TRACE FOSSILS AND SEDIMENTOLOGY OF THE APPALOOSA SANDSTONE: BEARPAW-HORSESHOE CANYON FORMATION TRANSITION, DOROTHY, ALBERTA

E. G. S. Field Trip Guidebook

By

Tom Saunders and S. George Pemberton

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CONTENTS

INTRODUCTION

Traditionally, Geologists have relied heavily on physical sedimentary structures in the interpretation of ancient clastic marine deposits, with little or no environmental significance given to their biogenic counterparts (ie., trace fossils). More recently, however, the potential of trace fossils as environmental indicators has been repeatedly demonstrated (cf. Howard, 1972; Fürsich, 1975; McCarthy, 1979; Howard and Frey, 1984; Pemberton and Frey, 1984; Curran, 1985).

In the present study, the fields of ichnology and sedimentology are combined in attempt to arrive at the depositional setting of a late Cretaceous marine sandstone sequence outcropping along the Red Deer River in southcentral Alberta. Our main objective here is to further demonstrate the value of an integrated analysis in the interpretation of ancient depositional environments.

GEOLOGICAL SETTING

An essentially flat lying succession of intertonguing shallow and marginal marine strata, forming the bases for this study, is exposed in the valley walls of the Red Deer River between the townsites of East Coulee and Dorothy (figures 1 and 2). The succession stratigraphically separates the marine shales of the Bearpaw Formation from the overlying terrestrial coal-bearing strata of the Horseshoe Canyon Formation. It therefore occupies a pivital position within the major regressive wedge of clastic sediments deposited in late Campanian-early Maestrichtian time as the epicontinental Bearpaw Sea regressed to the southeast across the southcentral plains region of Alberta.

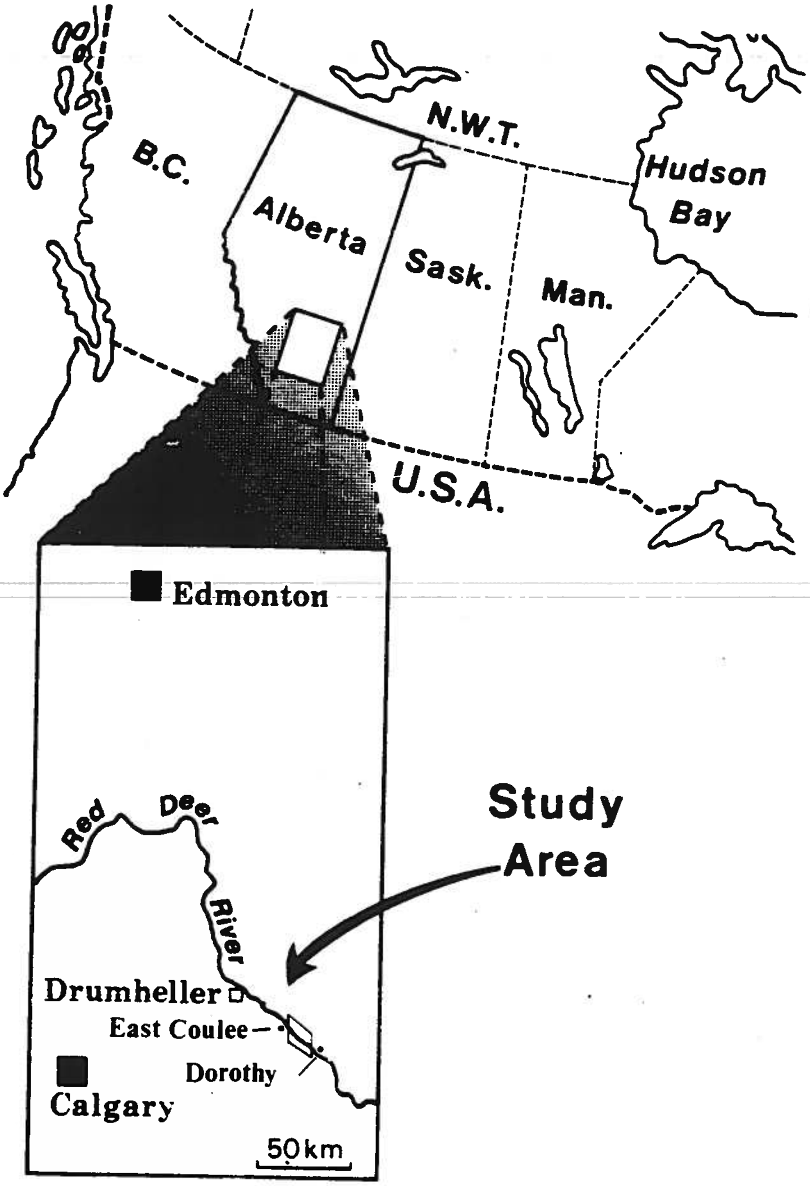


Figure 1: Location of study area (adapted from Rahmani, 1983).

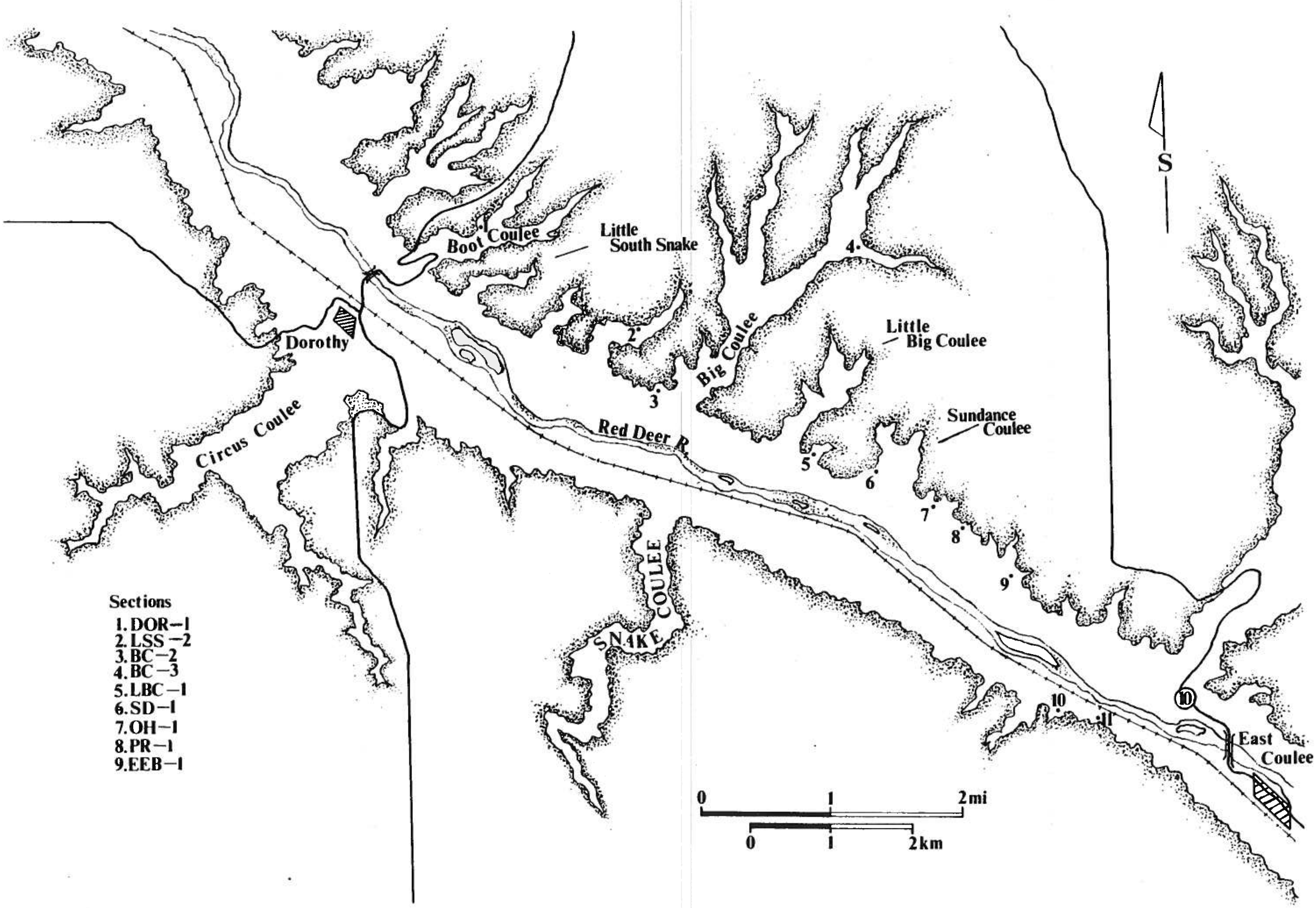


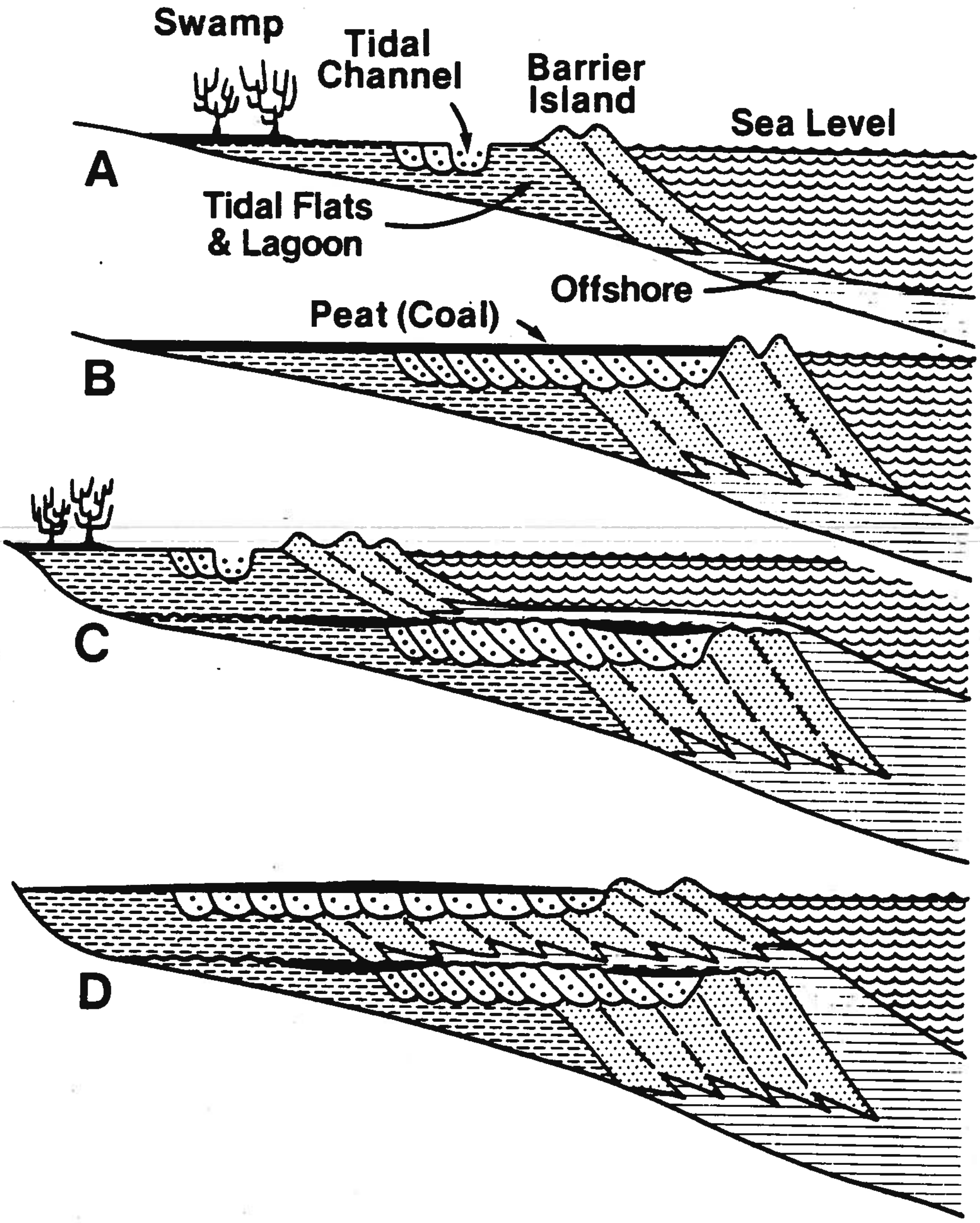
Figure 2: Map of study area showing location of measured Appaloosa sections.

PREVIOUS WORK

The study area (figure 2) adjoins those of Shepheard and Hill (1970, 1979) and Rahmani (1981, 1983), both of whom investigated a more "landward" extension of the succession outcropping to the northwest between East Coulee and Willow Creek. From here, Shepheard and Hill (1970) established the general depositional framework as that of an easterly prograding deltaic complex, drawing most of their analogies with the modern Mississippi Delta. Rahmani (1981, 1983) re-interpreted the succession, presenting strong evidence which instead favored deposition within a range of estuarine and barrier-island related envrionments associated with an "embayed" deltaic shoreline; analogies here were drawn with the mesotidal estuaries occurring along the Georgian coast, the estuaries of the Rhone Delta of southwestern Netherlands, and the Willipa Bay esturary on the Pacific Washington coast.

