Diplocraterion polyupsilon Smith, 1893

Lectotype: GSE 4954. Subsequently designated by Anderson (1936: p.73) as the `holotype and genotype': specimen figured by Smith (1893, plate 10) in Knox (1973).

Paralectotype: HM X59. This specimen was wrongly designated as the type specimen by Osgood (1970: p.314, plate 60; fig.6)

Topotype material: SM E19876-80 in Knox (1973).

Diplocraterion polyupsilon var. polyupsilon (Smith, 1893)

Plate 39 Fig. a

Diagnosis (taxonomic assignment: U-shaped burrow with unmistakable unidirectional retrusive spreite. Burrow depth exceeds the width (Text-Fig. 7.1). The spreite are irregular, partly deflected and discontinuous, but they are all arranged in the U-in-U pattern.

Remarks (diagnostic features): These U-shaped burrows have broad parallel arms, rarely divergent at the top of the U. In U-plane sections the structures exhibit a broad U-shape with retrusive U-in-U spreite. The average width is much shorter than the average depth but in some specimens these two dimensions are equal. In the study area the average width of the burrows is 5.6 cm and the average thickness is about 1 cm (Table 7.5B). The depth of these burrows varies from specimen to specimen and ranges from about 7 cm to 10 cm (Table 7.5B).

Description: The burrows mainly exhibit retrusive (unidirectional) spreite. Transverse sections show a dumbbell-shaped outline with two clearly defined circular openings/apertures and a relatively narrow limb of spreite. In the study area the burrows are

very well defined because of a marked colour contrast between them (white colour) and the red colour of the host rocks (Plate 39 Fig.a). Natural transverse sections through various depth intervals of the burrows and some sections cut above the free tubes will exhibit two apparently unconnected circular or subcircular openings/apertures. The spreite are readily discernible and are exposed in U-plane sections as weakly defined but regular and thin laterally continuously convex-downward laminae. In U-plane sections the width of the structures is moderately large but is still shorter than the burrow depth (i.e., W<D; Table 7.5B). The base of the U is broad and flat. The walls are thin and comprise dark colored clay. No special ornamentation occurs on the burrow surface. The apertures/openings are not well differentiated from the spreite, and this is especially true of oblique sections and transverse sections cut through the lower part of the burrow. However, the apertures/openings are well preserved and clearly defined in sections cut through the free tubes.

Comparison: The description of the burrows from the study area correspond to those of the original burrows documented by Smith (1893, p.290-291) as well as his records of two other occurrences of Polyupsilon in the Gowkha Quarry (Smith 1893, p.292) and on the Dumfrieshire coast (Smith 1910, p.43) in Knox, 1973, all three records being from Lower Carboniferous sandstone.

A Population density study by the distance-to-nearest-neighbor method is not practicable in the study area because of the nature of the orientation of the burrows. Most of the U-shaped burrows show a considerable degree of overlap because of

pronounced reworking or reburrowing (Plate 39 Fig.a) and hence resolution of which two tubes belong to the one burrows cannot be made without sectioning. Even then, it is practically impossible to make the necessary measurements.

Studied material: None of the burrows have been retrieved from the field. The photograph of the burrows in Plate 39 was taken in trace fossil subinterval ID2 of the Lower Newport Member at Bungan Head (area 13) and within measured section 13.1.1 (see Enclosure III.2 & III.3).

Distribution: The photograph of the burrows in Plate 39 Fig. a was taken in the lower part of Lower Member of the Newport Formation, within trace fossil subinterval ID2. The burrows are associated there with the other varieties of Diplocraterion. D. polyupsilon var. polyupsilon does not occur in any other trace fossil subinterval or at any other localities.

Preservation and association: These burrows occur as full-relief dwelling-burrows associated with other varieties of Diplocraterion but no other types of trace fossils.

Ichnofacies and palaeoenvironmental affinities: D. polyupsilon var. polyupsilon belongs to the Skolithos ichnofacies (see Text-Fig. 3.5) and formed in the slightly deeper part of a shallow-marine shoreline environment in a fluvially-dominated coastal estuary or lagoon.

Diplocraterion polyupsilon var. corophioides (Smith, 1893)

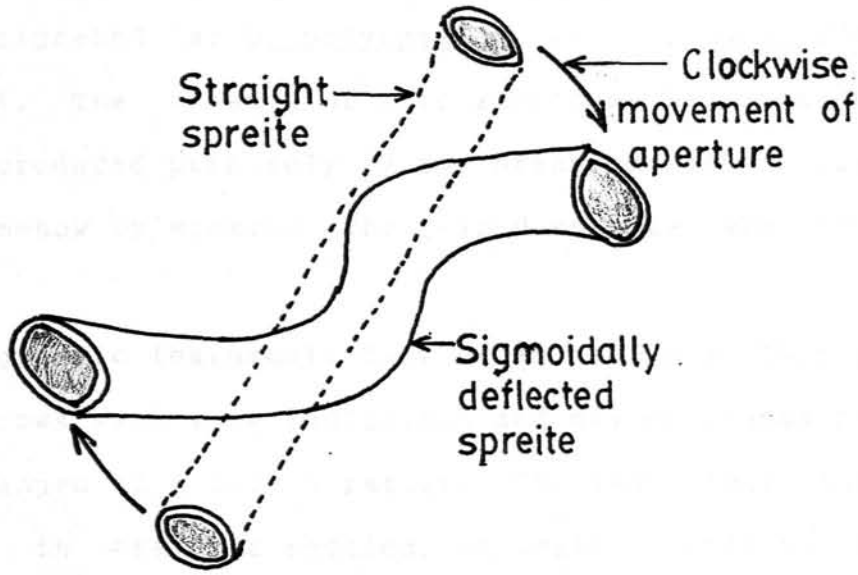
Plate 39, Figs. b & c

Diagnosis (taxonomic assignment: In the proposed classification this variety of very broad U-shaped burrow characterized by a U-

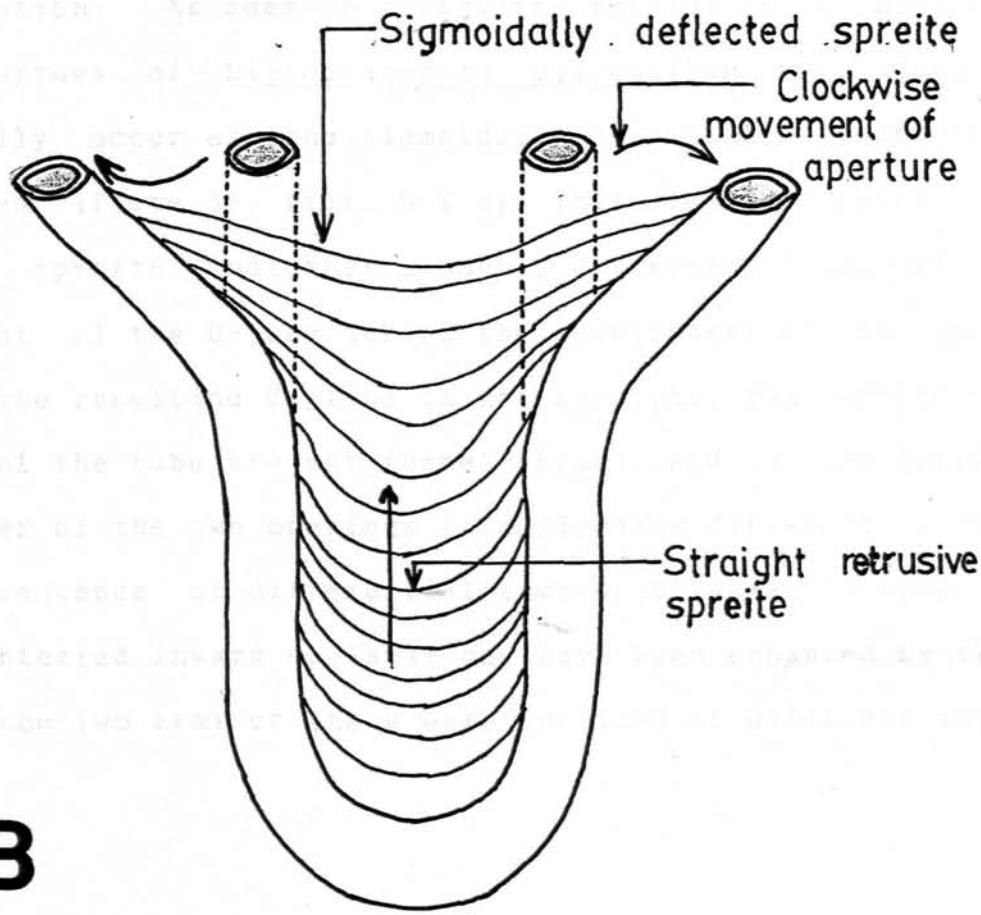
TEXT-FIG. 7.8. Diagram of Diplocraterion polyupsilon showing sigmoidally deflected nature of the U-plane which in turn indicates an opposing outward inclination of each arm of the U in a vertical plane (orthogonal to a vertical plane containing the base of the U). The spreite are retrusive, the lower (earlier) spreite being straight, not sigmoidal. The drawings are based on a natural exposure (transverse cross-section) in sample 1005a/MU.44426, illustrated in Plate 39 Figs. b & c.

A. Clockwise movements of the apertures resulting in sigmoidal deflection of the spreite in transverse section. Dotted lines show the undeflected (straight spreite) part of the burrow.

B. The same specimen viewed in U-plane section, showing sigmoidally deflected spreite in upper part and straight undeflected spreite in lower part.



A TRANVERSE SECTION



B U-PLANE SECTION

TEXT-FIG. 7.8

in-U pattern can only be designated under the ichnospecies D. Polyupsilon and due to the large value of the width/depth ratio (width is invariably greater than the depth, cf. Table 7.5B) it is here designated as D. polyupsilon var. corophioides (cf. Text-Fig.7.2). The broad U of this structure is considered to have been produced purposely by the organism rather than have resulted somehow by erosion. The U-in-U spreite are invariably retrusive.

Remarks (diagnostic features): Very broad and very thinly-walled U-shaped burrows with very indistinct and discontinuous retrusive spreite arranged in a U-in-U pattern. The individual tubes are semicircular in traverse section, of small diameter, and are readily distinguished from the spreite. The wall boundary is well defined by its contrasting dark colour against the lighter purplish-grey fine sandstone of the host sediment.

Description: As seen in transverse section on the bedding plane the burrows of Diplocraterion polyupsilon var. corophioides generally occur as long sigmoidally curvilinear dumbbell-shaped features (Plate 39. Figs. b & c). This sigmoidal pattern of the U-in-U spreite indicates a doubly deflected locus of lateral movement of the U-tube during the development of the burrow so that the resulting U-plane is not straight. The apertures/openings of the tube are not funnel-shaped, and in some burrows the diameter of the two openings is noticeably different, probably as a consequence of differential inward collapse. In some burrows this inferred inward collapse may have been enhanced by the fact that the two arms of the U were inclined at different angles at

right angles to the U-plane, in which case the more shallowly-inclined arm would have been more prone to compactional collapse. In transverse section the openings are subcircular and not easily distinguished from the connecting spreite but they and the spreite show a well defined boundary with the host sediment (Plate 39, Fig. C). No surface ornamentation is evident. In size the burrows range from 5 cm to 6 cm in width and are less than 5 cm in depth; the thickness varies from about 0.5 to 1 cm. Unambiguous and valid population density measurements of these burrows cannot be made because of the curvilinear geometry of the spreite limb between the two arms and because of the intimate association of these burrows of D. polyupsilon var. corophioides with burrows of D. parallelum var. parallelum (Plate 39, Fig.C). Measurements can safely be made only to describe the variation of size of the burrows. The spreite occur as very thin, discontinuous and retrusive laminae with U-in-U arrangement. Normally these spreite occur as thin flat partings but they are partly disturbed and distorted especially in cases where the tubes are not parallel to a common straight U-plane. The base of the U-tubes is generally semicircular and in some cases somewhat flat.

