowan and subdivided into his various macrofacies and microfacies. Secondly, because of the stratigraphically more limited focus of my work, my logging of the ichnologically important strata was at a much larger scale (i.e., 1:10 or larger) than that used by Cowan's (i.e., 1:100). Thirdly,Cowan's work on dominantly fluvial rocks and his conception of the degree of pedogenic influence in their development was strongly influenced by Retallack's earlier interpretations regarding this aspect of their origin (Retallack, 1973, 1976 & 1977), some of which interpretations are arguably wrong on the basis of the present ichnological work. For this reason some of the inferred palaeosol components of Cowan's microfacies are in my opinion in error. Fourthly, Cowan's definition of the various microfacies was made independent of a proper appreciation of the palaeoecological significance of their contained trace fossils and on the basis of the present work it can be shown that particular microfacies have marine affinities at some stratigraphic levels but not at others; hence, all such microfacies need to be redefined so as to take into account their ichnological characteristics. However, as explained in Chapter 1, the stratigraphic framework provided by Cowan is not in doubt and his detailed logs measured throughout the length of the Northshore coastal strip provided an indispensable basis for the further refinement embodied in the present work. Cowan's microfacies and mesofacies classification of the strata also formed the basis of his facies

TEXT-FIG. 3.6. Lithofacies classification and distribution of trace fossils relative to lithofacies in the study area. The classification of lithofacies is a simple one based on overall grain-size (Wentworth - Udden scheme) and bedding structure and comprises microfacies A to J, two of which (A & B) are subdivided into subfacies (A1, A2; B1, B2). Facies A through H define a spectrum of decreasing grain-size and bed thickness (see also Table 3.3 & Appendix II.6).

Facies A. Fluvial in-channel sandstone and rudite deposits.
Facies B. Thin-bedded fine sandstone of fluvial or estuarine origin.
Facies C. Ripple cross-laminated fine sandstone.
Facies D. Thin-bedded parallel-laminated fine sandstone.
Facies E. Thin-bedded very fine sandstone with parallel-stratification and small-scale trough cross-laminae (`rib and furrow' structure).
Facies F. Thin-bedded parallel-laminated very fine sandstone.
Facies G. Thin-bedded parallel-laminated siltstone.
Facies H. Medium- to thin-bedded claystone and shale.
Facies I. Palaeosols of different kinds and different textures.
Facies J. Clay-pellet (oolitic/pisolitic) sandstone.

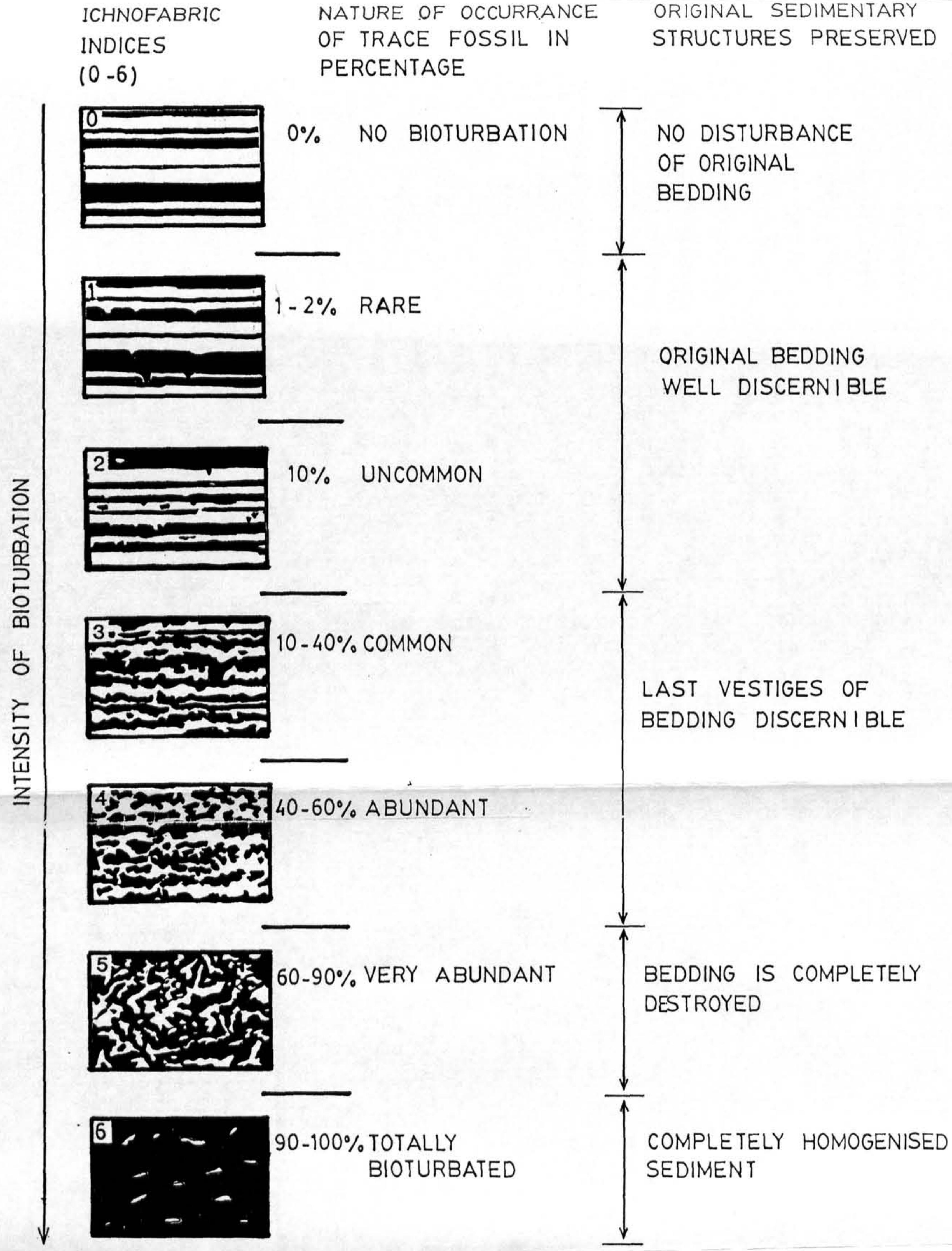
GRAIN SIZE.