In addition to establishing a working depositional model, within a 50 meter interval of the transitional succession Rahmani (1983) was able to trace the movements of the paleoshoreline through a series of transgressive-regressive cycles. Following the initial southeastern progradation of the main estuarine complex, a major transgression ensued ultimates leading to the establishment of a barrier-island complex at the shoreline. Figure 3 depicts the sequence of events which then followed as envisaged by Rahmani (1983).

FIGURE 3


Swamp
Tidal Channel
Barrier Island
Sea Level
A
Tidal Flats & Lagoon
Offshore
Peat (Coal)
B
C
D

THE APPALOOSA SEQUENCE (R_3)

The uppermost progradational sequence of Rahmani (1983) is represented by a distinctive cliff forming sandstone that begins near East Coulee and continues right across the present study area finally disappearing beneath the erosional landscape approximately 8 kilometers to the southeast of Dorothy. In order to facilitate future reference, this sequence is here informally designated as the "Appaloosa".

Throughout the study area, the sequence exhibits a characteristic upward shoaling succession of sediment textures and sedimentary structures, that when combined with the observed distribution of trace fossils, strongly implies deposition within a prograding barrier Island shoreline setting. Our interest in this sequence largely pertains to the contained assemblage of exceptionally well preserved marine trace fossils. Included are a wide diversity of forms, representative of the following ichngenera: *Ophiomorpha, Macaronichnus, Conichnus, Rosselia, Skolithos, Planolites, Palaeophycus, Gyrocorte, Aulichnites, Cylindrichnus, Asterosoma, Teichichnus, Lockeia, Chondrites, Rhizocorallium,, Diplocraterion*, and *Thalassinoides.*

Schematic representations of measured sections to be visited during the trip are shown in figures 4 to 8. The locations of these and other Appaloosa sections measured during the 1985 field season are then indicated on the map provided in figure 2. Based on fundamental sedimentologic and ichnologic changes that occur upward through the sequence, at all sections--with the exception of EC-5 (figure 8)--the Appaloosa can be readily subdivided into three distinct zones, here dubbed the "Lower", "Middle", and "Upper". Correspondingly, each zone can be attributed to deposition within a specific shoreline related sub-environment. In the pages that follow, the sedimentological and ichnological characteristics of each zone will be recounted. Depositional interpretations will then be made based on comparisons with modern systems, as well as with several of the more well established ancient barrier-island sequences displaying features found to be remarkably similar to those described herein.

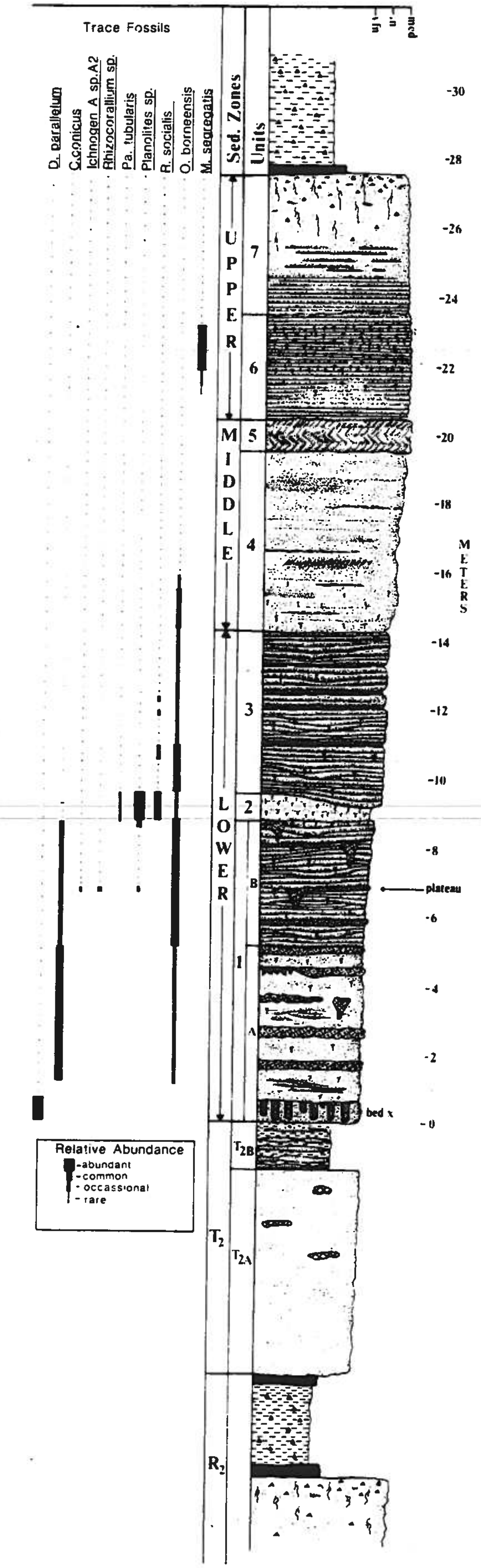


Figure 4. Schematic representation of measured section of Appaloosa Sandstone at Sundance Coulee. (S.D.-1)

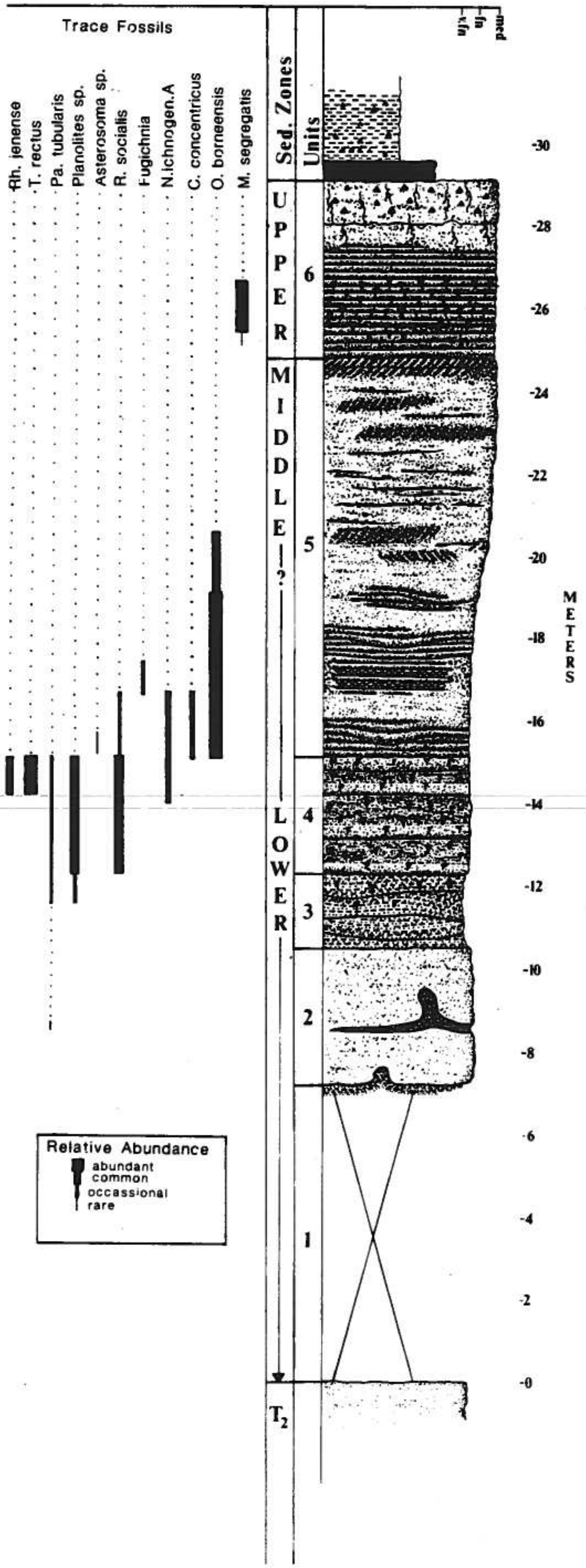


Figure 5. Schematic representation of measured section of Appaloosa Sandstone at Boot Coulee (DOB-1)

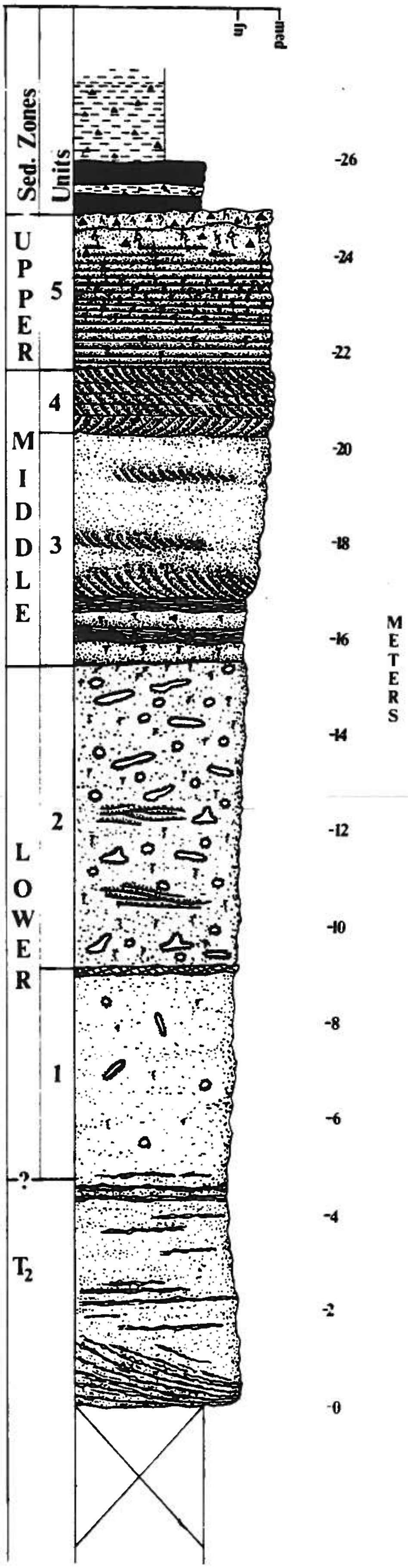


Figure 6. Schematic representation of measured section of Appaloosa Sandstone at OH-1.

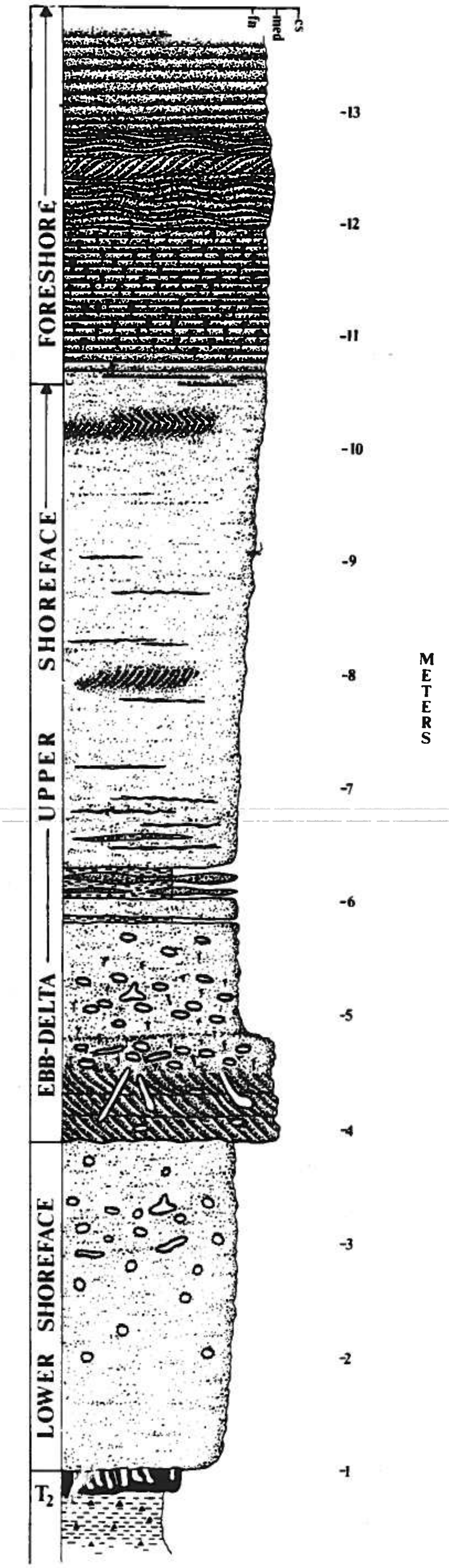


Figure 7. Schematic representation of measured section of Appaloosa Sandstone at FC-4.