Comparison: D. polyupsilon var. corophioides is identical to D. polyupsilon in all qualitative respects but differs from the latter in regard to the width/depth ratio. Whereas this ratio is about 1:4 in D. polyupsilon var. polyupsilon it is typically about 1:1 in D. polyupsilon var. corophioides (Text. Fig. 7.5; Table 7.5B). The distance-to-nearest-neighbour method of population density study is less applicable than in the other varieties of Diplocraterion because of the sigmoidally deflected nature of

the U-plane which in turn indicates an opposing outward inclination of each arm of the U in a vertical plane orthogonal to a vertical plane containing the base of the U (the latter being presumed to be straight and not sigmoidal; cf. Text-Fig. 7.8). The intimate association of D. polyupsilon var. corophioides with D. parallelum probably suggests that these two different kinds of U-shaped burrows were produced by different kinds of organisms rather than by the same species of organism for ethologically different reasons. Additionally, as explained in the caption to Text-Fig. 7.6 the limb-midpoint-to-limb-midpoint distance parameter of distance-to-nearest-neighbour is not suitable for U-shaped burrows made by deposit-feeders, and allusion to a deposit-feeder origin of D. polyupsilon has been made in an earlier section.

Studied material: Specimen 1005a/MU.44426.

Distribution: The studied specimen (1005a/MU.44426) was collected from the Lower Newport Member from trace fossil subinterval ID2.2 at Bilgola Head (area 10) from section 10a.1.1.

Preservation and association: The burrows are well preserved as full-relief forms in a host sediment of purplish-grey very fine sandstone. The rock is strongly bioturbated by these U-shaped burrows, especially by those of D. parallelum. D. parallelum burrows occur as pairs of apparently unconnected small openings in these rocks.

Ichnofacies and palaeoenvironmental affinities: As for D. polyupsilon var. polyupsilon. —

7.2.8. Application of the distance-to-nearest-neighbour method in population-density studies

An attempt has been made in this study to use modern ecological methodology in analyzing the spatial distribution of vertical U-shaped burrows. This kind of analysis provides information of potential importance to understanding a host of biotic interactions that have so far only been investigated in respect of modern organisms (Clark, 1955; Clark & Evans, 1954, 1955 and 1979) and less commonly in respect of in situ sessile body fossils.

The first population-density study of vertical burrows in Australia was that of Pickett (1972) on the Upper Permian Erins Vale Formation of the southern Sydney Basin. The first spatial distribution analysis of the ichnogenus Skolithos was from the Upper Ordovician Ely Spring Dolomite of Nevada and was made by Miller (1977). More detailed and comprehensive work was done by Pemberton & Frey (1984) on specimens of Skolithos and Diplocraterion in the Lower Cambrian Bradore Formation of southern Labrador and in the Middle Silurian Thorold Formation of southern Ontario (but where the spatial analysis investigation of the ichnogenus Diplocraterion was restricted to the Thorold Formation).

Procedures of distance-to-nearest-neighbour method:

The technique of using the distance from an individual to its nearest neighbor in analysing dispersion within a population of modern organisms was introduced by Hertz (1909). Subsequent studies using the same idea were made by Spooner (in Holme 1950), Dice (1952), Clark & Evans (1954, 1955), and Clark (1955). The technique is best applied to populations that can be mapped

(Clark & Evans, 1979).

In the present study area difficulties imposed by the topography of the rock exposures necessitate a special type of sampling procedure. Most of the exposures occur as vertical to near-vertical cliff sections where only random sampling sites can be located. Large blocks were extracted from such exposures or, alternatively, loose blocks were chosen for study from these exposures. The area of the relevant bedding-plane surface on such blocks was determined by graphic methods and all burrows were plotted on an overlay tracing (Text-Fig. 7.6); the distance-to-the-nearest-neighbour using the limb-midpoint to limb-midpoint distance between adjacent burrows was then measured and recorded (Table 7.5A). Application of the coefficient-of-dispersion statistic (Holmes, 1950) was not practicable in the present study because of the limited number of suitable exposures.

Application of the distance-to-nearest-neighbour method in the spatial distribution of Diplocraterion in the study area:

Choice of the distance-to-nearest-neighbour method for analysis of spatial distribution in multi-entrance burrows (e.g. Diplocraterion) was first made by Pemberton & Frey (1984). The methodology and refinements to it are explained in Text-Fig. 7.6. Several choices of measurement can be used for the nearest neighbour (Text-Fig. 7.6), but only one of these choices is effective, namely from the centre point of each nearest idividual, i.e., midway along the limb between the vertical arms. This measurement was chosen because the organisms that produced these burrows were suspension-feeders (e.g., Pemberton & Frey, 1984) and are believed to have established the burrows for dwelling. Use of this

TABLE 7.6. Representative burrow depth measurements of *D. parallelum*/*D. yoyo* in sample 1205/MU.44443.

Count No.	H (cm)	Burrow number cf. Text-Fig. 7.6A (exposed only on edges)
1.	8.45	Not recorded
2.	8.87	" "
3.	9.36	" "
4.	7.05	" "
5.	14.98	" "
6.	6.35	" "
7.	14.64	" "
8.	9.90	" "
9.	7.41	" "
10.	5.96	" "

n = 10
σn = 2.998
σ(n-1) = 3.16
$\bar{x}$ = 9.3
Σx = 93.47
Σx2 = 963.58

TABLE 7.7. Bed number (B) and bed thicknesses (cf. "G" Text-Fig. 7.10) and lithology of the samples.

1205/MU.44443 (cf. Plate 36 Figs. f & g)

B3 = 4 cm (fine sandstone) - (topmost bed)
B2 = 3.5 cm (very fine sandstone)
B1 = 7 cm (fine sandstone) - (lowermost bed).

1210/MU.44448 (very fine sandstone)

B6 = 1 cm (very fine sandstone) - (topmost bed)
B5 = 3 cm "
B4 = 1 cm "
B3 = 1 cm "
B2 = 1.5 cm "
B1 = 1.5 cm " - (lowermost bed)

1214/MU.44451 (fine sandstone)

B = 15 cm (single unit)

TABLE 7.8. Distance-to-nearest-neighbour (DNN) measurements of *Diplocraterion* burrows in sample 1205/MU.44443. (cf. Text-Fig. 7.6A).

NO.	Nearest neighbour	Distant-to-nearest-neighbour measurements (cm)	NO.	Nearest neighbour	Distance-to-nearest-neighbour measurements (cm)
1	2	2.28	48	47	1.95
2	3	1.3	49	65	1.96
3	2	"	50	51	1.32
4	5	1.01	51	50	"
5	4	"	52	53	2.83
6	5	1.01	53	52	"
7	4	1.67	54	55	0.82
8	9	1.62	55	54	"
9	10	1.6	56	57	1.47
10	9	"	57	56	"
11	12	1.61	58	57	2.34
12	13	1.7	59	60	2.46
13	12	"	60	61	0.97
14	19	1.15	61	60	"
15	16	1.58	62	63	1.47
16	15	"	63	62	"
17	18	0.98	64	66	2.37
18	17	"	65	49	1.9
19	14	1.2	66	67	1.2
20	19	1.66	67	66	"
21	22	2.24	68	69	1.27
22	20	"	69	68	"
23	35	2.5	70	69	1.67
24	23	2.63	71	74	1.7
25	26	1.24	72	69	1.75
26	27	0.91	73	70	1.84
27	26	"	74	71	1.7
28	29	0.83	75	73	1.92
29	28	"	76	74	1.79
30	31	1.07	77	76	2.14
31	30	"	78	77	2.15
32	34	2.41	79	75	3.25
33	32	2.83	80	81	1.35
34	32	2.52	81	80	"
35	23	2.47	82	83	1.06
36	37	2.73	83	82	"
37	38	1.17	84	85	1.64
38	37	"	85	86	1.82
39	40	1.53	86	87	0.77
40	39	"	87	86	"
41	50	2.0	88	91	1.45
42	47	2.01	89	90	1.46
43	44	3.05	90	89	"
44	45	1.23	91	88	1.47
45	44	"	92	91	3.25
46	47	1.43	93	94	1.9
47	46	"	94	93	"
			95	93	2.32

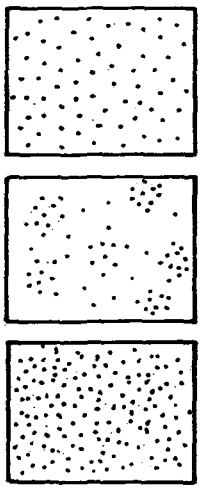
n = 95; $\bar{x}$ = 1.646; σn = 0.5945; σ(n-1) = 0.5976; Σx = 156.37;

Σx2 = 290.9587; Area = 636 cm2

measurement is quite reasonable because the point midway between the arms of the tube is a representative point or effective point of location for viewing the animal's biotic interactions (Pemberton & Frey, 1984).

The actual measurements were taken from sample 1205/MU.44443 illustrated in Plate 37 Figs. a-c, and the distribution of the burrows in this sample is illustrated in Text-Fig. 7.6; the measurements are consolidated in Table 7.8. It is necessary to measure the total area studied in such samples in order to be able to estimate the spatial distribution of the population per unit area.

The analysis of this sample of the U-shaped burrows suggests that they are uniformly dispersed ($\bar{x} > S.D.$; cf. Table 7.8 & Text-Fig.7.9) suggesting some kind of negative biotic interaction between individuals. This may also reflect less competition for dwelling space or for food gathering or direct negative interference of territorial behaviour as these are the principal causes of uniform dispersions (Holme, 1950; Johnson, 1959; Connell, 1963; Levinton, 1977, and many others). But uniform dispersion patterns can be ascribed to several factors: e.g., equidistant larval settlement; uniform abundance of food or feeding adaptation or other resources; or by equidistant relocation of new burrows by the organisms from their recently vacated burrows and existing still-occupied burrows. The spatial distribution of these dwelling-burrows of suspension-feeding organisms is seen to be more environmentally- (or substrate-) controlled rather than controlled by the distribution of food. Several



(1) Uniform, even or regular dispersion.
$\bar{X} > S.D^2$

(2) Clustered or gregarious dispersion.
$\bar{X} = S.D^2$

(3) Random dispersion.
$\bar{X} < S.D^2$

TEXT-FIG 7.9. Three possible types of population dispersion (from Gee,1986):
(1) Uniform, even or regular dispersion.
(2) Clustered or gregarious dispersion.
(3) Random dispersion.

$\bar{X}$ = mean distance to nearest neighbour measured between limb-midpoints of the U-shaped burrows.
S.D. = standard deviation of distance — to — nearest-neighbour.

See text for additional discussion.

degrees of density of the burrows of D. parallelum var. parallelum (sparse, normal and heavy density), but with uniform dispersion of the burrows, are illustrated in Plate 38 Figs. a - c. The rock pavements illustrated in this plate all occur in the same bed and occur only a few tens of metres apart.

7.2.9. Relationship between Diplocraterion burrow width and depth, bed thickness and lithofacies

The relationship between the width (W) and depth (H) of the Diplocraterion burrow and the bed thickness of its host sediment is used as an important environmental parameter in the present study. In the study of modern trace fossils of the littoral and sublittoral zones, the depth of the burrow can be taken as an indicator of the water depth because they have been found to be inversely related (Myers, 1970). However, little attention has been given to the application of this observation to ancient sediments and their trace fossils. Additionally, studies conducted by Knox (1973) and Legg (1985) on U-shaped burrows in ancient strata both confirmed the validity of application of burrow width as an indicator of water depth. Generally the depth of burrowing, including that of U-shaped burrows, decreases in the offshore direction (Legg, 1985). Thus, the depth of the burrow (H; cf. Text-Fig. 7.1) is inversely related to the water depth (D).