FACIES. / TRACE FOSSILS AND OTHER FOSSILS	FA	FB	FC	FD	FE	FF	FG	FH	FI	FJ
LITHOLOGY	MS	FS	FS	FS	VFS	VFS	ST	CL/SH	PS	CP
STRUCTURES,	MASSIVE	MASSIVE								
Agrichnium sp.				3	3					
Asteriacites sp?				2	2					
Barrenjoeichnus mitchelli ichno. gen. sp. nov			1	2	2	4	4			
Beaconites antarcticus.							1	2		2
Bifungites.		2	2							
Brookvalichnus obliquus.							4	2		
Chondrites spp.						3	3			
Type. A (horizontal, angular).						3	3			
var. 1 (dense, uniform size).						3	3			
var. 2 (non-uniform size).						3	3			
var. 3 (regular, uniform size).						3	3			
Type. B (oblique, radial).				2		3				
Type. C (oblique, asymmetrical).				2		2				
var. 1 (widely spaced).				2		2				
Colichnites howardi ichno. gen. sp. nov.		2		3		2				
Collapse-structures.			3	2						
Decapod crustacean fossil.							1	1		
Diplocraterion parallelum.				4						
D. yoyo.				3						
D. polyupsilon.				3		2				
D. polyupsilon var. polyupsilon.				3		2				
D. polyupsilon var. corophioides.				3		3				
Escape-structures.			3		4					
Type. A (bivalves),			3		4					
Adeiaichnus ichno. gen. nov.			3		4					
var. 1 (normal escape)			3		4					
A. kykleomotatus ichno. sp. nov.			3		4					
var. 2 (rapid escape)				4						
A. alyxis ichno. sp. nov.				4						
Type. B (crustacean/fish)				2		2				
Hannibalichnus amplius ichno. gen. sp. nov				2		2				
Flask-shaped structures (produced by bivalve)				3						
Fuersichnus communis?			3	3	2					
Imbrichnus sp.			2	3	2					
J-shaped structures.				3		2				
L-shaped structures.				3		2				
Microfossils.					3	3	3	3		1
A. Palynoflora (spores and pollen).					3	3	3	3	2	
B. Acritarchs.							2	2		
Ophiomorpha nodosa.						3	3	3		3
Type. A (individual, vertical).						3	3	3		3
Type. B (networks, horizontal).							3	3		3
Type. C (Type A with turn-around).						2	1	1		1
Palaeophycus alternatus.				3		3	3			
P. striatus.				3						
P. sulcatus.			2	3						
P. tubularis.			2	2						
Pelecypod (body fossil).			3		3					
Category A. Para-autochthonous.			3	2						
Category B. Autochthonous.			3	2						
Pelecypodichnus (=Lockeia)			2	3	2					
Pellets.			1	1	2	2	3	3		4
Type. A (faecal).							2	3		4
Type. B (feeding).					2	2	3			2
Type. C (excavation).				1	2	2	3			2
Type. D (Fe ooids).		2	2	2						
Phycodes bischoffi ichno. sp. nov.					2					
Planolites beverlyensis.				2	2	2				
P. montanus.					3	2				
Plant remains.						1	2	3	4	
Large leaf impressions.				3	3	2				
Small plant? stems							2	3	3	
Tree trunk (carbonised).							1	1	2	
Pytiniichnus trifurcatum.									2	
Resting traces.				3	1	2				
Rusophycus?				3		2				