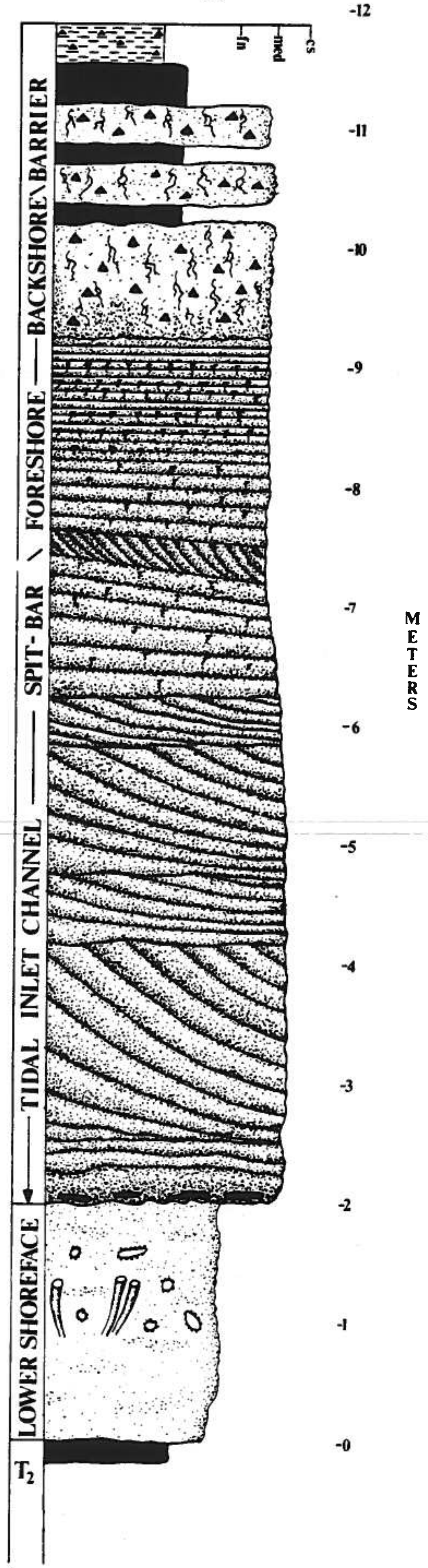


Figure 8. Schematic representation of measured section of Appaloosa Sandstone at EC-5.

LOWER ZONE: Lower Shoreface Sequence

Sundance Coulee Section (figure 4)

At Sundance Coulee, the Lower Zone disconformably overlies the T2 transgressive sequence and in turn comprises a 13 meter coarsening-upward succession of very-fine to fine-grained sandstone. Here, the Lower Zone can be further sub-divided into three units (figure 4), each characterized by a distinctive facies association. Each of these units will now be described followed by discussions of their depositional origins and genetic relationships.

As discussed in the paragraphs to follow, the sedimentological and ichnological characteristics of the Lower Zone combine to indicate a "Lower Shoreface" environment of deposition. Across a hypothetical storm influenced beach-offshore profile, such as envisaged here for the Appaloosa paleoshoreline, the lower shoreface corresponds with the transitional zone extending seaward from (1) the depth at which nearshore fairweather wave-related processes first begin to significantly influence the depositional record, to (2) the effective depth to which intense periodic storm waves are in turn capable of interacting with bottom sediments, thus exerting a dominant influence on sedimentation.

Unit 1: Lower Storm Succession

Unit 1 is characterized by an 8 meter ammalgamation of erosively based sand beds that increase upward through the unit with respect to both sand grain size and average bed thickness. Internally, the sands are relatively clean, and whereever the nature of bedding can be discerned, reveal either planar lamination, or more commonly, low-angle undulatory (hummocky) cross-stratification.

Subunit 1A: The lowermost 5.5. meters of Unit 1 consists largely of friable, deeply weathered, drab-colored dark-greyish sandstone occurring in poorly defined beds 0.2 to 1.0 meters thick. Prominent laterally discontinuous sideritic ironstone layers, 20 to 30 cm thick, are common throughout this part of the succession and appear to be exclusive to the very tops of individual beds, often occurring immediately subjacent to major first

FIGURE 9

FIGURE 9

APPALOOSA SANDSTONE
Lower Shoreface (Lower Zone) Deposits at Sundance Coulee

9A. Ammalgamated storm beds from subunit 1B; note swaley x-stratified sand bed at top of photo, and *Conichnus conicus* (c) immediately subjacent to a major discordant surface towards bottom of photo.

9B. Resistantly cemented Lower Zone storm beds from BC-1 displaying well-developed swaley cross-stratification; riddled throughout with *Ophiomorpha borneensis.*

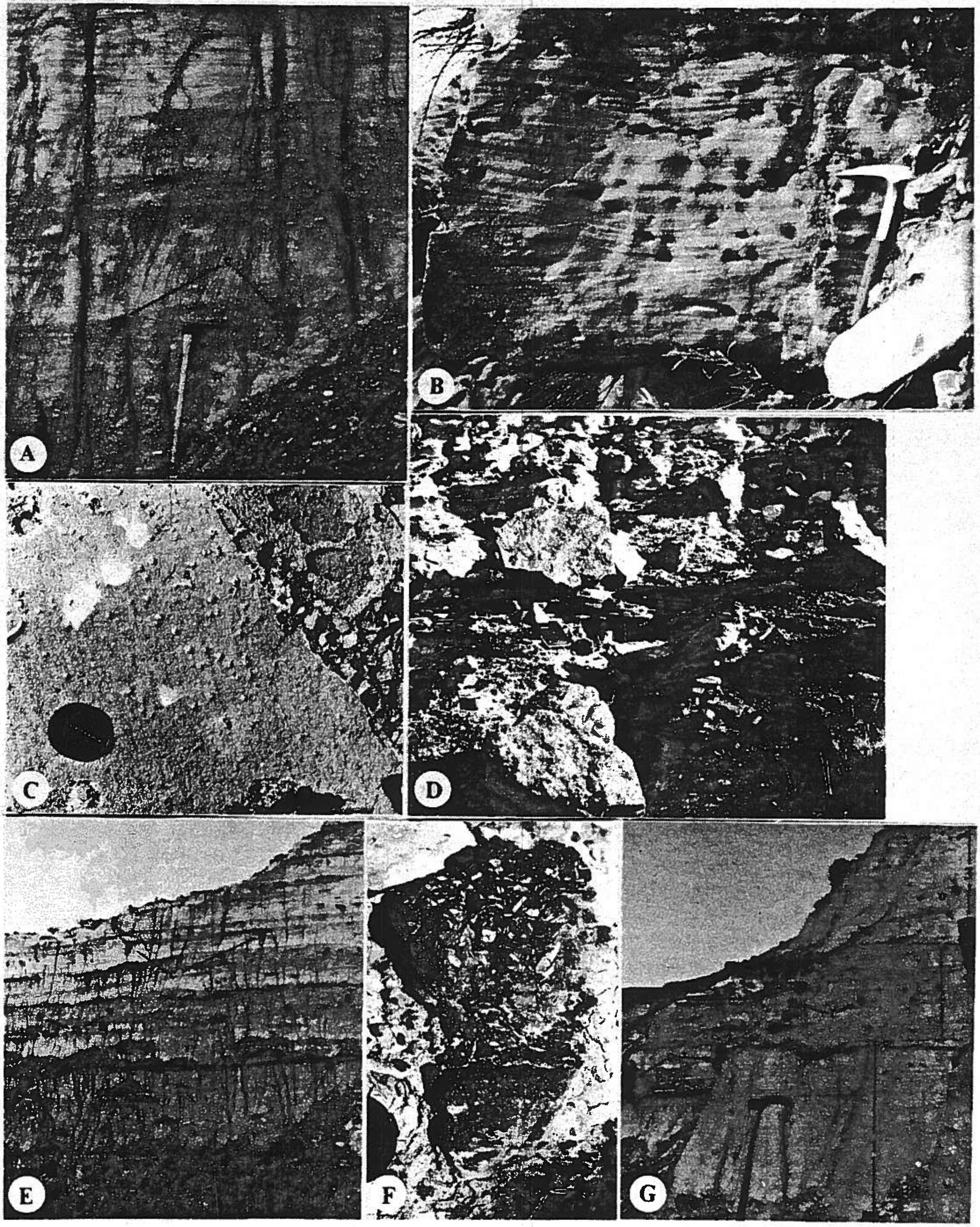
9C. Upper bedding surface from subunit 1B displaying well developed parting lineation with a profusion of superimposed *Skolithos linearis.* In bedding plane preservation *S. linearis* commonly forms distinct epichnial bumps representing the horizontal expression of vertically oriented cylindrical shafts; note distinctly lined specimen at very bottom centre of photo.

9D. Calcite cemented pod within lowermost storm bed of Unit 3 displaying well-developed hummocky cross-stratification; field book for scale.

9E. Photograph of Lower Zone taken off line of section at Sundance Coulee; note resistant sideritic layers and interspersed *Conichnus conicus* (c).

9F. *Conichnus conicus* Myannil, 1966. Sideritic specimen from subunit 1B showing typical concentration of fragmentary plant material. These burrows evidently represent the resting trace of large anemone or anemone-like organisms.

9G. Vertical face showing Unit 2 along with top of Unit 1 and the lowermost storm bed of Unit 3; note conspicuous sideritic trace fossils, including: *Conichnus conicus* (c), *Rosselis socialis* (r), and *Ophiomorpha borneensis* (o).


A
B
C
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G

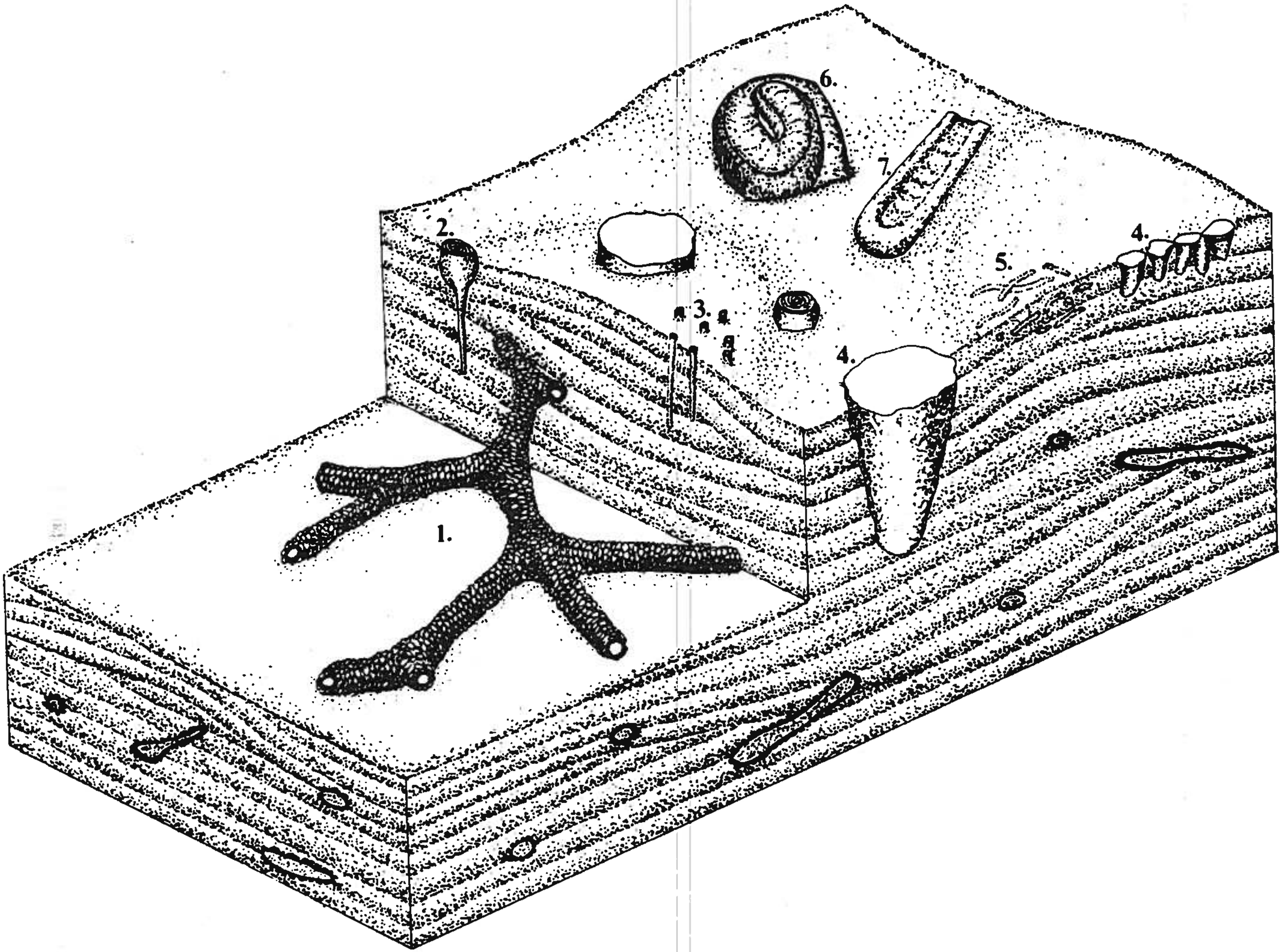
order erosion surfaces. These resistant ledge forming layers oxidize a distinctive iron-red color on exposure to the atmosphere, and thus stand out in stark contrast from the surrounding clay-cemented sands (figure 9E). Unfortunately, intense surface weathering has greatly obscured internal bedding within this part of the succession, however, within isolated calcite-cemented pods hummocky cross-stratification (H.C.S.) was found to be ubiquitous.