Bed thickness:

There is a tendency for very thin beds (<10 cm) to contain many trace fossils and for thick beds (>90 cm) to contain none (Legg, 1985, p.62). Hence, there is a tendency for the percentage of beds with trace fossils to decrease as bed thickness increases (Crimes et al., 1977). In the study area the

critical U-shaped burrows occur exclusively in relatively thin beds between 1 cm and 15 cm thick (Table 7.7, Text-Fig.7.10), consistent with the abovementioned earlier observations.

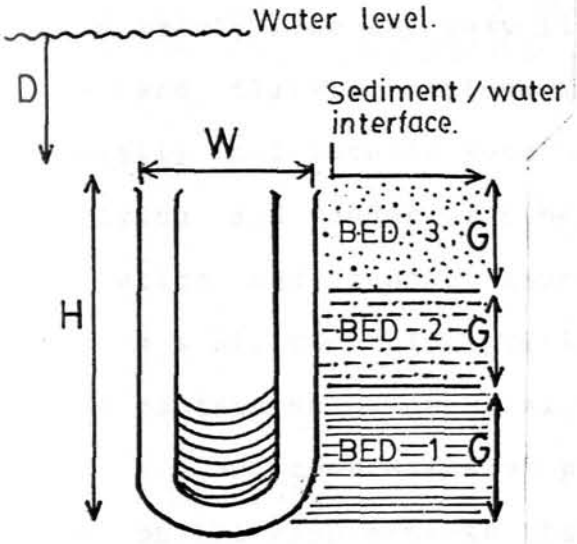
Width of the U-shaped burrows:

The width of the U-shaped burrow can be determined from either U-plane sections (cf. Text-Fig.7.1B) or from tranverse sections (cf. Text Fig. 7.6) by measuring the distance between the distant margins. Measurements of the width of burrows of D. parallelum var. parallelum and D. yoyo were made on three rock slabs retrieved from the field (Table 7.5A). The average width of these U-shaped burrows is less than 3 cm (Table 5A & Text-Fig. 7.10).

Diplocraterion burrow width and lithofacies:

Following the approach of Legg (1985) a plot of average burrow width against bed thickness was made using the data from lithofacies FD of the study area (Tables 7.5, 7.6 & 7.7; Text-Fig. 7.10). As can be seen in this plot (Text-Fig.7.10) the three data points plotted for the study area cluster in the area defined by an average burrow width of about 20 mm and bed thicknesses of less than 10 cm. On the basis of Legg's (1985, fig. 3) palaeoenvironmentally more comprehensive data relating burrow width and bed thickness and on the basis of his palaeoenvironmental interpretations regarding such data, the data from the present area indicate an intertidal mixed-flat palaeoenvironmental affinity. This intertidal mixed-flat lithofacies is characterized by a medium level of energy in the energy spectrum that characterizes tidal facies. The thickness of fossil-bearing beds

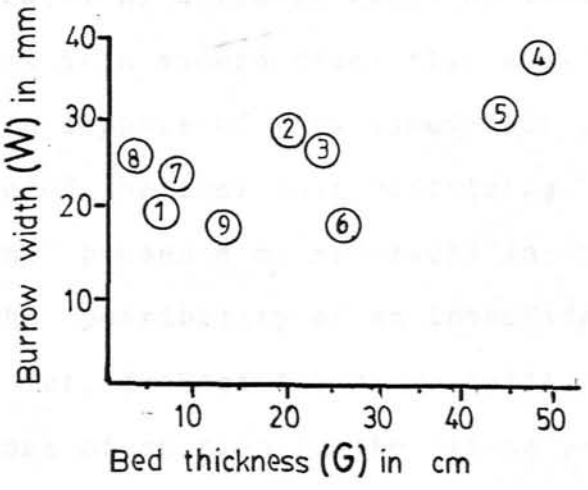
TEXT-FIG. 7.10. Plot of the width (W) of Diplocraterion burrows against the thickness (G) of the bed in which the burrows initially formed (following the approach of Legg, 1985, fig.3). Plot compares data from Legg (1985) from the Middle Cambrian of northern Spain (data points 1 to 6) and data from the present study area (data points 7 to 9; cf. Tables 7.5A, 7.6, & 7.7). This comparison illustrates that the depth of burrowing, as also reflected in the width of the U-tubes, can be taken as an indicator of water depth, and as a guide to onshore/offshore environments.



U-tube (diplocrateriids).

D Depth of water.
W Width of burrow.
H Depth of burrow.
G Bed thickness.

Measurements



1 Mixed-flat.
2 Barrier beach.
3 Sand-flat.
4 Estuarine channel.
5 Tidal channel.
6 Bar.

Inferred palaeoenvironments

Oville Sandstones (Middle Cambrian) (southern Cantabrian Mountains, Spain, Legg, 1985).

7 Sample no. 1205 (MU. 44443).
8 Sample no. 1210 (MU. 44448).
9 Sample no. 1214 (MU. 44451).

Lower Newport Member (Little Reef, Area 12)

TEXT-FIG. 7.10

in lithofacies FD ranges from about 5 cm to 1 cm and beds comprise mainly fine and very fine sandstone characterized by parallel- and flat-lamination. The thickness of these beds varies laterally and locally some beds can be seen to pinch out. The overlying and underlying beds commonly contain ripple cross-lamination and abundant asymmetrical current ripples (Plate 77 Figs. a & b). The thin interlayers or partings of shale or siltstone contain no biogenic structures.

No comprehensive palaeocurrent measurements have been made on the ripple-marks that occur immediately above and below the beds which contain the Diplocraterion burrows; but casual observations that I have made of their crestline directions indicate a degree of directional variability. The Diplocraterion burrows interpreted by Legg (1985) as of intertidal mixed-flat affinity were contained in strata characterised by a quadrimodal palaeocurrent pattern, cited by Legg, by analogy to quadrimodal current patterns in a modern tidal-flat environment studied by Klein (1970), in support of this mixed-flat interpretation. The bed thicknesses of the rock unit containing the Diplocraterion burrows and the presence of mudcracks in the overlying beds indicate that the possibility of an intertidal mixed-flat origin is quite likely (cf. de Raaf & Boersma 1971).

The concensus of opinion in the literature (e.g. Legg, 1985) suggests that Diplocraterion is found in a narrow range of the shallowest-water facies. In the tidal facies, the widest burrows are found in estuarine-channel facies (W = 38 mm); the burrows are 31 mm wide in tidal-channel facies, and 27 mm wide in sand-flat facies, with the narrowest burrows (20 mm) being found in

mixed-flat facies developed in the shallowest water (Text Fig. 7.10; and Legg, 1985 fig. 3). It can be concluded therefore that the burrow depth of Diplocraterion, as reflected in the width of the burrows can be taken as an indicator of water depth, and as a guide to onshore or offshore environments (Legg, 1985).

7.3. SPREITE-BEARING BEDDING-PARALLEL U-SHAPED BURROWS (RHIZOCORALLIIDS

7.3.1. Introduction

The classification of spreite-bearing bedding-parallel U-shaped burrows (i.e., the rhizocoralliidae) is much simpler than the classification of vertical U-shaped burrows: firstly, because the structures are more fully exposed as epirelief or hyporelief forms; secondly, because their classification is based mainly on the shape of the burrow as the major significant feature. Again, the justification of systematic features such as, significant features, and major and minor accessory features, is very important in the proposed classification. The best or genetically most meaningful classification for ichnology is one that is not solely dependent on morphology but which also places some value on ethology. If the ichnotaxonomist's approach to classification is exclusively morphological, then he will choose from among the numerous morphological features those which he considers significant and hence he will tend to disregard other arguably important features. It is very important and necessary to evaluate the significance of individual morphological features and it is also equally important for the ichnotaxonomist to evaluate these morphological features in terms of ethology.

The behavioral patterns which are responsible for the morphological features can be quite different in their degree of significance. The concept of significant features and accessory features was first used in trace fossil taxonomy by Fürsich (1974a & b). The significant features used in the present classi-

fication are the features that result from behavior judged to be of a high degree of significance; and similarly, major and minor accessory features are the features that result from behavior judged to be of a low degree of significance. There are also other accessory features that are of no taxonomic value at all (cf. Table 7.10). There are some weak points in the proposed classification in that some of the morphological features used therein must also have preservational aspect. Therefore the ichnotaxonomist must be aware of features that arise purely as artifacts of preservation. However, because the proposed classification is based both on morphology and ethology it results in genetically sound ichnogenera, ichnospecies and varieties which are therefore more meaningful to palaeoecology and sedimentology.

The proposed classification is based only on those morphological features that are judged to be of value to the ecology and do not reflect the systematics of the producers. Any approach to classification that involves the stratigraphic age of the form-taxa is judged here not to be justified and is excluded from the proposed classification.

Clarification of the meanings attached here to the terminology of morphological features used in reference to bedding-parallel spreite-bearing U-shaped burrows is detailed in Table 7.9.

7.3.2. Genetic interpretation of the rhizocoralliids

Rhizocoralliid-like trace fossils have been known for more than a century and variously interpreted as a coral (Zenker, 1836; Schmidt & Schleiden, 1846), as a sponge (Geinitz, 1846) and

TABLE 7.9. Glossary of terms used in the description of bedding-parallel/subparallel U-shaped burrows.

Orientation of rhizocoralliid burrows:	This refers to the orientation of the burrow with respect to the plane of bedding. Most of the rhizocoralliids are found to be either strictly parallel to the bedding plane or disposed in an oblique orientation with a shallow angle to bedding plane. However, the oblique forms are invariably found to occur together with the bedding-parallel forms on the same bedding plane and can grade into another.
Parallel form:	Bedding-parallel form.
Oblique form:	Bedding-oblique form with a shallow angle to the bedding plane.
Burrow outline:	The burrow outline of rhizocoralliids can take diverse forms or patterns: straight, variously short or long sinuous, planispiral or even trochospiral, and incomplete forms of J- and L- shapes. Furthermore, the burrow may be branched. Commonly several varieties can be found on the same bedding plane and some burrows show different forms in different parts of the burrow (cf. fursich, 1974a).
Spreite:	(cf. terminology for diplocrateriids in Table 7.1) There are three types of spreite: protrusive, retrusive and protoso-retrusive (Text-Fig. 7.11). The spreite of rhizocoralliids are invariably protrusive, but some forms are additionally protoso-retrusive (cf. Chisholm, 1970). However the behaviour responsible for the retrusive part during sediment deposition does not simply involve the animal retracing its previous path as in the case of the diplocrateriids (cf. D. yoyo in Text-Figs. 7.1 and 7.2), but involves a vertical shift of the U-tube concomitantly with animal's protrusive movement (Text-Fig. 7.10). This is why the final stage (part) of some rhizocoralliid limbs are vertically retrusive (Sellwood, 1970). The spreite still occupies the same plane between the original limbs but follows a curved ascending path, retrusive from the base (Text-Fig. 7.11).
Scratch marks (bioglyphs):	These features are produced by the claws of the burrow's inhabitant (especially pronounced in the case of crustaceans) during excavation. However, these patterns not only reflect the activities of their producers but also the physical constistency of the sediment at the time the burrow was excavated. If the sediment was still fairly soft, the scratch marks are unlikely to have been preserved, and this is also true in coarse-grained sediments. Bioglyph features are also known or referred to in the literature as morphological ornamentation or patterns on the burrrow surface.
Faecal pellets:	These are excretions or pellets left behind by the producers of the burrows. The composition of the pellets can shed some light on the nature of the inhabitant that produced them.
Wall margin:	cf. terminology for diplocrateriid in Table 7.1 and Text-Fig. 7.1A.
Wall thickness:	As for the diplocrateriids (cf. Table 7.1 & Text-Fig. 7.1A).
Burrow dimensions:	(cf. Text-Fig. 7.11).
Length:	The distance measured linearly along the burrow between the opening or aperture and the base of the U.
Width:	The distance measured between the distant margins of each parallel tube of the U.
Diameter:	Diameter of the tube opening or aperture.
Thickness:	Thickness of the U-tube measured from the side of the burrow (i.e., in the plane of the U). Corresponds in magnitude to the tube diameter.

especially as a group of algae (Saporta & Marion, 1881; Saporta, 1882, 1887; Delwalque, 1882; Bogatchew, 1908, 1909). After these burrows were classified as trace fossils, their interpretation consequently focused on the nature of the organism(s) that produced them (e.g., suggested organisms include: a sedentary polychaete worm (Sarle, 1906); tube-dwelling annelids (Reis, 1910); a Polydora-like annelid (Douville, 1908); crustaceans (Weigelt, 1929; Seilacher, 1955, 1967)) and elsewhere they were described in terms of the behavior of the producing organisms. The ethology/behavior varies according to the producer organism, be it a suspension-feeder (Richter, 1926; Müller, 1959), a vagrant suspension-feeder or predator (Bentz, 1929), a suspension- or deposit-feeder (Sellwood, 1970), or solely a deposit-feeder (Byrne & Branson, 1941; Seilacher, 1955, 1967; and Kemper, 1968).