Rusophycus-like traces				3						
Resting trace-like structures.				3						
Rhizocorallium jenense.			2	3		3				
R. jenense var. jenense.			2	3		3				
R. Jenense var. retrosus.			2		2					
Rhizocorallium irregulare.			1	3	1	3				
R. irregulare var. irregulare.			1	3	1	3				
R. irregulare var. birfucatum.			1	3	1	3				
R. irregulare var. nexus.			1	2	2					
Rhizocorallium uliarense.			1	3	1	2				
R. uliarense var. planuspirus.			1	3	1	2				
Ring-structures.				3	2	3	2	1		
Type. A (rings without column).				3	3	3	2	2		
Type. B (rings with column).				1	1	2	2	2		
Type. C (numerous rings with column).				2	2	3	3	3		
Type. D (Large ringed-structure).		1	2	2						
Roots and rootlets penetration structures.			2	2	2	3	3	3	4	
Rhizoliths.						1	3	3	4	
Type A. Root-mould.						1	3	3	4	
Type B. Root-tubules.						1	3	3	4	
Type C. Root-cast.						1	3	3	4	
Type D. Rhizoconcretion.						1	3	3	4	
Roots and rootlets						1	3	3	4	
Petrification structures (Type E).						1	3	3	4	
Scalarituba sp.						3				
Scoyenia gracilis.		2	2	3	2	3				
Scribbling grazing traces.						3	3	2		
Skolithos verticalis.		3	3	2	3	2	1			
S. linearis.		3	3	2	3	2	1			
S. monocraterion		3	3	2	3	2	1			
S. tigillites.		3	3	2	3	2	1			
S. annulatus.		3	3	2	3	2	1			
Skolithos sp.		3	3	2	3	2	1			
Spongeliomorpha (Type C).		1	3	3	3	1				
Star-shaped traces.		1	3	3	3	1				
Helikospirichnus veeversi ichno. gen. sp. nov.		1		3	3	1				
Straight horizontal filled burrows.				1	1	3	3	2		
Stuffed burrows.		1	3	3	1					
Thalassinoides suevicus (Type A).					1	1	3	3		
T. paradoxicus (Type B).		1	3	3	3	1				
Thalassinid Turn-around.		1	3	3	3	1	2	2		
Type. A (for an individual animal).		1	3	3	3	1	2	2		
var. 1 (cylindrical).		1	3	3	3	1	2	2		
var. 2 (Y- or V- shaped).		1	2	3	3	1	2			
Type. B (for a colony of animal).		1	3	3	3	1				
var. 1 (irregular-shaped).		1	3	3	3	1				
var. 2 (Y-shaped).		1	3	3	3	1				
Track marks.		1	3	3	3	3	1			
Type. A1 (large amphibia with unwebbed-feet).			3	2	3	1				
Type. A2 (Large amphibian with webbed-feet).			3	2	3	1				
Type. B (small amphibian), Moodieichnus			2	3	1	3				
Species 1. M. didactylus.			2	3	1	3				
Var. 1 M. didactylus var. permiansis.			2	3	1	3				
Var. 2 M. didactylus var. triassicus.			2	3	1	3				
Species 2. M. tridactylus ichno. sp. nov.			2	3	1	3				
Turimettichnus conaghani.				2	2	2	3	3		3
1. T. conaghani var. A.				2	2	2	3	3		3
2. T. conaghani var. B.			2	2	2	2	2	2		2
3. T. conaghani var. C.		3	2	2	2					
T. webbyi.						2	2	2		2
Unclassified structures.			2	3		3	1			
1. Small bean-shaped structures.				3		3	1			
2. Networks systems.			2	2		1	1			