Subunit 1B: 5.5. meters from the base of Unit 1 a fundamental change, traceable throughout the coulee, occurs in the color and weathering characteristics of the sandstone. Above this point, the sands become markedly lighter in color from that of the underlying subzone (see figure 9E), and improved outcrop conditions provide for a much clearer picture as to the internal structure of the sand. Two morphologically distinct variants of H.C.S. appear to be represented. The first form, referred to here as "classical" H.C.S. (sensu Harms et al., 1975), involves both antiformal and synformal laminae sets which conform to internal bed discordances, and intersect one another at low angles (< 15 ; figure 9D). The second variant better complies with the description of "swaley" cross-stratification (S.C.S.) introduced in the literature by Leckie and Walker (1982) in which synformal scours and conformant to slightly divergent laminae sets constitute the dominant bedding element; hummocks or internal convexities of any kind appear to be absent (figures 9A & 9B). Within subunit 1B, sideritic ironstone layers persist with reduced thickness and frequency from the underlying subunit.

Trace Distributions: The overall assemblage of trace fossils occurring within Unit 1 is summarized diagrammatically in figure 10. Not all of the forms illustrated, however, were observed in direct association with one another. *Conichnus conicus* and *Ophiomorpha borneensis* occur sporadically distributed throughout the unit; *Conichnus conicus* being most common within subunit 1A, whereas within subunit 1B *Ophiomorpha borneensis* predominates. *Conichnus conicus* penetrates the tops of beds, and along with the sideritic ironstone layers from which they commonly subtend, these conspicuous burrows provide an excellent means of identifying concealed-bed-junctions on deeply weathered vertical exposures where the nature of bedding cannot readily be determined (see figure 9E). Network developments of *Ophiomorpha borneensis* can be found at

FIGURE 10

Figure 10: Composite block diagram depicting the overall assemblage of trace fossils occurring within Unit 1 of the Sundance Coulee section. Included are: *Ophiomorpha borneensis* (1), *Conichnus conicus* (4), *Skolithos linearis* (3), *Rosselia socialis* (2) *Planolites sp.* (5), *Rhizocorallium sp.* (7), *N. ichnogen. A sp. A2* (6).



1.
2.
3.
4.
4.
5.
6.
7.

virtually all levels within any given bed (see plate 4, figure 1). On exposed bed top bedding surfaces a common sedimentologic-ichnologic association involves parting lineation with superimposed profusions of *Skolithos linearis* (figure 9C). Finally, *Rhizocorallium sp.*, *N. ichnogen A sp. A2*, and *Planolites sp.* were all observed at a single level within subunit 1B, situated within a plateau forming sideritic layer (Plate 12, figures 1-3 & 5; Plate 7, figure 1; Plate 11, figure 2).

Unit 2: Fairweather/Minor Storm Deposits

Overlying Unit 1 on the line of section is a bed 0.5 meters thick consisting of intensely weathered fine-grained sandstone, locally containing minor amounts of admixed silt and carbonitized organics. The unit is largely built up of relatively thin (5 to 20 cm), irregularly layered and somewhat poorly defined beds (figure 9G). Profusions of *Planolites sp.* occur throughtout the unit, being concentrated at the tops of thicker beds, while completely prevading the thinner beds. In addition to the distinctive bioturbate texture imparted from *Planolites sp.*, isolated burrow specimens of *Rosselia socialis*, *Ophiomorpha borneensis*, and *Palaeophycus tubularis* were also recorded (see figure 5). In adjacent coulees, equivalent deposits revealed similar ichnofaunas, but were further characterized by the common occurrance of *Rhizocorallium jenense* and *Teichichnus rectus* (see unit 4 in figure 5). Traced laterally a short distance away from the main line of section, Unit 2 vanishes beneath the lowermost bed of the overlying storm succession (Unit 3) which incises through and ammalgamates with the uppermost bed of Unit 1.

Unit 3: Upper Storm Succession

Completing the Lower Zone sequence above Unit 2 is a 5 meter unit of relatively clean fine-grained sandstone comprising a succession of sharp, sometimes erosively based beds ranging in thickness from 15 to 70 cm. Rather than ammalgamated, however, individual beds are seperated by thin (5-10 cm) deeply weathered zones enriched with dense concentrations of carbonaceous laminae. There carbonaceous zones are laterally discontinuous and appear to conform with the tops of beds. Internally, the sand beds themselves are not, in most respects, unlike those described from Unit 1. Nowhere within this part of the sequence, however, was classical H.C.S. observed. Instead, thinner beds, where bedding could be discerned, appear horizontally stratified whilst thicker beds reveal well developed swaley cross-stratification.

O. borneensis constitutes the dominant trace fossil of Unit 3, and is most abundant within the thick sand bed occurring at the base of the unit. As well, the occassional *O. borneensis* tunnels recorded from the underlying Unit 2 probably represent deeply excavated tiers associated with these burrow systems, Isolated specimens of *R. socialis* occur within the lower half of the unit, subtending from the tops of sand beds.

Lower Zone Interpretations

Many of the shoreline sandstones characterizing regressive hemicycles from the Cretaceous of the Western Interior evidently formed along shorelines subject to major storm disturbances. In virtually all cases, this has been inferred from the lower shoreface through offshore depositional record in which relatively thick beds of clean hummocky cross-stratified sand, unequivocally emplaced during major storm events, occur either in ammalgamation, or superimposed on a background gradient of deposits reflecting fair and minor storm weather conditions. As discussed in the paragraphs to follow, within the Lower Zone of the Appaloosa sandstone this relationship appears to be clearly expressed.

Units 1 and 3 (Major Storm Deposits)

Sedimentological Aspects: The sharp based beds of clean laminated sand dominating the Lower Zone (Units 1 and 3) strongly resemble storm beds documented from both modern (c.f. Ainger and Reineck, 1982; Howard and Reineck, 1981; and Kumar and Sanders, 1976) and ancient lower shoreface deposits (cf. Howard and Frey, 1984; Leckie and Walker, 1982; Balsley, 1981; and Campbell, 1971). During intense storms (e.g. tropical hurricanes and mid-latitude winter wave cyclones) shallow marine depositional environments are subject to extreme modification (Duke, 1985; Reinson, 1984). Although depositional processes operative during storms can be highly variable and are not as yet well understood (Niedoroda et al., 1984; Walker, 1984), the general process occurring on the lower shoreface can be summarized as follows. High-energy storm waves will impinge on the seabed, and if of sufficient magnitude, will scour into and resuspend surficial sediments. At the same time, suspended sand eroded from higher up the beach face may undergo a net seaward transport onto the lower shoreface (Field and Roy, 1983; Dupré, 1984; Neidoroda et al., 1984; Bourgeois, 1980; Kumar and Sanders, 1976). As the storm subsides, suspended sand is then redeposited as a seaward thinning layer of laminated sand. Correspondingly, if the thickness of fair and minor storm weather deposits allowed to accumulate between successive major storms is repeatedly less than the depth of bottom scour accompanying these events, ammalgamation will result (e.g. Unit 1).

A storm interpretation for Units 1 and 3 is further suppported by the occurrence of hummocky and/or swaley cross-stratification. Although the precise mechanism by which H.C.S. and S.C.S. form is still somewhat conjectural (see Duke, 1985; and Allen and Pound, 1985 for discussions), it is, however, generally agreed that oscillating storm wave action is either in whole or in part requisite to their development.

Ichnological Aspects: In order to explain the distribution of trace fossils characterizing Units 1 and 3, it is necessary to first consider certain ecological ramifications that might be expected to accompany a major storm disturbance. During and immediately following a storm, the lower shoreface benthic environment will have undergone considerable change. The sudden impingement of erosive stormwaves on the seabed followed immediately thereafter by the rapid deposition of a thick sand layer, would undoubtably generate levels of physiological stress capable of devastating the resident infauna. Thus, with the fairweather community temporarily abated or displaced, the post-storm conditions could provide an environment ecologically favorable for colonization by infaunal opportunists[1] normally associated with shallower water environments (Crimes, 1970; Pemberton and Frey, 1984).

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[1] the term "opportunist is applied to certain species of organisms, plant or animal, that have evolved life-history characteristics such as rapid dispersal, high reproductive rates, broad environmental tolerances, and generalized feeding habits that enable them to quickly locate and briefly exploit a new habitat following a physical disturbance such as a storm. As conditions following the disturbance revert back to normal, the opportunists will ultimately be displaced by succeeding colonists of the resident equilibrium community (Pemberton and Frey, 1984; Thistle, 1981; McCall, 1976).

To illustrate the ichnological implications of this relationship, consider the vertical change in trace fossil associations occurring across the boundary between Unit 2 and the overlying storm bed (see Figure 4 and 9G). As will be discussed shortly, the trace fossil association characterizing Unit 2 can be considered more/less representative of the resident equilibrium ichnocoenose. The sudden dissappearance of this suite implies that upon deposition of the overlying storm bed, the resident ichnofaunal community was presumably wiped out. At the time, the lower shoreface would have been blanketed by a thick layer of clean sand that was then colonized by an opportunistic crustacean fauna, here represented by the extensive tunnel systems of *O. borneensis* . Similarly, *Conichnus conicus* , *Skolithos linearis* , *Rhizocorallium sp* ., and *Ichnogen A sp A2* are also interpreted here as representing the post-storm activities of opportunistic organisms.

Unit 2 (Fairweather/Minor Storm Deposits)

Although Unit 2 at Sundance Coulee constitutes a relatively minor Lower Zone lithofacies, it holds important clues as to the precise environment across which deposition of the contiguous storm successions occurred. Across a typical beach-offshore profile, benthonic species diversities and individual abundances culminate in the lower shoreface below mean fairweather wave base, where: (1) sedimentation rates and wave action are low (yet bottom waters are maintained fully oxygenated); and (2) food is abundant (Dorjes and Hertweck, 1975). Correspondingly, it is also here that intense biogenic reworking first appears as prolonged periods of fairweather quiescence allow infaunal organisms colonizing this ecologically stable environment sufficient time in which to rework the substrate (Ainger and Reineck, 1982; Howard, 1975; Howard and Reineck, 1972). In short, therefore, from the contained assemblage of relatively diverse and ethologically varied trace fossils occurring within Unit 2 (see figure 4) along with the pervasive nature of biogenic reworking, it can be inferred that deposition occurred in a lower shoreface environment situated below mean fairweather wave base.

The overall ichnological characteristics of the unit clearly indicate that throughout the depositional history of Unit 2, periods of prolonged fairweather quiesence occurred. The irregular beds of relatively clean sand comprising most of the unit, however, were probably emplaced during periods of higher than normal wave energy or "minor" storm disturbance. Although the exact ecological impact these minor high-energy disturbances might have had on the benthic community has not as yet been fully determined, it is, however, relatively safe to assume that the level of severity was far less than that accompanying a "major" storm event as discussed earlier. This is based on the fact that a number of lebensspuren (e.g. *R. socialis* , *Rh. jenense* , and *T. rectus*) exhibit what are here referred to as "storm response/re-equilibriation structures" indicating that the trace makers were able to escape the initial adversities of the storm by retracting deep within their burrows, and then following storm cessation and deposition of an increment of sand, re-equilibriate their burrows with the new sediment-water interface. In *R. socialis,* this behaviour is manifested in the form of a vertically stacked succession of up to 4 individual feeding cones (see plate 9, figures 1, 2, 4, and 6). An interesting point worth noting here, is that emplacement of the entire storm succession with which the *R. socialis* tracemaker has re-equilibriated must have occurred during the life span of a single organism. Thus a scale of "absolute" storm frequency can, in such cases, be reconstructed from the ichnological record.

***Diplocraterion* at the T2 - Appaloosa Contact:** Occurring within bed X at the base of Unit 1 (see figure 4), is one of the more intriguing ichnofossil occurrences recorded anywhere from within this part of the succession. Here, on the line of section, a vertical face of this resistantly cemented sand bed reveals a monodominant association comprising multiple superbly preserved specimens of *Diplocraterion parallelum* (text-figure 4; plate 1, figs 1 - 8). Along this face, complete cross-sections of the burrows can be seen, all of which appear to subtend from a common sedimentological interface corresponding with the top of bed X.