However the proposed classification of the rhizocoralliids used here is not so much dependent on the taxonomic affinities of the organism that produced them but is based more specifically upon the behavior and ethology of the organisms responsible for them. There are two possible modes of life of the organisms that produced these burrows (Fürsich, 1974a).

Rhizocoralliids produced by suspension-feeders:

The following features characterize some rhizocoralliids and suggest a suspension-feeding mode of life of the producer organism(s).

Burrows with short and straight U-tubes: This type of structure can be produced by infaunal suspension-feeders and provides the advantages of proximity to the sediment-water interface and

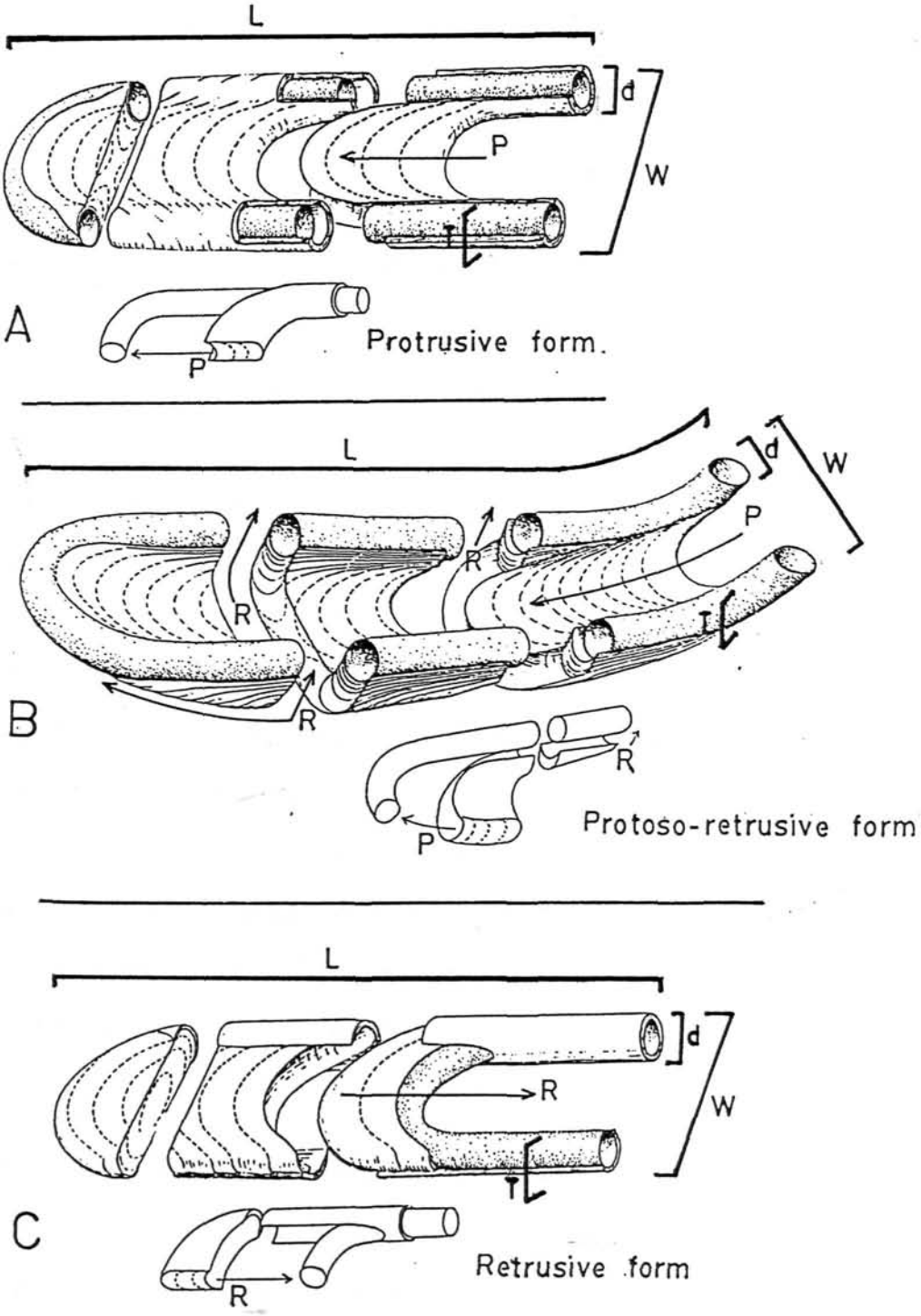
TEXT-FIG. 7.11. Anatomy of the rhizocoralliid burrow as produced by suspension-feeders. Diagrams are modified from Seilacher (1967).

A. Bedding-parallel/subparallel protrusive burrow. This protrusive burrow form is indicative of burrow extension in the U-plane in response to slight substrate degradation.

B. Bedding-parallel/subparallel protruso-retrusive burrow. This burrow is protrusive in the plane of the U but is retrusive vertically. This burrow indicates response to bed accretion.

C. Hypothetical bedding-parallel/subparallel burrow that is retrusive in the plane of the U (not yet recorded in nature).

L - Length of a burrow.
W - Width of a burrow.
d - Diameter of a aperture.
T - Thickness of a burrow.
P - Protrusive spreite.
R - Retrusive spreite.



L - length of burrow
W - width of burrow
d - diameter of aperture
T - thickness of burrow
P - protrusive spreite
R - retrusive spreite

TEXT-FIG. 7.11

therefore the suspended food supply as well as protection.

Burrows that are oblique to bedding: The advantage of building the burrow at a shallow oblique angle to bedding (i.e., sediment-water interface) is enhancement of water circulation/exchange between the animal and the overlying water while maintaining protection by staying in the lower part of the burrow. A disadvantage of the shallow oblique disposition is that the burrow is more prone to the effects of erosion and sedimentation. In such cases the organism will either die in the burrow or else escape and build a new home. However, the animal can still cope with slow sedimentation by retrusively shifting its burrow vertically upwards (Text-Fig. 7.11B).

Vertical retrusive features: In a normal situation of slow progressive vertical accretion of the sediment substrate, the organism has to maintain the ultimate (optimum) depth of the burrow by moving upwards vertically and in so doing will produce vertical retrusive spreite (Text-Fig. 7.11B). The relatively thin development of the vertically-retrusive spreite is also further evidence that the producing organism was a suspension-feeder because the amount of sediment typically reworked by suspension-feeders is less than that reworked by deposit-feeders (Sellwood, 1970; and Fürsich, 1974a).

Rhizocoralliids produced by deposit-feeders:

The following features are found in still other types of rhizocoralliids and indicate a deposit-feeding mode of life of the producer organisms.

Long sinuous, branching, planispiral or trochospiral burrows:

These types of burrows are not favoured by suspension-feeders because the burrow forms are incompatible with the easy and good water circulation that is essential for all suspension-feeders. However, even where the burrows are very long, the producing animal still maintained it at a regular depth relative to the sediment-water interface.

Bedding-parallel disposition of the burrow: Most of these burrows lie in the bedding because it is along these planes that food particles are normally concentrated and hence mining along them is the most rewarding food-gathering behavior or pattern for deposit-feeders (Text-Figs. 7.14 & 7.15). The formation of spreite is the result of the mining process and morphological variations of this pattern (such as coiling, branching and spiralling; Text-Fig. 7.12) simply increase the area of substrate exploitation for food gathering.

Interpretation of rhizocoralliid environments:

The areal and stratigraphic distribution patterns of the above two different types (ecological variants) of rhizocoralliids (i.e., suspension-feeders and deposit-feeders) reflect variation of the sedimentary environment in terms of its ecological suitability for the suspension- and deposit-feeding producing organisms.

Short and straight rhizocoralliids: The short straight rhizocoralliids are found especially in sandy environments (i.e., in sandstone beds either within simple or composite bedsets) and the sediment is relatively free of organic matter. Additionally, the sandy substrate is likely to have been moderately unstable or

shifting due to erosion and sedimentation thus explaining the prevalence of vertically retrusive spreite in these burrows (Text-Fig. 7.11). In the present study area the short bedding-parallel to partly oblique forms of Rhizocorallium jenense var. jenense are found to occur within omission surfaces, associated with Y-shaped thalassiniids (Plate 19, Fig. b, Plate 20, Figs. a, b, & h, Text-Fig. 7.13; see also Bromley, 1975).

Long sinuous, branching or spiral rhizocoralliids: Descriptions in the literature (e.g. Fürsich 1974a) and observations in the present study area indicate that the long rhizocoralliids occur in the more silty or argillaceous sediments interbedded with sandy units (Plate 21, Figs. a - c, & Plate 24, Figs. a - c). This kind of substrate is ideal for deposit-feeders because it affords the dual advantages of easy excavation (in the sand) and good food supply (in the mud). Where long burrows occur they lay almost parallel to bedding as a consequence of the producing organisms having mined along organic-rich layers in sandy bed-sets.

7.3.3. Revised classification of the rhizocoralliids

Formulation of the proposed new classification of the rhizocoralliids was necessary because of the many difficulties that were encountered in trying to deal with taxonomic considera-tions, especially at the specific and intraspecific levels. It was also found necessary to revise the classification by way of extending it to the variety level since morphological variations occur within the species and result from specific behavior dif-ferences of the producing organism rather than from sedimento-

TEXT-FIG. 7.12. Classification scheme for bedding-parallel/subparallel U-shaped rhizocoralliid burrows based on various ethologically significant morphological criteria detailed in Table 7.10. This scheme involves emended ichnotaxonomic names as detailed in Table 7.11. The previous names are shown in the boxes defined by dashed lines and the proposed new names in the solid boxes numbered 1 to 7. Although shown at bottom-left for completion, spreite-free bedding-parallel/subparallel U-shaped burrows are excluded from the classification. Asterisks indicate burrow forms that are present in the study area.

U-TUBE BURROWS

DIPLOCRATERIIDAE

RHIZOCORALLIIDAE

Horizontal or spreiten | strictly inclined burrows

ARENICOLITIIDAE

U - SHAPED

SUSPENSION FEEDER

Short U, J & L shaped, horizontal (bedding-parallel) or strictly inclined (bedding-oblique) with shallow angle.

RHIZOCORALLIUM (ZENKER, 1836).

IRREGULAR SHAPED (EXTENDED U).

DEPOSIT FEEDER

IRREGULAR

Long, sinuous, branching and strictly horizontal.

COILED

Long planispiral or trochospiral.

R. jenense (Zenker, 1836).

R. irregulare (Mayer, 1954)

R. uliarense (Firtion, 1958)

① One plane. Protrusive. (J & L incomplete structures of U).

② Two planes. Protrusive and vertically retrusive (sedimentation).

③ Long, straight, sinuous and curved (less than half circle (> 180°).

④ Bifurcated (Y-shaped). Protrusive.

⑤ Interconnected Us, Js & Ls. Protrusive.

⑥ Planispiral (full circle 360°) Protrusive.

⑦ Trochospiral. Protrusive.