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

(RELATIVE ABUNDANCE SCALE SEMI-QUANTITATIVE)

TEXT-FIG. 3.6.



TEXT-FIG. 3.7. Schematic diagram of ichnofacies indices that can be related to infaunal population-density defined by degree of bioturbation of one or more ichnotaxa. Ichnofabric indices 0 through 6 and representative examples can be defined as follows: 0, no bioturbation, all sedimentary structure is preserved (0% of bioturbation); 1, rare trace fossils (less than 2% bioturbation), original bedding is well preserved; 2, sporadic uncommon trace fossils (up to 10% bioturbation), original bedding structure is disturbed; 3, common occurrence of trace fossils (10% to 40% bioturbation), about half of the original bedding structure is disturbed; 4, abundant trace fossils (40% to 60% bioturbation), more than half to last vestiges of bedding structure is discernible; 5, very abundant trace fossils (60% to 90% bioturbation), burrow structures are still discrete but the nature of original bedding is completely destroyed; 6, bioturbation completely pervasive (90% to 100% bioturbation), all original bedding totally obliterated because of complete homogenisation of sediment. This infaunal population-density scheme is applied in the distribution charts shown in Text-Figs. 3.6, 4.1, and 4.2 (see also Appendix II.1d).

transition analysis of these formations and consequently his refinement of their (as assumed by him) exclusively fluvial environmental affinities. Inasmuch as the trace fossil work in the present project has demonstrated that only some 10% or less of the entire stratigraphic thickness of the Bald Hill Claystone to top of Newport Formation interval is marine-influenced, and affects predominantly the fine-grained microfacies, the stratigraphic bulk of Cowan's work including his fluvial interpretations remain intact. Resolution of which of Cowan's microfacies are marine-influenced will be attempted in a subsequent section of this report.

The lithofacies classification used here (Table 3.3; Text-Fig. 3.6) is a relatively simple one based on overall grain-size and bedding structure and consists of ten facies (A to J), two of which (A and B) are subdivided into subfacies (A1, A2; B1, B2). With the qualification that facies I accommodates palaeosols of different kinds and different textures, facies A through to H define a spectrum of decreasing grain-size and bed thickness. Subfacies A1 and A2 are fluvial in-channel sandstone and rudite deposits which generally lack trace fossils and hence have not been the focus of much attention in this study. Subfacies B1 and B2 are thinner-bedded fine sandstone, possibly of fluvial or estuarine origin in some cases and which commonly contain trace fossils (e.g., Plate 85, Figs. c & d). Facies C comprises ripple cross-laminated fine sandstone commonly with trace fossils (Plate 77, Figs. a - c; Plate 81, Fig. a). Facies D comprises thin-bedded parallel-laminated fine sandstone commonly

TABLE 3.3. Definition of lithofacies and lithofacies codes used in this report (see also Text-Fig. 3.6).

1.	**FA.2**	FACIES **A**	Thick bodies of trough cross-bedded medium sandstone in some cases with thin basal granule conglomerate and or mudstone breccia.
	FA.1	FACIES **A**	Thick bodies of structureless and /or crudely flat-bedded medium sandstone, commonly with basal mudstone breccia and/or granule conglomerate.
2.	**FB.2**	FACIES **B**	Moderately thick bodies of trough cross-bedded fine sandstone.
	FB.1	FACIES **B**	Moderately thin structureless and/or flat-bedded fine sandstone.
3.	**FC**	FACIES **C**	Moderately thin-bedded fine sandstone with ripple cross-laminae and ripple marks.
4.	**FD**	FACIES **D**	Thin-bedded fine sandstone with parallel-stratification.
5.	**FE**	FACIES **E**	Thin-bedded very fine sandstone with parallel-stratification and small-scale trough cross-laminae.
6.	**FF**	FACIES **F**	Thin-bedded very fine sandstone with parallel-stratification.
7.	**FG**	FACIES **G**	Thin-bedded siltstone with parallel-stratification.
8.	**FH**	FACIES **H**	Medium to thin-bedded claystone (non-fissile) and shale (fissile).
9.	**FI**	FACIES **I**	Palaeosols involving different grainsizes and bed thicknesses; bed thickness is commonly irregular.
10.	**FJ**	FACIES **J**	Clay-pellet (Oolitic/pisolitic) sandstone.

containing trace fossils (e.g., Plate 70). Facies E comprises thin-bedded very fine sandstone with parallel-stratification and small scale trough cross-laminae ('rib and furrow' structures). This facies commonly contains trace fossils, mainly vertical burrows (e.g., Plate 85, Fig. b). Facies F comprises thin-bedded parallel-laminated very fine sandstone with abundant trace fossils (e.g., Plate 84, Fig. c). Facies G comprises thin-bedded parallel-laminated siltstone with abundant trace fossils (e.g., Plate 84, Fig. b). Facies H comprises medium to thin-bedded claystone and shale commonly with trace fossils (e.g., Plate 84, Fig. c). Facies I accommodates a variety of palaeosols in both the Bald Hill Claystone and the Newport Formation, mainly in the Lower and Middle Members (e.g., Plate 82, Figs. c & d; Plate 53 Figs. a & c). The last facies, Facies J comprises clay-pellet (oolitic/pisolitic) sandstone, which is mainly developed in the upper part of the Bald Hill Claystone and the lower part of the Lower Newport Member equivalent to the Garie Formation. The distribution of the various trace fossils in relationship to these various lithofacies is detailed in Text-Fig. 3.6 and will be discussed in later chapters.