Ordinarily, the mass occurrence of *D. parallelum* , the dwelling burrow of a suspension feeding crustacean (see later discussion), would be considered characteristic, if not exemplary of the *Skolithos* ichnofacies--thus evidencing an environment characterized by loosely shifting sandy substrates with relatively high levels of wave and/or current energy (cf. Seilacher, 1967; Frey and Pemberton, 1984). Instead, however, it is here evident that at the time of burrowing the substrate, rather than loose or shifting, was frozen in a semi-lithified or "firm-ground" state; i.e., the requisite conditions for the *Glossifungites* ichnofacies (cf. Pemberton and Frey, 1985). This is directly inferred from several aspects of the burrow morphology, primarily: (1) the absence of any form of burrow wall re-enforcement needed to maintain an open dwelling within an unconsolidated sandy substrate--burrow walls instead being unlined and sharp; and (2) the presence of delicate claw markings locally preserved on the external surface of the burrows (see plate 1).

Firm Ground Development: In argillaceous sediments, internal cohesion results primarily from dewatering and compaction (Pemberton and Frey, 1984). Bed X, on the contrary, is composed of clean arenaceous sediment; hence, an alternate explanation must be sought. Based on preliminary observations of the diagenetic characteristics of the sand (bed X being cemented by a microcrystalline mosaic of calcite and siderite) we suggest a mechanism whereby internal cohesion of the sand had developed through incipient void filling cementation, in response to early stage methanic diagenesis. The presence of siderite, however, although perhaps representing a later diagenetic phase makes it highly improbable that cementation occurred at, or even close to the sediment-water interface (Berner, 1981; Gautier and Claypool, 1985). It is therefore quite likely that firm-ground conditions within bed X developed through a major cycle of burial and erosion. Upon exhumation, the "firm ground" stratum was then colonized by an opportunistic crustacean fauna, evidently well adapted to life within semi-lithified substrates. Elsewhere within the study area, similar developements of the *Glossifungites* ichnofacies, characterized by profusions of scratch marked *D parallelum* , occur within inferred back-barrier mudstones and coals that directly underlie major transgressive surfaces (see plate 2).

MIDDLE ZONE: Upper Shoreface Sequence

With the exception of localized calcite-cemented nodules, Middle Zone sands are clay cemented and extremely friable. Consequently, outcrop exposures at most sections are typically more intensely weathered than either the Lower or Upper Zones, further inhibiting any form of detailed surficial description. Instead, during the course of field investigations a number of vertical trenches were excavated from which the general sedimentological characteristics for this zone could be ascertained.

Description

Middle zone sands are relatively clean, yellow to buff in color, and typically coarsen upward from fine-grained at the base of the zone to fine-medium or medium grained at the top. The zone ranges in thickness from a minimum of 5 meters to an estimated maximum of 8 meters. Bedding throughout most of the zone appears horizontal to low-angle (albeit sometimes irregular and uneven), and although superficially similar to, is easily discerned from the storm bedding prevading the underlying Lower Zone sands. Laterally discontinuous zones of concentrated carbonaceous laminae are common throughout the lower two-thirds of the zone, and in many instances appear to directly overlie internal discordances. Sets of decimeter to large scale cross-bedding occur interspersed with the more prevalent horizontal/low-angle bedding, and at a number of sections (OH-1, LBC-1, and FT-1) a stacked succession of multidirectional decimeter scale trough and tabular cross-bedding forms a discrete subzone, 1 to 1.5 meters thick, situated immediately subjacent to the Middle-Upper Zone discontinuity (Figures 11A, B, and C).

Interpretation

The observed textural/structural sequence within the Middle zone, combined with a stratigraphic position between inferred lower shoreface and foreshore deposits, implies deposition across the intervening "upper shoreface" or zone fairweather wave build-up and surf. In contrast to the lower shoreface, during fair weather periods the substratum

FIGURE 11

FIGURE 11

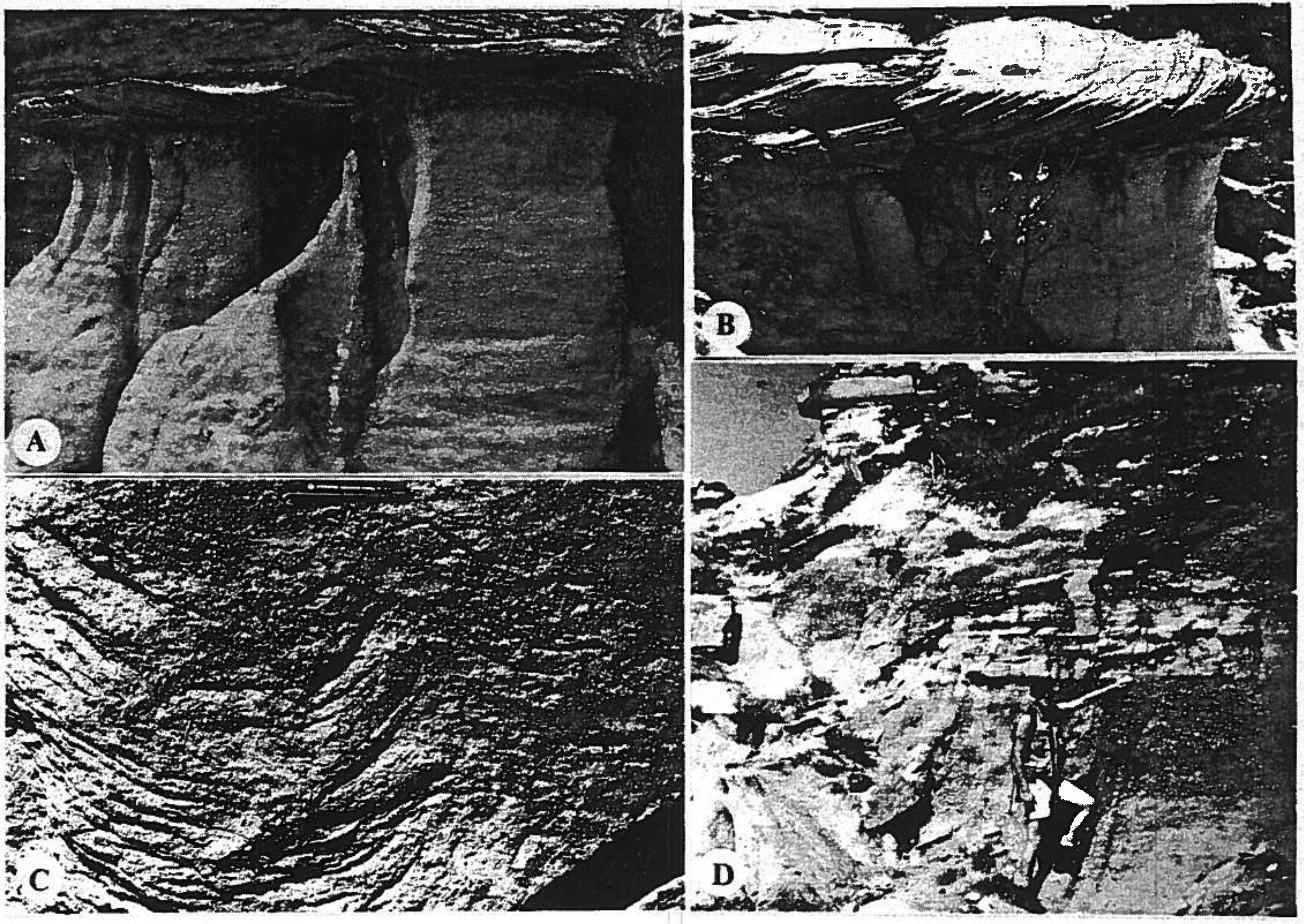
APPALOOSA SANDSTONE
Upper Shoreface (Middle Zone) Deposits

11A. Transitional zone of medium scale cross-bedding at top of Upper shoreface sequence of section OH-1.

11B. Aerial view of strata from figure 4A highlighting calcite cemented set of planar tubular cross-bedding capping the sequence.

11C. Plan view of medium-scale troughs of upper shoreface - foreshore transition zone at OH-1.

11D. Lower shoreface -- Edd-tidal delta -- Upper shoreface sequence characterizing Appaloosa at EC-4; geologists' hand points to erosional contact between preferentially cemented, medium-coarse grained, x-stratified edd-delta sand and underlying very-fine to fine-grained, more intensely weathered Lower shoreface sand.


A
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D

here will remain in more or less continuous motion under the influence of waves and wave induced currents (Howard and Reineck, 1981). This is reflected in the resultant deposits in which physical sedimentary structures predominate over biogenic ones, particularly in the more landward reaches of the environment. At a number of sections, mud-lined or silicified *Ophiomorpha* tunnels, lacking the characteristic iron-carbonate mineralization of the Lower zone specimens, may be occassional to common within the lowermost beds of the zone. Elsewhere within the Upper Shoreface sequence, biogenic structures are conspicuously absent, and it can therefore be inferred that preserved burrows are those constructed to depths well below the zone of active physical reworking (e.g., deeply penetrating *Ophiomorpha* systems).

In short, the sequence of textures and physical structures characterizing the Middle zone, when considered along with the almost complete absence of biogenic structures, seems consistent with an upper shoreface interpretation for these deposits. Using stratigraphic thickness as a surrogate for water depth (cf. Elliott, 1986; Klein, 1974), the upper shoreface paleoenvironment can be inferred to have extended seaward of the low water line into depths of 5 to 8 meters, further inferring deposition within an intermediate to high-wave energy shoreline regime (cf. Howard and Reineck, 1981). Although little can be said at this stage concerning the precise hydro-morphodynamic setting, the common occurrence of angle-of-repose cross-bedding confirms the existence of undirectional currents and/or bottom wave surge within the environment. Furthermore, the discrete zone of cross-bedding found locally at the top of the Middle Zone, compares closely with the foreshore-shoreface transition facies documented by Howard and Reineck (1981) and the Inner-Rough facies described by Clifton et al (1971). Along topographically simple high wave energy shorelines, this facies typically developes in the plunge zone or position of breakers at low tide (Howard and Frey, 1984). Its recognition in ancient sequences, therefore, may be important in approximating the actual shoreface-foreshore boundary, which in regards to the present sequence would presumably coincide with the top of the Middle Zone.

Throughout most of the study area, the Middle-Lower Zone boundary varies from being gradational to sharp and discordant. In the northwesternmost corner of the study area in the immediate vicinity of EC-4, an erosional tongue of cross-bedded "ebb-delta" sand directly overlies the lower shoreface sequence (Figures 7 and 11D). Continuing northwest from EC-4 along the northeast side of the valley, the ebb-delta sand along with the overlying coarsening-upward upper shoreface sequence grades laterally into a classic fining-upward "tidal inlet" sequnece (figure 8).

UPPER ZONE: Foreshore-Backshore-Barrier Island Sequence

The uppermost sedimentologic zone of the Appaloosa disconformably overlies the Middle zone sands (upper shoreface sequence), and in turn is disconformably capped by a thin seam of coal or carbonaceous shale. This zone averages 5.0 meters in thickness ranging from a maximum of 8.0 meters (LBC-1) to a minimum of 3.5 meters (OH-1). Compositionally, it comprises moderately well sorted fine-medium to medium grained highly feldspathic sandstone , and at most sections a slight upward fining can be detected through the zone. At a number of sections, particularily those where the underlying shoreface-foreshore transitional zone of cross-bedding is well developed (e.g., SD-1, OH-1, LBC-1), a sharp decrease in grain size also occurs upward across basal discontinuity of the zone.

Foreshore Sandstone

Sedimentological Aspects

The lowermost 2 to 3 meters of the Upper zone is characterized by clean, moderately well sorted sandstone, internally displaying well-developed horizontal to low-angle planar lamination. Laminae typically occur in large scale wedge sets 10 to 50 cm thick, intersecting one another at extremely low angles. Associated sedimentary structures, although only locally observed, include low amplitude wave ripples, parting lineation, swash marks, and landward dipping decimeter scale tangential cross-bedding.