R. jenense Zenker, 1836	R. jenense Zenker, 1836	R. irregulare (Mayer, 1954)	R. irregulare (Mayer, 1954)	R. irregulare (Mayer, 1954).	R. irregulare (Mayer, 1954).	R. uliarense (Firtion, 1958).
① R. jenense var. jenense. (Zenker, 1836)	② R. jenense var. retrorsus. (Zenker, 1836)	③ R. irregulare var. irregulare. (Mayer, 1954)	④ R. irregulare var. bifurcatum. (Mayer, 1954)	⑤ R. irregulare var. nexus. (Mayer, 1954)	⑥ R. uliarense var. planuspirus (Mayer, 1954)	⑦ R. uliarense var. trochospirus (Firtion, 1958)

Excluded form.

Horizontal or inclined (bedding-parallel and oblique) spreite-free form.

e.g., Rhizocorallium jenense (Zenker, 1836) in Fursich & Mayer, 1981.
Corophioides scagliai (Berrello, 1966) in Knox, 1973.

ORIGINAL NAME

NEW PROPOSED NAME

TEXT-FIG. 7.12

TABLE 7.10. Morphological features used in the proposed classification of the rhizocoralliids and other features and criteria of no value in the classification.

Significant features (generic level)

(1) U-shaped burrows (with two parallel or subparallel arms).
(2) Presence of spreite.
(3) Bedding-parallel orientation (can be shallowly oblique in some portions).

Major accessory features (specific and varietal levels).

(1) Burrow outline.
    (a) Short and straight.
    (b) Long and sinuous.
    (c) Branched.
    (d) Bifurcated.
    (e) Planispiral.
    (f) Trochospiral.

Minor accessory features (varietal level).

(1) Type of spreite.
    (a) Retrusive.
    (b) Protrusive.
    (c) Protoso-retrusive.

Other features (of no value in the classification).

(1) Scratch marks on burrow surface.
(2) Associated of faecal pellets.
(3) Taxonomy of producer.

TABLE. 7.11. Revised nomenclature of the rhizocoralliids of the proposed classification (cf. Text-Fig. 7.12).

Original (previous) name.	New (proposed) name.
(1) R. jenense Zenker, 1836.	R. jenense var. jenense (Zenker, 1836).
(2) R. jenense Zenker, 1836.	R. jenense var. retrorsus (Zenker, 1836).
(3) R. irregulare Mayer, 1954.	R. irregulare var. irregulare (Mayer, 1954).
(4) R. irregulare Mayer, 1954.	R. irregulare var. bifurcatum (Mayer, 1954).
(5) R. irregulare Mayer, 1954.	R. irregulare var. nexus (Mayer, 1954).
(6) R. irregular Mayer, 1954.	R. uliarense var. planispirus (Mayer, 1954).
(7) R. uliarense Firtion, 1958.	R. uliarense var. trochospirus (Firtion, 1958).

(Excluded forms in the present classification). Spreite-free U-shaped bedding-parallel forms can be the result of preservational aspect.

Original (previous) name.	New (proposed) name.
(1) R. jenense (Zenker, 1836) in Fürsich & Mayr, 1981.	Unnamed.
(2) Corophioides scagliai Berrello, 1966, in Knox, 1973.	Unnamed.
(3) Cavernaecola bartlingi Bentz, 1929, in Fürsich, 1974b.	Unnamed.

logical or other preservational phenomena. The proposed classification (Text.Fig. 7.12) is based on that of Fürsich (1974b) but embodies a revision and updating of the taxonomic problems of bedding-parallel U-shaped burrows and will hopefully reduce the number of ichnospecies that were either synonymous, or else poorly defined and poorly differentiated.

The proposed classification attempts to eliminate these problems by resolving which major features of the bedding-parallel U-shaped burrows should be regarded as significant at the generic-level and which major and minor accessory features should be regarded as important at the specific varietal levels. The classification is applicable only to spreite-bearing bedding-parallel and shallowly-oblique U-shaped burrows (oblique segments of the burrow typically occur at the aperture end where the bedding-parallel part of the burrow is connected to the (former) sediment interface). The classification excludes bedding-parallel spreite-free U-tubes (cf. Text-Fig. 7.12). The type genus and species of Rhizocorallium jenense Zenker (1836) is chosen as the type species of this latter (i.e., spreite-free) group. The various features used at the different ichnotaxonomic levels in the proposed classification and the rationale and justification for their selection are elaborated in Table 7.10 (see also Text-Fig. 7.12) The existing and proposed new ichnotaxonomic names of the rhizocoralliids are given in Table 7.11.

There are three major groups in the proposed classification. The first group belongs to short simple U- or J- or L-shaped burrows that are progressively protrusive with or without vertical retrusive spreite (Text-Fig. 7.11). Within this

group are two varieties significantly defined respectively by the presence and absent of vertical retrusive spreite and they are both believed to have been produced by suspension-feeders. R. jenense (Zenker, 1836) is the type species of this group. The second group, of which R. irregulare (Mayer, 1954) is the type species, is characterized by a long, sinuous, and in some cases branching type of development produced by deposit-feeders. Within this group three significant varieties can be differentiated by distinctive morphologies which relate to variable behavior. The first variety, R. irregulare var. irregulare, is long and sinuous but unbranched; the second variety is R. irregulare var. bifurcatum with bifurcated branching; and the third variety is R. irregulare var. nexus with special J- or L-shaped laterally-connected burrow segments. The third group is spirally arranged, either planispirally or trochospirally, and R. uliarense (Firtion, 1958) is the type species of this group. Two varieties occur (Text-Fig. 7.12): a planispiral form, R. uliarense var. planispiral; and a trochospiral form, R. uliarense var. trochospirus.

7.3.4. Previous records of rhizocoralliids from Australia outside the Sydney Basin

Veevers (1962) provides a review of the history of discovery of Rhizocorallium in Australia. The occurrence of rhizocoralliid trace fossils in the Permian rocks of the Carnarvon Basin (Western Australia) was, according to Veevers (1962, p.7), noted by Teichert (1946 and 1951) but not documented by him. The first published record of the occurrence of Rhizocorallium in Australia was made by Opik (in Sullivan and Opik, 1951)

from the Lower Cretaceous of the Rumbalara area of the Northern Territory. The next discovery was in the Jurassic to Cretaceous aged rocks of the Camooweal area of northwestern Queensland by Opik and others in 1953 (cf. Veevers, 1962, p.6), and was followed by other discoveries by Casey further south in the Georgina River area in Cretaceous rocks. Rhizocorallium was collected by Casey and others in 1955 from the Cretaceous Godfrey Beds in the northeastern part of the Canning Basin. Collections of Rhizocorallium were also made by Veevers in 1957 from the Kidson Beds south of Lake Tobin in the Canning Basin (Veevers, 1962, p.6). Two unrecorded rhizocoralliid specimens from the ?Permian and Lower Cretaceous of the Canning Basin were found by Veevers and Wells in the museum of the Bureau of Mineral Resources, Canberra (cf. Veevers 1962, p.6; see also Veevers & Wells, 1961, p. 173).

A detailed and comprehensive study of rhizocoralliids was made by Veevers (1962). This paper documents (p.4) the stratigraphic distribution of all previous records and collections of Australian rhizocoralliids from 15 different localities in the Canning and Eromanga Basins. Fourteen of these localities are from Lower Cretaceous rocks and one, whose locality and ichnotaxonomic determination are both doubtful, is from Permian rocks.

7.3.5 Previous records of rhizocoralliids from the Permian of the Sydney Basin

The first published record of rhizocoralliids in the Permian of the Sydney Basin was by Carey (1978) from the (mid-Permian) Snapper Point Formation (southern Sydney Basin). She

described and illustrated (in her fig.20A) R. jenense as a straight or curved U-shaped burrow with spreite orientated obliquely to the bedding. She described and illustrated (her fig.20B) other specimens of rhizocoralliids? as horizontal U-shaped burrows generally lacking spreite, or perhaps destroyed by Recent erosion.

The second published record was by McCarthy (1979) from the Lower Permian Wasp Head Formation (southern Sydney Basin). He described the rhizocoralliids as horizontal U-shaped burrows, 15 cm to 18 cm long, generally with parallel arms whose axes are about 8 cm apart, with tube diameter of about 2-3 cm, and occurring on bedding planes as epirelief forms. Although McCarthy gives details on the dimensions of the tubes (as indicated above), he also states (p.360) that "neither tubes nor apertures are preserved". Spreite are preserved as closely-spaced, low, discontinuous ridges between the arms of the tubes.

7.3.6. Rhizocoralliids from the Triassic of the Sydney Basin

The present discovery of rhizocoralliids from Triassic rocks of the Northshore Sydney Basin is the first record for the Triassic of Australia. Numerous specimens (involving different species and varieties) were collected from two stratigraphic intervals from the Lower and Middle Newport Member (see Text-Fig. 4.1). The best specimens were collected from the topmost horizon (subinterval IE9) of the Middle Newport Member in the South Palm Beach area (area 4b) and from the same horizon at Bungan Head (area 12b). Specimens of lesser quality were collected from subintervals ID1.2-ID1.3 in the Lower Newport Member from the St.

Michaels Cave locality (area 5).

Three representative ichnospecies of rhizocoralliids have been recorded from the study area (see stratigraphic distribution chart in Text-Fig. 4.1 and geographic distribution chart in Text-Fig. 4.2). The first species, R. jenense with two varieties (cf. Text-Fig. 7.12), is recorded from subinterval ID9 of the uppermost part of the Middle Newport Member in the South Palm Beach area (area 4b), and interval ID1 of the lowermost part of the Middle Newport Member in the St. Michaels Cave area (area 5). The second species, R. irregulare and its three varieties, is recorded from subintervals ID9 of the Middle Newport Member of South Palm Beach and subinterval ID1 of the Mona Vale Head area (area 14). The third species, R. uliarense var. planispirus (sole variety encountered) is recorded from subinterval IE9 of the Middle Newport Member in the South Palm Beach area (area 4b). The variety, R. uliarense var. trochospirus (cf. Table 7.11), is not recorded from these rocks.

7.3.7. Systematic ichnotaxonomy of the rhizocoralliidae

Rhizocorallium jenense Zenker, 1836.

Tentatively, the underlying list of synonymy can be given as in Fürsich (1974b):

?Lithochela problematica Gumbel, 1861.
Rhizocorallium commune Schmid, 1876.
?Taonurus ultimus Saporta & Marion, 1881.
?Taonurus panescorsii Saporta & Marion, 1881.
?Taonurus saportai Dewalque, 1882.
Glossifungites saxicava Lomnicki, 1886.
Rhizokorallium hildesiense Menzel, 1902.
?Cavernaecola bartlingi Bentz, 1929.
?Rhizocorallium devonicum Hecker, 1930.
Rhizocorallium weigelti Abel, 1935.
?Upsiloides permiana Byrne & Branson, 1941.

Rhizocorallium jurensis Mayer, 1953.

Emended diagnosis: More or less short and straight U-shaped or incomplete J- or L-shaped spreite-bearing burrows, bedding-parallel or shallowly-inclined to bedding, with or without vertically-retrusive spreite. Produced by suspension-feeders but excludes spreite-free forms (which are probably not produced by suspension-feeders). The emended classification also excludes high-angle bedding-oblique forms because they belong more to the diplocrateriids rather than the rhizocoralliids.

Variety 1: R. jenense var. jenense. Lacks vertically retrusive-spreite. This form is very common and is mainly bedding-parallel.

Variety 2: R. jenense var. retrorsus (type species for Rhizocorallium). Characterized by vertically-retrusive spreite. This form is less common and is mainly bedding-oblique.

The list of synonymy is still problematical because the original burrow morphology in many cases of the inferred synonyms was not well defined. It is neither necessary nor recommended in the proposed classification that incomplete U-shaped burrows of the J- and L-shaped types be regarded as new species.

Rhizocorallium irregulare Mayer, 1954.