The distinctive planar lamination pervading these sands strongly resembles "beach lamination" described from modern foreshore deposits (cf. Thompson, 1937; Clifton, 1969), developing in response to wave swash processes on the exposed beach surface. Coarse-fine laminae couplets resembling the swash-backwash grain segregations described by Clifton (1969) are also a common feature of Appaloosa foreshore sands. The predominance of planar lamination and relative absence of landward dipping foresets suggests that the foreshore surface, at least during the more reflective accretionary

FIGURE 12

FIGURE 12

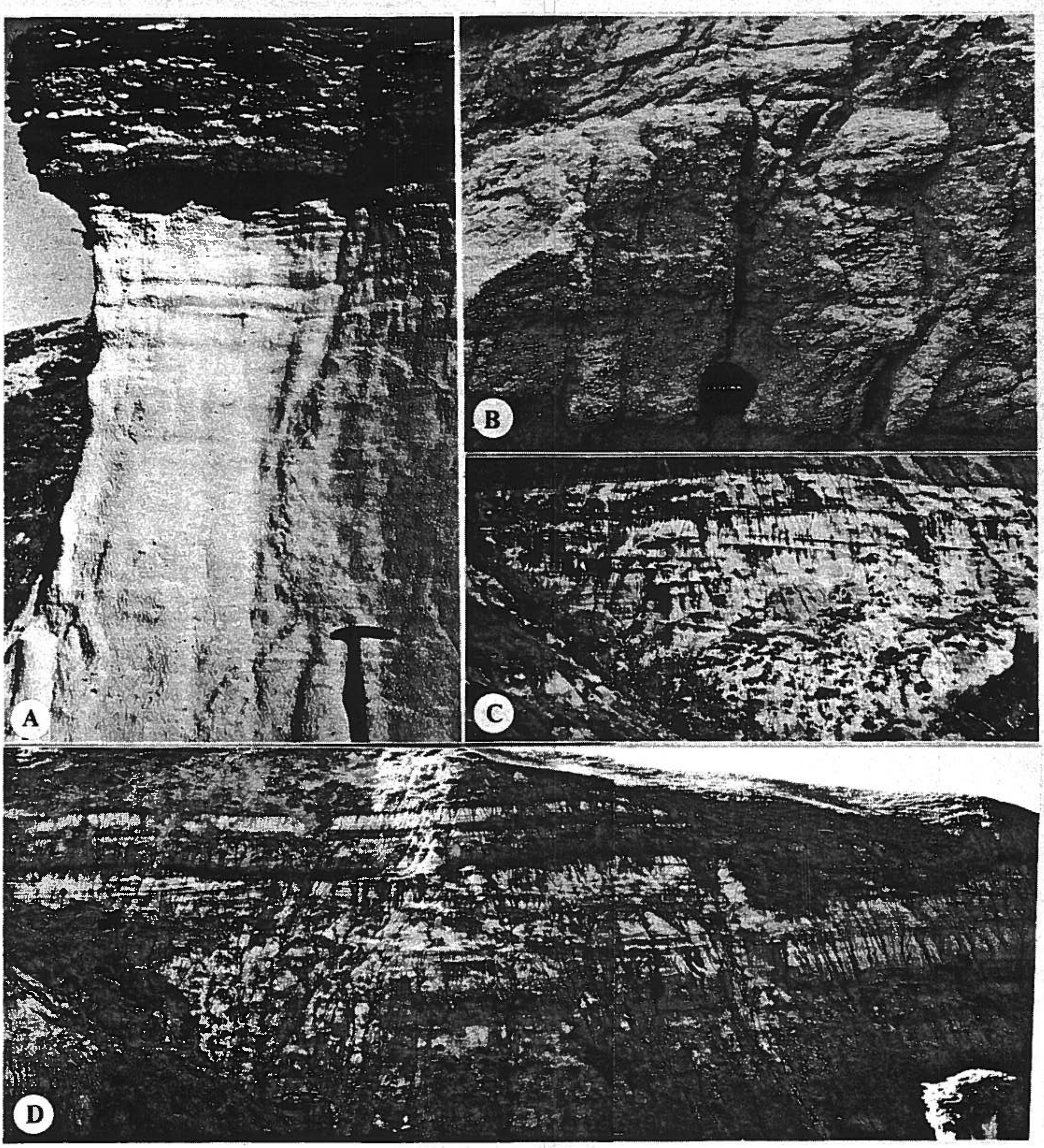
APPALOOSA SANDSTONE
Foreshore - Backshore - Barrier Island Sequence (Upper Zone)

12A. Uppermost Foreshore -- Backshore -- Barrier Island transition at OH-1; note faint horizontal to low angle planar lamination throughout and resistantly cemented carbonaceous and rooted sand bed disconformably overlying relatively clean laminated backshore sands.

12B. Vertical face of Upper foreshore sands at BC-1 showing zonal development of *Macaronichnus segregatis;* differential weathering serves to illustrate the pervasive nature of burrowing.

12C. Northwest - southwest oriented (shoreline perpendicular) face at Little South Snake displaying seaward dipping depositional surfaces cross-cutting the backshore-foreshore; note also tidal channel (TC) erossionally overlying the Appaloosa coal seam.

12D. Southwest-northeast oriented face (shoreline parallel; looking northwest from OH-1) showing characteristic undulations of upper surface; note large scale X-beds within ridge at left of photo, and also pronounced thickening of overlying coals within swales.


A
B
C
D

stages (cf. Wunderlich, 1972; Hunter et al., 1979), was topographically simple, devoid of ridge runnel systems. The occurrence of low-angle wedge-like set intersections (figure 12A) reflects subtle changes in the slope of the beach, presumably in response to fluctuating wave conditions (cf. Reinson, 1984; Howard and Frey, 1984).

Ichnological Aspects

The foreshore environment of an exposed beach setting is typified by extreme energy conditions and ever-shifting substrates. High velocity transitional bores repeatedly uprush the beach face and retain a large proportion of available food, including most particulate organic matter and associated microbes, suspended in the water column. Consequently, ichnofaunas, where preserved typically comprise low diversity assemblages of vertically oriented domiciles recording the inhabitance of predominantly suspension feeding communities (cf, the *Skolithos* ichnofacies; Frey and Pemberton, 1984; Seilacher, 1967).

Apart from the occassionally encountered unlined *Skolithos linearis* specimen, vertically oriented traces reflecting a suspension feeding mode of existence are otherwise absent from Appaloosa foreshore sands. Instead, virtually every outcrop examined revealed a laterally persistent zone of intense biogenic reworking that invariably begins 0.7 to 1.2 meters above the basal foreshore discontinuity and continues upwards for 0.6 to 1.1 meters before terminating abruptly (figure 12B). The zone is composed entirely of intrastratal bedding concentrations of *Macaronichnus* --a horizontal trace unequivocally formed by a highly mobile infaunal deposit feeding organism (Clifton and Thompson, 1978; see also later discussion under "systematics"). Within the main zonal concentration, burrows herein assigned to *M. segregatis* constitute the prevalent morphology. Below this, burrow densities drop off radically, and *M. segregatis* is sometimes joined by isolated occurrences of *M. spiralis* ; burrows commonly persist downward to but never below the basal foreshore discontinuity. At most sections, particularily where the mafic content of the ambient sand is low, the traces are extremely subtle in appearance, and often are made visible only by scrutinizing freshly scraped vertical faces.

In order to understand the ethologic and environmental significance of this seemingly paradoxic trace occurrence, it is first important to realize, that because a sandstone appears clean, devoid of "organic detritus", does not necessairily mean that at the time of deposition it was incapable of sustaining a deposit feeding mode of existence[2]. In the present situation, the *Macaronichnus* tracemaker, as inferred from its burrow morphology, appears to have fed preferentially on micro-organisms colonizing the surfaces of sand grains (epigranular microbial biomass). However, due to the overall limited availability of this resource, in order to extract sufficient energy from the environment it was evidently necessary for the tracemaker to employ various means of maximizing its foraging efficiency. As inferred from the nature of wall/infill grain segregations and bedding surface burrow configurations (see figure 13), it is plainly evident that this was at least partially accomplished by: (1) selectively removing, prior to ingestion, less energetic grains that in effect would reduce the net energy gain per unit time feeding; and (2) exercizing phobotaxic and stigmotaxic behavioural response mechanisms thereby offsetting costly energy expenditure losses that might result from burrow interpenetration.

Controls on zonal distribution of *Macaronichnus* : Within an exposed high-energy foreshore, strong hydrodynamic forces accompanying swash infiltration introduce dissolved oxygen and nutrients deep with the porous and permiable sand column. This in turn allows epigranular microbes--primairly bacteria--to flourish

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[2] Most Ichnologists evidently consider the non-living organic fraction of the substrate as the primary food resource of infaunal deposit feeding organisms. A perusal of the recent ecological literature, however, reveals a number of studies (cf. Fenchel and Jorgenson, 1977) clearly indicating that such material, typically comprising fragmentary plant remains, is too refractory for the digestive capabilities of most marine benthos. Instead, deposit feeders evidently derive most of their nutrition from the more digestible living micro-organisms--primarily bacteria--that degrade the non-living organics (decompositional microbial biomass) as well as colonize the surfaces of sediment grains (epigranular microbial biomass) [cf. Newell, 1969; Fenchel, 1970; Anderson and Meadows, 1969; Dale, 1974; Taghon, et al., 1978; Levinton, 1979, 1982; Yamamoto and Lopez, 1985; Levinton and Bianchi, 1981; Fenchel and Kofoel, 1976; Miller, 1985). The common correlation between predominantlt deposit feeding biocoenoses (or fodonichnial ichnocoenoses) and oxic organic-rich fine-grained substrates, is therefore, in part, a reflection of the high decompositional and epigranular microbial biomasses typically occurring in such deposits.

to tremendous depths (sometimes up to several meters) below the sediment water interface. Interestingly enough, ecologists have further been able to show that in such settings, bacteria tend to concentrate in the moist sand at and above Mid Tide Level, but well below the depth of maximum physical disturbance where: (1) water input and percolation are high; (2) stagnation is minimal; and (3) pulsing currents are not too severe. It is therefore not surprising to find, within the Appaloosa, *Macaronichnus* concentrated in a specific zone 0.6 to 1.1 meters thick stratigraphically situated within the middle to upper portion of the foreshore sequence. This and other ichnological relationships revolving around the occurrence of *Macaronichnus* within high-energy foreshore sands will be discussed at length while in the field.

Backshore-Barrier Island Sandstone

Above the *Macaronichnus* zone, planar lamination may persist for several meters before dissappearing altogether. Here, however, the distinctive wedge-like set intersections of the underlying foreshore sands do not occur, and instead lamination takes on a more horizontal aspect. At the Sundance Coulee section (figure 4) this transition appears to take place across an irregular diagenetic boundary: moderately well cemented foreshore sands below giving way to resistant, ledge-forming calcite-cemented sand above. At all sections, carbonitized plant fragments, woody imprints, and veritcal root structures become increasingly abundant upward, usually culminating at the top of the zone in an irregular, resistantly cemented layer of extremely carbonaceous and extensively rooted sand (figure 12A).

The vertical transition from clean laminated sand to carbonaceous root-penetrated sand towards the top of this zone, records the final stages of shoreline progradation, marking the passage of the sub-aerial backshore-barrier-island land surface into and across the site of deposition. The upward increase in vegetal matter implies that the density of plants colonizing the barrier increased progressively landward away from the shoreline. Furthermore, the presence of coal or carbonaceous shale capping these sands testifies to the existance of a peat forming swamp or marsh environment flacking the landward side of the barrier. At most localities, the coal/carbonaceous shale facies is in turn overlain by dark grey-brown carbonaceous mudstone of inferred back-barrier lagoonal origin; elsewhere, tidal channel sands have eroded through lagoonal muds and rest directly on the coal (figure 12C). Nowhere, however, were these channels observed to have eroded through the coal and into the underlying barrier-island sands.

The thickness of the backshore-barrier island sequence may vary tremendously, and along southwest-northeast trending coulee walls (shoreline parallel) the upper surface typically reveals large scale undulatory ridge and swale topography (figure 12D). Within the ridges sets of root -penetrated large scale cross-bedding can usually be discerned overlying the planar laminated backshore sands. In such cases, these ridges are thought to represent small incipient backshore dune field developments.

SYSTEMATIC ICHNOLOGY

SYSTEMATIC ICHNOLOGY

Ichnogenus *Diplocraterion* Torell, 1870

Diplocraterion Torell, 1870, p. 17, Fürsich, 1974a, Hantzschel, 1975, p. W67

Diagnosis: Vertically oriented cylindrical U-shaped spreiten burrows.

Remarks: Fürsich (1974) revised the taxonomy of vertical, U-shaped spreiten burrows to include a single valid ichnogenus, *Diplocraterion*. Based primarily on burrow outline and the directional growth of the spreite, 5 distinct ichnospecies are currently recognized: (1) *D. parallelum - diplocrateria* having parallel walls and unidirectional spreite; (2) *D. helmerseni - diplocrateria* exhibiting a markedly expanded base; (3) *D. biclavatum - diplocrateria* in which the area hyperextend the base of the U-tube forming 2 blind pouches; (4) *D. habichi - diplocrateria* with upward divergent arms; and (5) *D. polyupsilon - diplocrateria* possessing spreite that are partially or completely bidirectional (Fürsich, 1974).

Diplocraterion parallelum Torell, 1870

Pl. 1, fig. 1-8; Pl. 2, fig. 1-5

Description: (Bed X specimens) Vertically oriented tubular burrows embodying full length unidirectional protrusive spreite. U-tubes are circular to sub-circular in cross-section, and possess sharp, unlined, sometimes irregular walls; infills, where preserved, are composed of fine sand containing abundant admixed plant detritus and rod-shaped facal pellets. Two distinct size associations occur: (1) relatively large specimens with tube diameters, widths, and lengths (sensu Knox, 1973) averaging 12 mm, 70 mm, and 250 mm, respectively; and (2) comparitively small specimens with corresponding average measurements of 3 mm, 15 mm, and 40 mm. Among the larger size class, burrow arms, characteristically remain straight and near parallel throughout the full length of the structure, although minor lobate expansions and contractions do occur in a number of specimens: in the smaller burrows, the arms although remaining parallel, begin with a vertical orientation, then deflect horizontally into the plane containing both arms. In specimens paralleling the plane of preservation, erosion of the main spreiten body locally reveals uniform patterns of well preserved scratch marks incised into the rock adjacent to the burrow wall. Individual scratch-marks form relatively continuous, uniformly sized and spaced furrows (average width 1mm) that roughly parallel one another and conform to the overall curvature of the spreite. Tube diameter to spreiten width ratios average 1:5.

Discussion: In many cases, reconstructing the ethology and identity of a tracemaker solely from the morphologic characteristics of its lebenssperen will allow for a considerable amount of speculation. Quite often, however, the ethology will be clearly expressed, and by applying working knowledge of the range of organisms producing similar lebenssperen in the modern, some degree of speculation can be made with certainty as to the general trophic level and gross identity of a tracemaker (Osgood, 1975; Dorjes and Hertweck, 1975).

In the case of *D. parallelum*, the vertical aspect and distinctive U-shaped spreiten morphology readily identifies these structures as the domichnia of suspension feeding organisms (cf. Pemberton and Frey, 1984a; McCarthy, 1979; Fürsich, 1974a). Among modern marine benthos, certain species of suspension feeding Polychaetes, Echiuroids, and Crustaceans are known to construct U-burrows that bear spreite and thus closely approximate the *Diplocraterion* structure (see Fürsich 1974a for a complete discussion). Regarding the bed X specimens, the presence of surficial claw-markings automatically discludes both Polychaetes and Echluroids, while strongly favoring a Crustacean origin for these burrows.

Ichnogenus *Teichichnus* Seilacher, 1955

Teichichnus rectus Seilacher, 1955

Pl. 3, fig. 1-4

T. rectus Seilacher 1955, p. 378, Pl. 24, fig. 1; Fürsich, 1974, fig. 27b, 33, p. 40; Howard and Frey, 1984, p. 211-212, fig 21.

Diagnosis: Vertical blade-like spreiten structures consisting of several closely concentric, horizontal or inclined, longitudinally nested individual burrows adjoining single parent trunks; spreiten typically retrusive but may be protrusive (Howard and Frey, 1984).

Description: Straight horizontal, vertically retrusive, cylindrical burrows, commonly displaying a slight longitudinal complexity and where fully preserved are adjoined at either end by an upward reaching aperatural shaft; the overall structure, therefore, approximates a broad, flat bottomed "U" having a length/depth ratio in the order of 3-5: 1. Final tubes, when present display circular cross-sections with a diameter range of 6 - 12mm. Most specimens, however, preserve only the spreite, which characteristically thicken towards the longitudinal axis, and usually record relatively short retrusions, averaging 1 cm, with a recorded maximum of 3.5 cm. Individual burrows commonly interpenetrate but never branch.

Discussion: Fürsich (1974) described specimens from the Corallian of England and Normandy characterized by an extensive spreiten wall, and suggested that the most probable tracemaker was a vermiform deposit-feeding organism systematically exploiting the substrate for food. The specimens described here, however, record relatively short retrusions, strongly resembling the recent burrows of *Nereis diversicolor* figured by Seilacher (1957). In this case, the spreite probably represent an equilibrium response of the tracemaker in attempt to maintain the bottom of its burrow at an optimal depth below the sediment-water interface within an continually aggrading substrate.

Ichnogenus *Gyrocorte* Heer, 1865

Gyrocorte comosa Heer, 1865

Pl. 3, fig. 5-8

Gyrocorte Heer, 1865, p. 142; Hallam, 1970, p. 190-195; Heinberg, 1973, p. 228-231; Häntzschel, 1975, p. W65.

Diagnosis: Predominantly horizontal, unbranched, blade-like, vertically penetrative bilobate trails.

Description: Straight to tortuous, distinctly bilobate horizontal bedding trails that commonly interpenetrate but never branch. Modular morphology of epichnial specimens consists of twin, parallel hemi-cylindrical lobes, tangentially adjoined creating a narrow median furrow; better preserved specimens reveal the characteristic oblique biserial transverse lobe segmentation. The penetractive nature of these structures was confirmed by scrutinizing specimens which, along their length, transect a succession of bedding surfaces. Trail widths vary from 2 to 15 mm; lengths commonly exceed 30 cm with a recorded maximum of 52 cm. Corresponding hypichnia comprise twin furrows and a median ridge.

Discussion: At present *Gyrocorte* encompasses a single ichnospecies, *G. comosa* . Heer (1877) in his original description, interpreted *Gyrocorte* as Algae, or alternatively, the egg strings of Molluscs. Later interpretations include (1) trails formed by *Corophium* (Nathorst, 1981); (2) the repeated impressions formed through the collapse of a plant in beach sediment at successive low tides (Funcini, 1936); and (3) amphipod collapse tunnels excavated just beneath the sediment-water interface (Hallam, 1970). It has since, however, been convincingly demonstrated based on an analysis of exceptional specimens from Greenland (Heinberg, 1973), that *Gyrocorte* represents a crawling-feeding structure formed by an elongate Polychaete-like organism which fed while moving obliquely through the sediment; this was interpreted by Heinberg as an adaptation towards better exploitation of the sediment for food.

Ichnogenus *Ophiomorpha* Lundgren, 1891

Ophiomorpha Lundgren, 1891, p. 114-118; Häntschel, 1975, p. W85-W86; Frey, Howard and Prior, 1978, p. 199-275; Howard and Frey, 1984, 204-206.

Diagnosis: Simple to complex burrow systems distinctly lined with agglutinated pelletoidal sediment.

Remarks: The morphologic, taxonomic and environmental significance of the ichnogenus has been reviewed by Bromley and Frey (1974) and Frey et al (1978). In the modern, thalassinidean shrimp, including certain species of *Callianassa* , *Upogebia* , and *Axius* , construct complex burrow systems identical in fabrication to *Ophiomorpha* (Frey et al, 1978). At present, four distinct ichnospecies, differentiated primarily on the bases of wall construction, are recognized: *O borneensis* , *O. nodosa* , *O. annulata* and *O. irregulaire.*

Ophiomorpha borneensis Keij, 1965

Pl. 4, fig. 1-7

Diagnosis: Burrow walls consisting predominantly of dense, regularly distributed biobate pellets.

Description: Large, complex burrow systems, with overall configurations ranging from (1) predominantly horizontal maze-like tunnel networks having only minor vertical components (Plate 4, figure 1), to (2) irregularly branched three-dimensional boxworks involving all of vertically through horizontally oriented components (Plate 4, figure 2). Cross-sections vary from circular to elliptical (tunnels only); component diameters range from 0.4 to 4.0 cm, becoming markedly enlarged at points of branching. Burrow walls characteristically display a mammilated outer lining, and most when viewed in cross-section, reveal an inner somewhat irregular lining, 0.5 to 6.0 mm thick, consisting of sideritized mud with varying amounts of admixed sand: here, a concentric layering may be evident. External pellet morphologies of the outer wall are dominantly bilobate --1.5 to 6.0 mm in height, 2 to 5 mm in width, and 3 to 13 mm in length--with pellets almost always oriented transverse to burrow axis; in most burrows, single, ovoid to polygonal pellets occur interspersed with the doubles, and locally may constitue the dominant pellet morphology. Internally, pellets are composed of agglutinated, concentrically laminated sand and mud. Usually, tunnel roofs and walls are densely mammilated with well developed, uniformly distributed pellets; towards tunnel bottoms, however, pellet morphologies and distributions become increasingly irregular, and pellets are commonly either sparse, or all together absent. Burrow infills consist predominantly of structureless sand same as host stratum; occassionally isolated burrow components may reveal distinct meniscate backfill, or inclined to horizontal laminary infills. Of 29 thin sections cut, most revealed subperbly preserved ellipsoidal fecal pellets, occurring randomly distributed throughout both burrow infills and the inner and outer wall linings; pellets consist of either sideritized or calcified clay sized material, and some appear to contain traces of collophane; diameters average 2.5 mm, with a maximum recorded length of 5 mm; internal pellet structure reveals a distinctive bilaterally symmetrical configuration of x-sectionally cresentic canals; four inward facing marginal pairs, along with an outward facing central pair.

Discussion: On the basis of internal fecal pellet morphology the *O. borneensis* tracemaker for the Appaloosa specimens has been tentatively identified as a species of *Axius* , an extant genus belonging to the tribe *Thallasinidae*. Modern "*Ophiomorpha* "-like burrows of Axius serratus were investigated from the Strait of Canso, Nova Scotia by Pemberton et al. (1976).

Ichnogenus *Arenicolites* Salter, 1857

Diagnosis: vertically to sub-vertically oriented spreitenless U-burrows.

Arenicolites variabilis Fursich, 1974

Pl. 6, fig. 5-8

A. variabilis Fursich, 1974, p. 5-9, fig. 4, 5b, and c; Howard and Frey, 1984, p. 201-202, fig. 4.

Diagnosis: Simple, unlined to thinly lined, vertical to slight oblique, cylindrical U-shaped tubes having no spreiten; outline geometry of U-tube highly variable.

Description: The vast majority of the Appaloosa specimens are know only from bedding surfaces, preserved as either (1) conspicuously paired hemi-spherical to sub-hemispherical ridges, or (2) endichnia made visible from the surrounding matrix either by having a contracting color and/or composition , or by possessing a thin (<1mm) fine-grained, commonly sideritized wall lining. Tubes are circular to sub-circular in x-section with diameters ranging from 1.5 to 17.0 mm, and inter-opening spacings from 1 to 12 cm; no correlation between diameters and spacings was recognized. In addition to the more common bedding surface preservation, a small number of vertically exposed burrows were observed, revealing a full range of U to V-shaped x-sectional geometries, most being somewhat irregular and asymmetric in outline; perfectly symmetric U-bends were not observed; maximum observed burrow length was 28 cm.

Although in most specimens the two burrow openings are identically sized, a number of the larger specimens display one aperature that is grossly enlarged with respect to the rest of the burrow, forming an upper expanding funnel with top diameters 1.2 to 1.5 times that pervading the rest of the structure; such burrows may also reveal a subsidiary trunk branching off the main U-structure at one end.

Remarks: The individual burrow openings of *A. variabilis* , when viewed on bedding surfaces, are indistinguishable from *S. linearis* , and can therefore only be indentified by the conspicuous occurrence of burrow pairs. Consequently, where densities are moderate to high, individual *A. variabilis* entities may become impossible to discern; in the absence of longitudinal sections this problem is unavoidable.

Ichnogenus *Palaeophycus* Hall, 1847

Diagnosis: Distinctly lined, horizontal to sub-vertical, straight to gently curved, cylindrical burrows. Wall linings range from very thin to relatively thick, and are either smooth, longitudinally striated, or longitudinally striated and transversly annulated. Infills typically are of the same composition as the host stratum.

Discussion: *Palaeophycus* is differentiated from the superficially similar ichnogenera *Planolites* and *Macaronichnus* primarily by the presence or of absence of a wall-lining, and the character of the burrow infill; lined burrows infilled with sediment more or less identical to the host stratum are assigned to Palaeophycus, whereas unlined burrows characterized by structureless infills differring texturally from the host sediment are assigned to either *Planolites* or *Macaronichnus* (Pemberton and Frey, 1982). It is of fundamental importance, however, that the mantle concentration of mafic grains characterizing burrows assigned herein to *Planolites sp.* and *Macaronichnus* (ethologically reflecting a specialized deposit feeding behavior), not be taxonomically confused with the true burrow linings of *Palaeophycus* (ethologically representing a fabricational wall re-enforcement of an open burrow).

Palaeophycus tubularis **Hall, 1847**

Pl. 11, fig. 3, 6, &7

P. tubularis, Hall 1847, p. 7-8; Pemberton and Frey, 1982; Pemberton and Frey, 1984

Diagnosis: *Palaeophycids* possessing thin, unornimented wall linings.

Description: Horizontal to sub-horizontal, cylindrical burrows possessing a thin, dark organic mud wall lining up to 1 mm thick. Cross-sections are circular to sub-circullar, with diameters of 4 to 8 mm recorded; known solely from relatively short, straight, unbranched, poorly preserved endichnia, and epichnia.

Ichnogenus *Planolites* Nicholson, 1873

Diagnosis: Cylindrical, small to moderately sized, predominantly horizontal, straight to tortuous, commonly undulant, infrequently branched, cylindrical burrows that characteristically interpenetrate, display smooth unlined walls, and are infilled with sediment that differs fundamentally from the host stratum implying some form of biogenic manipulation on behalf of the tracemaker.