Emended diagnosis: Long sinuous, bifurcating (branching), or interconnected U- J- or L-shaped protrusive-spreite-bearing burrows established in the one bedding plane. Vertically-retrusive spreite are absent. Produced by deposit-feeding organism(s). The emended diagnosis excludes the planispiral U-shaped spreite-

bearing burrows of Mayer (1954).

Variety 1: R. irregulare var. irregulare (type variety of R. irregulare). Long straight or curved arcuate burrows in which the arc of the burrow is less than 180°.

Variety 2: R. irregulare var. bifurcatum. Bifurcated (branching) burrow.

Variety 3: R. irregulare var. nexus. Interconnected U- J- or L-shaped burrows.

Rhizocorallium uliarense Firtion, 1958.

Emended diagnosis: Planispiral or trochospiral U-shaped spreite-bearing burrows produced by deposit-feeders. The emended diagnosis includes the planispirally-coiled U-shaped spreiten-burrows of Mayer (1954).

Variety 1: R. uliarense var. planispirus. Planispirally-coiled burrow.

Variety 2: R. uliarense var. trochospirus (type variety of R. uliarense). Trochospirally-coiled burrow.

Rhizocorallium Zenker, 1836.

R. jenense Zenker, 1836.

Diagnosis (specific assignment): Short U-shaped burrows with parallel arms, orientated parallel or subparallel to bedding and with well developed protrusive spreite. Believed to have been produced by suspension-feeders.

Remarks (diagnostic features): Short, straight and U-shaped bedding-parallel/subparallel structures with well-defined spreite developed as closely-spaced curved laterally-continuous or discontinuous ridges between the arms of the tube. Scratch marks or

bioglyphs are present in some forms (Plate 19, Figs. b & c, and Plate 20, Fig. d) on the surface of the burrows. No faecal pellets are observed to be associated but the burrows are associated with Y-shaped thalassiniids and turn-arounds (Text-Figs. 7.13 & 9.3.; Plate 10, Fig.a).

Variety (1): R. jenense var. jenense (Zenker, 1836)

Plate 19, Figs. a - d
Plate 20, Figs. a - h
Plate 22, Figs. a - e
Plate 75, Fig. d

Diagnosis (varietal assignment): U-shaped burrow with parallel/subparallel arms, parallel/subparallel to bedding, with protrusive spreite.

Description: The Rhizocorallium jenense var. jenense burrows mainly occur as simple horizontal U-shaped forms, in which the openings/apertures of the tubes are not clearly discernible. The overall width of the burrow ranges from 8.6 cm to 14.7 cm, the tube diameter from 3.6 cm to 4 cm, and the length from 13.9 cm to 28.6 cm (Table 7.12). Usually the crescent-shaped protrusive spreite formed as ridges are most clearly evident in the lower basal part of the burrow. The spreite occur only in the protrusive pattern (forward-moving) and they terminate laterally against the proximate wall of the tubes. The definition of the U-shaped tubes is enhanced by the clear preservation of bioglyphs which are either subparallel to the arms (Plate 19 Figs. b & c, and Plate 22 Fig. e) and/or oblique to the arms (Plate 20 Fig. d, f & g). Some burrows lack preserved bioglyphs on the surface, especially in the incomplete (J- and L- shaped) forms (Plate 22, Figs. c & d). Vertically-retrusive spreite are absent in all

forms.

Comparison: R. jenense var. jenense is believed to have been produced by a suspension-feeder, probably a crustacean. Most modern crustaceans are suspension-feeders, especially those which reside permanently inside a dwelling-burrow. A behavioral pattern of suspension-feeding is consistent with the presently observed association of R. jenense var. jenense in sandy substrates and also with its association with thalassiniids. Most of the rhizocoralliids from the study area are considerably larger than the rhizocoralliids from the Lower Cretaceous of Australia (cf. Veevers, 1962), but their size range is comparable with the rhizocoralliids in the Permian of the Sydney Basin (cf. Carey, 1978 and McCarthy, 1979).

Incomplete U-shaped (i.e., J- and L-shaped) structures also occur (Plate 33 Figs. c & b) within the same trace fossil interval containing R. jenense var. jenense at South Palm Beach and these are also included in this same form-taxa. Incomplete burrows of the J- and L-shapes occur but are not aligned as in the case of R. irregulare var. nexus, nor is any interconnection demonstrable as in the latter (cf. Text-Fig. 7.12).

Studied material: Most of the specimens remain in field and their documentation here is through photographs. Some of the specimens collected are: 403/MU.44396, 404/MU.44397, 408a/44514, 1301/MU.44455 and 1302/MU.44456.

Distribution: The specimens come from two trace fossil intervals and two separate localities. The first locality discovered was from trace fossil subinterval ID1 in the Lower Newport Member of

the Bungan Head area (area 13), and the second discovery was in trace fossil subinterval IE9 in the Middle Newport Member of the South Palm Beach area (area 4b) (see stratigraphic and geographic distribution charts in Text-Figs. 4.1 & 4.2).

Preservation and association: Rhizocoralliids world-wide occur in a wide range of substrate type but in the rocks of the present study area they frequent mainly fine to very fine sandstone, reflecting relatively medium- to high-energy environments. In the South Palm Beach area the rhizocoralliids occur within an omission-surface of the Glossifungites ichnofacies in hard-substrate (cf. Text-Fig. 7.13). At Bungan Head the rhizocoralliids occur in a Skolithos ichnofacies on soft-substrate (Plate 22, Figs. b - e). In the south Palm Beach area the rhizocoralliids are found as convex-hyporelief forms on the sole surfaces of a bed in association with thalassiniids (T. saxonicus and T. paradoxicus) and with the latter's turn-arounds (Text-Fig. 9.3; Plate 28. Figs. a & b). R. jenense var. jenense exhibits scratch marks which are confined to them and do not occur on the walls of the associated thalassiniids notwithstanding the fact that these thalassiniids are also of crustacean origin. This implies that the bioturbation by the rhizocoralliids took place at a later stage than that of thalassiniids, when the sediment was cohesive enough to preserve delicate scratch marks. This conclusion is supported too by the cross-cutting and overprinting relationship of the rhizocoralliids to the thalassiniids as clearly observed in Plate 20, Figs. a - c & h. These observations diminish the likelihood that the association of the two ichnogenera, both produced by crustaceans, demonstrates contemporaneity of the two

TEXT-FIG. 7.13. Interpreted superimposition of preomission, omission and postomission trace fossil suites in subinterval IE9 of the upper part of the Middle Newport Member at South Palm Beach (area 4b). The beds and its burrow association depicted in these schematic diagrams are illustrated in Plates 19, 20, and 28.

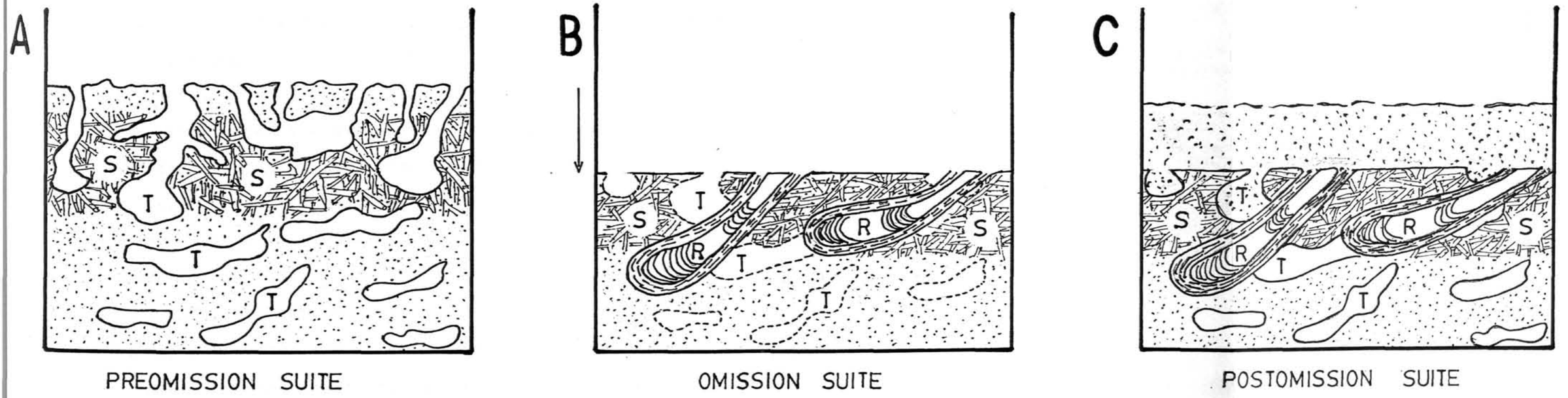
A. Preomission suite (Skolithos ichnofacies)
Thalassiniid burrows (T; networks and turn-arounds) and Spongeliomorpha burrow networks (S), both produced by crustaceans in soft unconsolidated host sediment without preserving scratch marks on the burrow surfaces (mode of preservation is inconspicuous).

B. Omission suite (Glossifungites ichnofacies)
The preomission burrow suite (thalassiniids) are followed by rhizocoralliid burrows (R; U-shaped with scratch marks, also produced by crustaceans) after erosion, non-deposition and synsedimentary lithification of substrate as a hardground during a depositional hiatus (mode of preservation is enhanced).

C. Postomission suite (barren suite)
Renewed deposition of coarser sediment fills burrow cavities of the omission suite.

TEXT-FIG. 7.14. Schematic drawing of spatially episodic protrusive spreite formed in a rhizocoralliid burrow as a result of mining processes by a deposit-feeder only in the most food-rewarding sites in mud laminae.

TEXT-FIG. 7.15. Schematic drawing showing the tiering relationship between a spreite-bearing U-shaped subhorizontally orientated rhizocoralliid burrow (R) and superimposed spreite-free vertically orientated small U-shaped arenicolitiid burrows (A) in the alternating units of trace fossil subinterval IE9 and IE10 in the Middle Newport Member at Mona Vale Head (area 14). This burrow association with the superimposition of the arenicolitiid burrows on the rhizocoralliid burrows is shown in Plate 24, Figs. b & c.

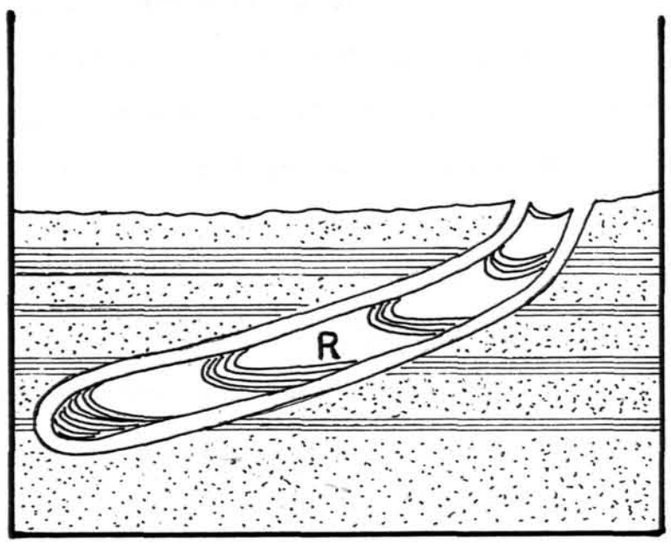


PREOMISSION SUITE

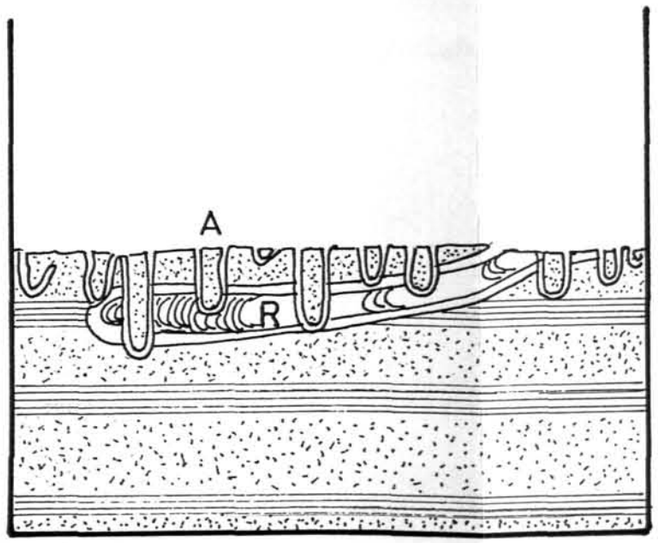
OMISSION SUITE

POSTOMISSION SUITE

TEXT-FIG 7.13



TEXT-FIG 7.14



TEXT-FIG 7.15 .

sets of burrows. The thalassiniids established themselves during a preomission stage (cf. Text-Fig. 7.12A) followed by the establishment of rhizocoralliids during an omission stage (cf. Text-Fig. 7.13B), and followed in turn by a postomission stage (barren stage with no trace fossils, cf. Text-Fig. 7.13C).

During the non-depositional or omission stage (Text-Fig.7.13B) the substrate was partly lithified and hardened to form a hard-ground which attracted colonization by a different type of infauna that produced the rhizocoralliid burrows involving a different type of burrowing behavior (i.e. U-shaped burrows rather than the networks which characterize the thalassiniids). The ichnocoenosis of the omission suite may also differ in kind from that which preceded the interruption. This difference may be due to a change in the behavioural patterns of the ichnofauna in response to the stabilization of the substrate.

Ichnofacies and palaeoenvironmental affinities: The R. jenense var. jenense discussed here belongs to the Skolithos ichnofacies which is characteristic of soft-substrates and also to the Glossifungites ichnofacies which is characteristic of firm-substrates in medium- to high-energy brackish- to shallow-marine environments. The Skolithos ichnofacies is represented solely at the Bungan Head locality whereas at South Palm Beach the Glossifungites ichnofacies overprints the earlier developed Skolithos ichnofacies (cf. Text-Fig.7.13).

Variety (2): R. jenense var. retrorsus.

Plate 23, Figs. a - d

Diagnosis (varietal assignment): Short to long U-shaped burrows

with parallel/subparallel arms, orientated parallel/subparallel to bedding, with well-developed protruso-retrusive spreite. Believed to have been produced by suspension-feeders.

Remarks (diagnostic features): Straight, short to long U-shaped bedding- parallel/subparallel burrows. Some parts of the burrow show well-defined laterally-continuous spreite, especially in the basal part of the burrow. The spreite are arranged protrusively in the U-plane and retrusively in the vertical plane and hence combine to form a protruso-retrusive pattern (cf. Text-Fig. 7.11B).

Description and ethology: R. jenense var. retrorsus mainly occurs as horizontal U-shaped burrows in which the apertures/openings of the tube are clearly discernible as circular openings. The overall burrow width ranges from 6.7 cm to 11.2 cm, the tube diameter ranges from 1.1 cm to 1.4 cm and the burrow length from 29.4 cm to 51.5 cm (Table 7.12). The distinctive crescent-shaped laterally-continuous protrusive spreite are well developed in the basal part of the burrow. But the spreite are not developed in a single plane but follow instead the progressive vertical upward movement of the arms of the U as the animal relocates the burrow in response to vertical accretion of the sediment substrate (Text-Fig. 7.11B). Hence the spreite occupy the plane between the original position of the arms of the U but also define a curved plane ascending from the base of the retrusive structure up to the final position of the U. This type of protruso-retrusive form normally results when the inhabitant tries to build a slightly obliquely disposed burrow which cannot react directly to, or readily accommodate, substrate accretion or degradation in con-

TABLE 7.12. Dimensions of Rhizocorallium burrows from the study area.[1]

Plate no.	Fig. no.	MU.no. (sp.no.)	Length L (cm)	Width W (cm)	Th. (cm)	d. (cm)
(1) *R. jenense* var. *jenense*						
19	a	NRFF	25.30	9.60	x	NWP
	b,c	"	13.90	10.70	x	3.60
	d	44379 (404)	19.80	13.60	2.5	NWP
20	a,b	NRFF	17.30	8.60	x	NWP
	c	"	18.70	9.60	x	"
	d (R)	"	23.90	11.80	x	"
	d (L)	"	25.10	11.60	x	"
22	a	44396 (403)	7.60(+) (IC)	9.30	2.0	4.00
	b	44455 (1301)	28.60	14.70	5.5	3.75
(2) *R. jenense* var. *nexus?*						
22	c	NRFF	19.30	9.45	x	3.75
	d	"	19.75	8.80	x	2.97
(3) *R. jenense* var. *retrorsus*						
23	a,b	NRFF	51.51	11.20	x	1.40
	c,d	"	29.40	6.70	x	1.07
(4) *R. irregulare* var. *Irregulare*						
24	a	NRFF	80.00	19.10	x	3.60
	b	"	39.60	16.30	x	2.90
	c	"	42.10	14.10	x	2.27
(5) *R. irregulare* var. *bifurcatum*						
21	a	NRFF	? (IC)	14.30	x	NWP
(6) *R. irregulare* var. *planispirus*						
21	b	NRFF	? (IC)	14.20	x	NWP
	c	"	? (IC)	15.00	x	"

1. Abbreviations as in Text-Fig. 7.10 and as follows: IC = Incomplete burrows; NRFF = burrow not retrieved from field; NWP = U-tube not well preserved; R/L = measurements made on right/left burrow in plate illustration.

trast to vertically-orientated burrows (e.g., Diplocraterion yoyo, cf. Text-Figs. 7.1 & 7.2). In the case of rapid erosion or deposition, the organism must either die or move elsewhere. In the case of the slightly oblique U-shaped burrow the inhabitant organism can still cope with slight progressive sedimentation by gradually shifting its burrow upwards thus producing the vertically-retrusive spreite (Text-Fig. 7.11B). However, in the case of erosion the inhabitant organism simply has to extend its tube by forward movement in the U-plane (cf. Text-Fig. 7.11B). The retrusive formation of spreite in the U-plane section, especially in rhizocoralliids, is not found in nature presumably because the organism tries to move the tube vertically upward rather than moving backward in the U-plane section (cf. Text-Fig. 7.11C). In respect of substrate accretion the retrusive response of the inhabitant organism in bedding-parallel burrows is the only appropriate response that infaunal suspension-feeders can make in order to retain contact with the sediment-water interface and at the same time maintain the best protection possible.

Comparison: Development of the retrusive spreite tends to be limited to the basal part of the burrow (i.e., basal part of the U). Such retrusive behavior is not confined only to short burrows (cf. Fursich, 1974*b*), but also occurs in long burrows (length range from 30 cm to 51 cm, see Table 7.12) as in the case of burrows in the present study area. Retrusive spreite is conspicuous in all bedding-oblique simple U-shaped burrows produced by suspension-feeders, and manifests the animals' attempts to cope with the effect of slight to moderate substrate accretion.

Studied material: The specimens shown in Plate 23 have not been retrieved from the field. Documentation here is through photography.

Distribution: Both specimens shown in the Plate 23 occur in subintervals ID1.2 and ID1.3 of the Lower Newport Member from the St. Michaels Cave area (area 5).

Preservation and association: Both specimens occur as concave-epirelief forms in very fine to fine sandstone beds. The first specimen (Plate 23, Figs. a & b) is associated with Skolithos and Turimettichnus, and the other specimen (Plate 22, Figs. c & d) is associated with Planolites, Chondrites and the vertebrate trackmark Moodieichnus didactylus (Sarjeant, 1971).

Ichnofacies and palaeoenvironmental affinities: In both substrates, the presence of Skolithos, Planolites, and Chondrites in association with R. jenense var. retrorsus suggests that the environment was probably a littoral sand-flat. Additionally, the presence of the tetrapod trackways suggests that the environment was part of a shoreline zone or complex accessible to terrestrial vertebrates. All these trace fossils belong to the Skolithos ichnofacies.

Rhizocorallium Zenker, 1836

Rhizocorallium irregulare Mayer, 1954

Diagnosis (specific assignment): Long sinuous U-shaped burrows which may bifurcate, or interconnect J- and L- shaped burrows, with subparallel arms orientated almost parallel to the bedding plane with appreciable development of exclusively protrusive spreite. Believed to have been produced by deposit-feeders. The

emended diagnostic features do not include the planispiral coiling type of U-shaped spreiten-burrow variation described by Mayer (1954) from the Muschelkalk of southwest Germany and in which the coiling arc exceeds 180°.

Remarks (diagnostic features): Long sinuous or arcuate U-shaped burrows in which the arc does not exceed 180°, or bifurcating burrows of similar character, or interconnected J- and L- shaped burrows, with subparallel/parallel arms, orientated almost parallel to bedding. The laterally-continuous to discontinuous crescent-shaped spreite are exclusively protrusive and are either patchily or extensively developed (as a function of preservation) between the two subparallel arms (Plate 24, Figs. a - c). No bioglyphs occur on the outer surface of the tubes. No faecal pellets are present in R. irregulare but the latter is associated with the spreite-free, vertically-orientated U-shaped burrow Arenicolites (Plate 24, Figs. b & c).

Variety (1): R. irregulare var. irregulare (Mayer, 1954)

Plate 24, Figs. a - c

Diagnosis (varietal assignment): Long sinuous or arcuate U-shaped burrows, in which the arc of the burrow does not exceed 180°, but which are unbranched and lack incomplete (J- or L-shaped) burrow segments. The arms of the U-tube are parallel/subparallel, with exclusively protrusive spreite, and are oriented parallel/subparallel to bedding.

Remarks (diagnostic features): As for varietal assignment.

Description: R. irregulare var. irregulare mainly occurs as long sinuous, bedding-parallel burrows with U-shaped subparallel arms and protrusive spreite. The openings/apertures of the U-tube are

not clearly defined, partly due to modern erosion. The overall burrow width ranges from 14 cms to 19 cms, tube diameter from 2.3 cms to 3.6 cms, and the burrow length ranges from 39.6 cms to as much as 80 cms (Table 7.12). Normally the crescent-shaped protrusive spreite are developed across the entire limb of the burrow, but are not everywhere laterally-continuous across the limb for one reason or another, one possible explanation being that the animal mined out sediment in its quest for food only in the finer-grained organic-rich interbeds arranged in a vertically irregular pattern within the substrate (cf. Text-Fig. 7.19), or perhaps secondly, because of modern erosion. The U-tube is not sharply differentiated from the spreite limb. No bioglyphs or faecal pellets are present. Vertically-arranged retrusive spreite are absent in all specimens.

Comparison: R. irregulare var. irregulare is believed to have been produced by deposit-feeders. This interpretation is suggested by its long sinuous tubes which would have been incompatible with the good water circulation necessary for suspension-feeders. If it be argued that the structure was produced for shelter by a suspension-feeder then there is no obvious functional reason why the animal should have increased its distance from the sediment-water interface given that most/all suspension-feeders maintain a uniform depth below this surface. However, such burrow elongation makes perfect sense if the burrows are interpreted as morphological artifacts of animals leading a deposit-feeding mode of life. Thus, the spreite formed as a result of mining for food-gathering and the morphological extension of the burrow's length (whether

sinuous or regularly-curved) increased the exploited area/volume of substrate. Furthermore, these U-shaped structures are more commonly horizontal rather than oblique, and it can be argued that this orientation focused or guided the mining process along the finer organic-rich layers (i.e., along the most food-rewarding planes in Text-Fig. 7.14).

Studied material: None of the specimens illustrated in Plate 24 have been retrieved from the field. Their documentation here is confined to photography.

Distribution: This variety of Rhizocorallium occurs at two localities: the first specimen (Plate 24, Fig. a) comes from subinterval ID1.2 in the Lower Newport Member at Bilgola Beach (area 10b) and the other two specimens (Plate 24, Figs. b & c) come from subintervals IE9 and IE10 in the Middle Newport Member at Mona Vale Head (area 14).

Preservation and association: All specimens occur either as convex-hyporelief forms or concave-epirelief forms in fine sandstone and siltstone beds. The specimen shown in Fig. a of Plate 24 occurs as a solitary form in siltstone and the others in Figs. b and c of this plate occur in fine sandstone associated with U-shaped, spreite-free vertically orientated Arenicolites (Text-Fig.7.15).

Ichnofacies and palaeoenvironmental affinities: The deposit-feeding types of rhizocoralliids belong to the Cruziana ichnofacies (low-energy or quite environment). The association with R. irregulare var. irregulare with Arenicolites, which is wide-ranging in many shallow-water ichnofacies, cannot be used in the reconstruction of the environment. An estuary or protected lagoonal type of

environment or a slightly deeper shallow-marine environment below wave-base is indicated (as possibly also suggested by the absence of ripple-marks and cross-stratification in the host sediments).

Variety (2): R. irregulare var. bifurcatum

Plate 21, Fig. a

Diagnosis (varietal assignment): Long sinuous or arcuate bifurcating U-shaped burrows with parallel/subparallel arms parallel/subparallel to bedding and with exclusively protrusive spreite.

Remarks (diagnostic features): As for varietal assignment. Tube diameter is very small in comparison with the width of the spreite limb.

Description: Knowledge of this variety of Rhizocorallium in the study area is based on only two specimens, one of which is illustrated in Plate 21. Fig. a. The burrows occur as horizontally-orientated bifurcated forms in which the apertures/openings of the U-tubes are not clearly differentiated from the spreite limbs except in some parts. The overall burrow width is 14.3 cm; the tube diameter cannot be measured because of poor preservation. The burrow length is difficult to define because of its incompleteness and the branching pattern. The branching angle is 45°. The crescent-shaped protrusive laterally-discontinuous spreite are poorly preserved and are evident only in limited parts of the burrow. No bioglyphs have been observed on the burrow surface, nor do faecal pellets occur in association with the burrows. Vertically-retrusive spreite are absent.

Comparison: R. irregulare var. bifurcatum is believed to have

been produced by deposit-feeders. This interpretation is favoured by the long, branching form which suggests that the inhabitant made this structure simply as a result of mining for food; it is not the type of structure (and inferred behaviour) characteristic of suspension-feeders. Moreover, the nature of the branching is consistence with the patterns produced by deposit-feeders. Such branching patterns arise where the deposit-feeder decides that a particular place that it is mining is not sufficiently rewarding, and hence stops mining there and moves on to a more rewarding site by making a branch. This bifurcating type of rhizocoralliid burrow was first recognized by Mayer (1954) on a bedding plane at the top of the Oxfordian Bencliff Grit, east of Osmington Mills, on the Dorset coast of southern England. In those examples Mayer (1954) explained that the producer of the trace fossils had mined along the nutrient-rich troughs of asymmetrical ripples. The trace fossil does not occur on rippled surfaces at the Narrabeen Group localities where it is known to occur but the organism seems to have produced the same scavenging pattern as the Jurassic rhizocoralliids of southern England.

Studied material: The specimens have not been retrieved from the field. Documentation here is through photography.

Distribution: The specimens occur in subinterval IE9 of the Middle Newport Member at South Palm Beach (area 4b).

Preservation and association: The burrows occur as convex-hyporelief forms in a bed of fine sandstone. They are associated with varieties of R. irregulare and R. uliarense.

Ichnofacies and palaeoenvironmental affinities: These deposit-feeding types of rhizocoralliids belong to the Cruziana ichnofa-

cies (low-energy quite environment). An estuarine or lagoonal type of protected environment or a slightly deeper shallow-marine setting below wave-base is indicated. The burrows are not associated with ripple-marks or other tractional sedimentary structures.

Rhizocorallium uliarense Firtion, 1958

Diagnosis (specific assignment): Long planispirally-coiled U-shaped burrows with subparallel arms, orientated parallel/subparallel to bedding with appreciable development of protrusive spreite; coiling arc of burrow exceeds 180°.

Remarks (diagnostic features): Elongated planispirally-coiled U-shaped burrows with subparallel arms disposed subparallel to bedding with poorly-defined laterally-discontinuous crescent-shaped spreite. The protrusively arranged spreite is observable only in some parts of the burrow (?due to the modern erosion). The coiled U-shaped burrows occur as convex-hyporelief forms in fine sandstone; vertically-retrusive spreite are absent and there is no trochospiral form in the pattern of coiling as in R. uliarense var. trochospirus (cf. Text-Fig. 7.12).

Variety (1): R. uliarense var. planispirus (Mayer, 1954)

Plate 21, Figs. b & c

Diagnosis (varietal assignment): Long acruate planispirally-coiled U-shaped burrows with parallel/subparallel arms which are oriented parallel/subparallel to bedding. Spreite are exclusively protrusive.

Remarks (diagnostic features): As for varietal assignment. Diame-

ter of U-tube is probably small in comparison with the width of the spreite limb. Also, the coil may appear to be branched at a high angle.

Description: Knowledge of R. uliarense var. planispirus in rocks of the study area is based on only two specimens which are illustrated in Plate 21 Figs. b and c. R. uliarense var. planispirus occurs as elongated planispirally-coiled U-shaped burrows. The U-tube and the apertures/openings of the tube are not well defined. Consequently, differentiation of the tube from the spreite limb is ill-defined. In each of the two specimens from the study area (Plate 21, Figs. b & c) the planispiral burrow appears to be branched at a high angle to the coil, perhaps indicating a connection to or a transition with the straight form R. irregulare var. irregulare. The overall burrow width ranges from 14.2 cm to 15 cm, the tube diameter is not measureable due to poor preservation, and the burrow length is not measurable because of incomplete preservation. The reconstructed diameter of the planispiral coil is measured for comparison: 35 cm in Plate 21 Fig. b; and 30 cm in Plate 21 Fig. c. The spreite occur exclusively as the protrusive type but are poorly preserved and are only discernable in some parts of the burrows, mainly adjacent to the proximate margins. No bioglyphs have been observed on the burrow surfaces and no faecal pellets occur, and no other types of trace fossils are associated with R. uliarsense var. planispirus.

Comparison: R. uliarense var. planispirus is believed to have been produced by a deposit-feeder. This interpretation is strongly indicated by its elongated spiral nature. The inhabitant of

this burrow made it simply as a result of its mining activities for food. The producer organism located a favorable place that was rich in nutrient on the substrate and mined spirally around in this spot. This type of structure is believed to have been produced by a deposit-feeder and was placed variously under the form-taxa R. jenense (Muller, 1959) and R. irregulare (Fursich, 1974). However, this structure is presently believed to manifest a special type of behavior of an organism and hence must be considered to be a different variety than R. jenense and R. irregulare, and one more related to R. uliarense (cf. Text-Fig. 7.12; Table 7.11).

Studied material: The specimens have not been retrieved from the field. Documentation here is confined to photographs.

Distribution: R. uliarense var. planispirus occurs in subinterval IE9 at South Palm Beach (area 4b).

Preservation and association: The specimens occur as convex-hyporelief forms in fine sandstone. They are not associated with other trace fossils.

Ichnofacies and palaeoenvironmental affinities: R. uliarense var. planispirus belongs to the Cruziana ichnofacies and is characteristic of low-energy quite environments, such as estuaries, lagoons or slightly deeper shallow-marine settings (below wave-base). A protected environment such as these is also suggested by the absence of ripple-marks on other tractional sedimentary structures in the host sediments.

7.4 SPREITE-FREE SIMPLE VERTICAL U-SHAPED BURROWS

7.4.1. Introduction

As mentioned in Section 7.1 of this chapter, small spreite-free vertical U-shaped burrows occur in the study area and are attributable to Arenicolites (Salter 1857). Arenicolites has previously been described from the marine Lower Permian Snapper Point Formation of the southern Sydney Basin by Carey (1978) but this is the first record of it from the Triassic of the Sydney Basin.

The relationship of the arenicolitiidae to the diplocrateriidae and rhizocoralliidae in the general classification of U-shaped burrows is shown in Text-Fig. 7.2.

7.4.2. Systematic ichnotaxonomy of the arenicolitiidae

Arenicolites Salter, 1857

Plate 24, Figs. b & c
Plate 64, Fig. a

Diagnosis (specific assignment): Small vertical U-shaped spreite-free burrows (including J- and L-shaped incomplete forms). On the bedding surface these normally occur as small apparently unconnected circular to subcircular openings, with or without funnel-shaped apertures.

Remarks (diagnostic features): Simple U-shaped, spreite-free burrows, disposed normal to bedding. Variations of the burrow include: tube diameter, degree of definition of the walls, burrow width and burrow depth. The arms are typically branched, some with a funnel-shaped aperture, and either with or without a wall-lining. Where a wall-lining is present or preserved, sculptures commonly occur on the burrow surface but otherwise the

surface is smooth. The burrows can extend to a considerable depth.

Description: As seen on bedding-plane exposures Arenicolites mainly occurs as two apparently unconnected spreite-free small holes or openings. Some of the openings/apertures are funnel-shaped. The overall width of the burrow is only a few cms, the tube diameter ranges from 3 mm to 5 mm, and the burrow depth is invariably larger than the burrow width by a few cms. A wall-lining is only sporadically present and where present preserves surface ornamentation. Most of the burrows have been actively back-filled by fine dark sediment and some are passively-filled by overlying sediment.

Comparison: Arenicolites can be ascribed to the activities of worms or worm-like organisms, mainly as a result of feeding activities, as indicated by the common presence in many burrows of faecal stuff, but in some cases the burrows probably also served as domiciles (i.e., in cases where faecal stuff is not in evidence). The apertures are not well defined but are funnel-shaped. The length of the burrow is very much shorter than the 1-m-long burrows of Arenicolites from the Upper Cretaceous siliceous sandstones and chalk of the Western Interior Region of the USA (cf. Frey & Howard, 1970). The sizes of the present Triassic burrows are quite comparable with those of Arenicolites from the Mid-Carboniferous deltaic sediments of the Central Pennine Basin of England (Eagar et al., 1985). In the latter examples all forms have funnel-shaped apertures with J- and L-shaped variations of the burrow. Such variations of burrow shape have not been encoun-

tered in the present study area. The length and width of the present specimens are much smaller than and are not comparable with either of the species (species A and B) described by Carey (1978) from the Lower Permian Snapper Point Formation of the southern Sydney Basin.

Studied material: No specimens were retrieved from the field. Documentation here is restricted to photographs.

Distribution: The studied specimens come from two different localities: the first group of specimens (Plate 24, Figs. b & c) are from subintervals IE9 and IE10 of the Middle Newport Member at Mona Vale Head (area 14), where they show a tiering association with rhizocoralliids (Text-Fig. 7.14); the second group of specimens (Plate 64, Fig. a) occur in subinterval ID2 of the Lower Newport Formation at the Hole in the Wall (area 11).

Preservation and association: All burrows occur as full-relief structures. The Arenicolites burrows at Mona Vale Head occur in very fine sandstone and are associated with R. irregulare; those at the Hole in the Wall occur in siltstone and are associated with Planolites and Skolithos. Mud cracks occur in the same bed as the burrows at the latter locality and trains of asymmetrical ripple-marks occur in the immediately overlying bed.

Ichnofacies and palaeoenvironmental affinities: Most of the arenicolitiids are facies-independent, and hence occur everywhere (i.e., they are not confined to any particular environment). At the Hole in the Wall locality the presence of Planolites burrows and asymmetrical ripple-marks indicates a very shallow-water environment, such as a tidal-flat, estuary or lagoon, or any part of a slightly deeper shallow-marine environment. This kind of

setting is characteristic of the Skolithos ichnofacies. At Mona Vale Head the association of Arenicolites burrows with R. irregulare (formed by deposit-feeders) belongs to the Cruziana ichnofacies and is indicative of the deeper part of a shallow-marine environment (below wave-base, not associated with ripple-marks).