Planolites sp.

Pl. 11, fig. 1-5 &7

Planolites sp. Heinberg, 1974, p. 15. *Macaronichnus segregate* ; Clifton and Thompson, 1978, p. 1294, fig. 2,3; Curran, 1985, p. 263-264, pl. IB, C, +D.

Description: Distinctly walled, unlined, predominantly horizontal, straight to randomly curving and meandering, cylindrical burrows that characteristically interpenetrate; only rarely was true branching observed. Burrows defined by mineralogic segregations in which predominantly dark grains--micas, shale and volcanic fragments, and heavy minerals--have been selectively removed from the infills and discarded exteriorly alongside burrow wall; infills, therefore, comprise clean, well sorted, structureless to faintly meniscate sand, conspicuously lighter in color than host stratum; the mantle concentration of biogenically displaced mafics helps to further excentuate this contrast. Burrows exibit circular to sub-circular cross-sections, with constant along burrow diameters of 1.5 to 8.0 mm; bimodal size distributions commonly occur within a given population.

Discussion: These burrows strongly resemble specimens described by Heinberg (1974) from the Jurassic of Greenland, subsequently included in the synonomy of *Planolites* prepared by Pemberton and Frey (1982). Furthermore, these burrows are identical in terms of their modular morphology to specimens tentatively assigned herein to *Macaronichnus* (soon to become a junior synonym of *Planolites*), but warrant ichnospecific separation from these forms because of fundamental differences in grazing configuration: where bedding densities are moderate to high, *Planolites sp.* will characteristically interpenetrate, whereas *Macaronichnus,* as the result of strong phobotaxic and/or thigmotaxic behavior exercized by the tracemaker, will not (see figure 13). The exact relationship of this form with existing ichnospecies of *Planolites* (*P.beverleyensis, P.montanus,* and *P. annularis)* has yet to be determined.

Ichnogenus *Marcronichnus* Clifton and Thompson, 1978

Tentative Diagnosis: Unlined, distinctly walled, predominantly horizontal, randomly curving and meandering to distinctly spiraled cylindrical burrows that rarely interpenetrate, never branch, and commonly possess a thin mantle concentration of mafic mineral grains; infills markedly cleaner than host sand and are either structureless or indistinctly backfilled.

Taxonomic Problems with Macaronichnus: The combination of infill character and wall structure (modular morphology) has proven invaluable in establishing a working taxonomy for the group of ichnofossils encompassing horizontal to inclined cylindrical burrows (cf. Pemberton and Frey, 1982; Frey et. al., 1984). In terms of modular morphology, burrows presently included in the concept of *Macaronichnus* are best diagnosed as being: (1) unlined but distinctly walled [the characteristic mantle concentration of mafic grains not constituting a true burrow lining (sensu Pemberton and Frey, 1982) as suggested by Curran (1985)]; and (2) infilled with clean, mafic deficient sand, either structureless or faintly meniscate. The question that arises is whether or not this particular infill-wall combination is taxonomically unique. In other words, was the designation of a new ichnogenera (*Macaronichnus*) warranted, or can such burrows in fact be included a new ichnospecies of an already existing ichnogenus? An affirmative answer to this question will be given in a forthcoming taxonomic re-evaluation of the ichnogenus *Macaronichnus.* In our present estimation, however, we feel that this particular modular morphology is not unique to *Macaronichnus*, and instead is essentially that diagnosed by Pemberton and Frey (1982) as *Planolites* (unlined, distinctly walled burrows infilled with sediment, either structureless or displaying poorly developed backfills, but differing compositionally from the host stratum). Therefore, unless some other aspect of the burrow morphology proves diagnostic at the ichnogeneric level, *Macaronichnus* will be relegated to a junior synonym of *Planolites.* We would then further suggest that the distinctive random-avoidance and spiral grazing configurations represented in *M. segregatis* and *M. spiralis,* respectively, be given increased taxonomic significance at the ichnospecific level; *M. segregatis* and *M. spiralis* would therefore be retained as new species of *Planolites.*

Macaronichnus segregatis Clifton and Thompson, 1978

Pl. 10, fig. 1-6 & 8; text fig. 13

Diagnosis: *Macaronichnians* displaying random, non-systematic but highly phobotaxic grazing configuations.

Description: Unlined, distinctly walled, cylindrical burrows preferentially oriented along horizontal planes with minor subhorizontal to sub-vertical components. Burrow infill noticeably lighter in color than host sand resulting from the almost complete absense of mafic mineral grains; a thin, but distinct mantle concentration of such grains (pseudo-lining) commonly occurs immediately exterior to wall, further excentuating burrows from host sand. At a glance, infills appear structureless, however, upon close examination faint sand-on-sand meniscate backfills are often, but not always disernable. Burrow cross-sections are circular to eliptical showing a pronounced horizontal flattening; diameters measured horizontally range from 1.5 to 3.0 mm (commonly 2.0-2.5), are extremely constant along burrow length, and at any given outcrop a common diameter usually prevails amoungst all burrows. Along bedding surfaces where densities are moderate to high, individual burrows tend to follow smooth but randomly curving and meandering paths. In spite of high burrow densities, interpenetrations and close contact cross-overs are extremely rare; instead where one burrow converges on another, the typical response is to either curve sharply away, coming within a finite distanct (phobotaxic behavioral response), or to swing parallel maintaining a more-less constant separation for a short distance before again diverging off (thigmotaxic behavioral response). On crowded bedding surfaces, the repetition of such responses imparts what is herein referred to as a "random avoidance" pattern of exploitation (figure13).

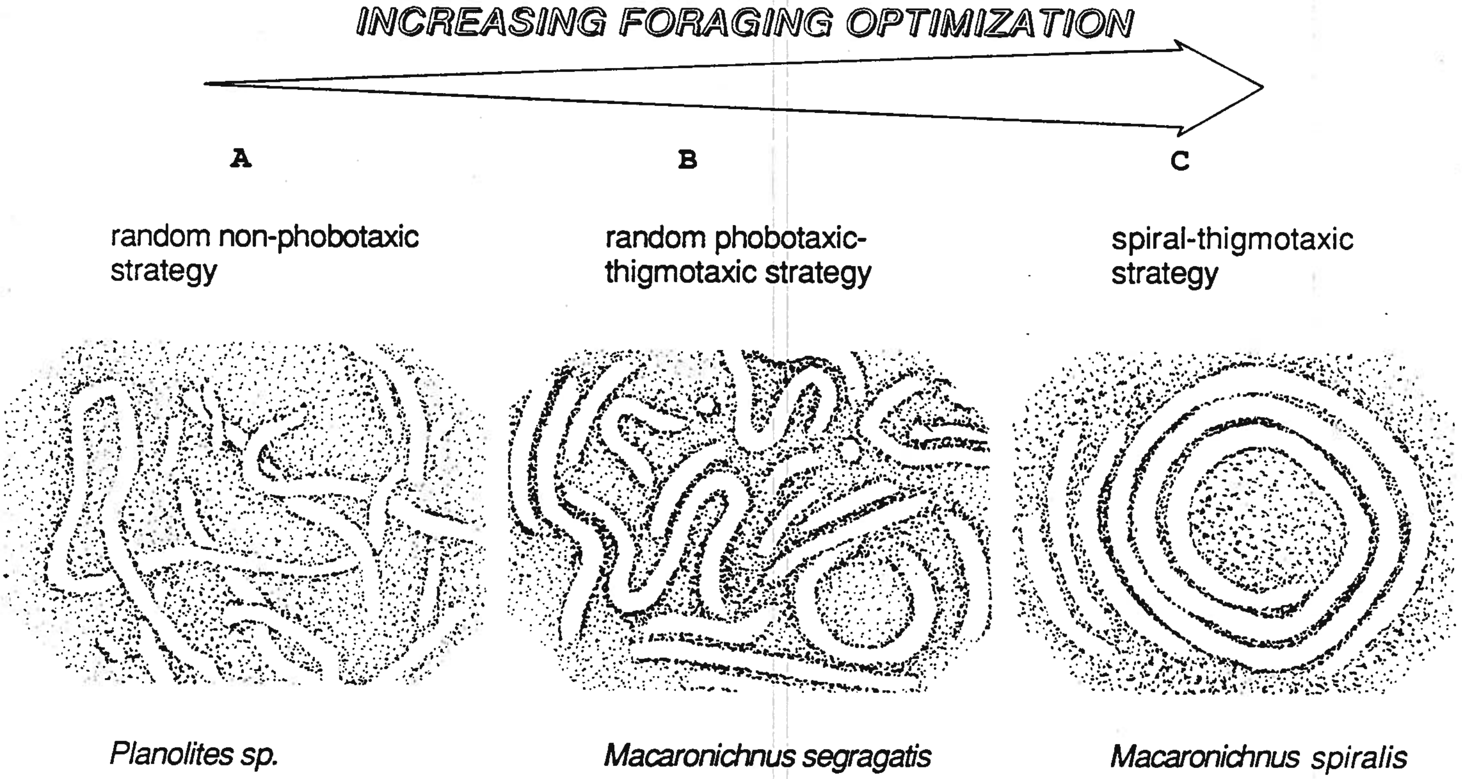
Macaronichnus spiralis n.icnosp.

Pl. 10, fig. 7, 9, & 10; text fig. 13

Diagnosis: *Macaronichnians* displaying distinct planispiral grazing configurations that vary in size and level of perfection.

FIGURE 13

FIGURE 1. Three distinct levels of foraging systematization represented along a continuum between *Planolites sp., M. segregatis,* and *M. sprialis*; in all cases the tracemaker--a highly mobile endobiont--was exploiting an epipsammatic food resource uniformly distributed about a planar bedding surface. The randomly interpenetrating trails of *Planolites sp.* (1A) record the least efficient of the three foraging pathways, indicating that the tracemaker was able to extract sufficient energy from the environment without having to avoid interpenetrating burrows already emplaced. *M. segregatis,* on the other hand, represents a fundamental change in foraging strategy towards higher pathway efficiency; the tracemaker here evidently exercized strong phobotaxic and thigmotaxic response mechanisms in order to offset energy expenditure losses resulting from path interpenetration--the result is a random but non--duplicating coverage of the food bearing horizon. Finally, the transition from a random avoidance pattern of exploitation (*M. segregatis*) to a compact spiral configuration *(M. sprialis*) represents yet another step towards reaching an optimal foraging strategy. By spiraling, the total path length is maximized while the total areal utilization is reduced to a minimum. The apparent advantage here is that the tracemaker greatly minimizes its chances of encountering other burrows; energy that otherwise would have been expended in having to react phobotaxically, is therefore conserved. The absence of fully developed spirals from crowded bedding surfaces (eg. figure B) is probably the result of intraspecific competition for available space; an increase in the density of tracemaking individuals simultaneously exploiting the same horizon, would result in a concomitant increase in the number and frequency of burrow encounters.


INCREASING FORAGING OPTIMIZATION
A
random non-phobotaxic strategy
B
random phobotaxic-thigmotaxic strategy
C
spiral-thigmotaxic strategy
Planolites sp.
Macaronichnus segragatis
Macaronichnus spiralis

Description: On bedding surfaces characterized by low burrow densitites, individual burrows were on occasion found displaying distinctive planispiral bedding configurations of varying levels of perfection. Where well developed, burrows spiral outwards, in either dextral or sinistral fashion, from an initial circular to sub-circular coil l.5 to 2.5 cm in diameter, with an observed maximum of 12 coils. In most specimens, an open but close and relatively constant spacing is maintained between successive coils (commonly 0.5 to 2.0 mm), although minor irregularities do occur in all specimens.

Ichnogenus *Skolithos* Halderman, 1840

Skolithos linearis Halderman, 1840

Pl. 6, fig. 1-4; text fig. 14

S. linearis Halderman, 1840, p. 3; Alpert, 2974, p. 661-663; McCarthy, 1979, p. 360 fig. 3i; Pemberton and Frey, 1984, p. 297-298, fig. 7a.

Diagnosis: Simple, vertically to sub-vertically oriented cylindrical shafts possessing a distinct, unlined to thinly lined wall structure.

Description: Predominantly vertical, unlined to thinly lined, straight to gently curved, circular to sub-circular cylindrical shafts. Linings, where present, seldom exceed 1 mm, and consist of either: (1) dark organic mud; or (2) clean agglutinated sand lighter in color than both the casting medium and burrow infill. Diameters range from 1 to 9 mm with lengths up to 14 cm recorded.

Discussion: Preserved as epichnial ridges, and less commonly as endichnia. Interpreted as the dwelling structure (domichnia) of suspension feeding annelids, ie.; certain polychaetes and phoronids (cf. Pemberton and Frey, 1984). Unlined forms probably represent temporary dwellings of itinertant organisms (cf. McCarthy, 1979), whereas the presence of a distinct wall lining, albeit thin, implies a more permanent residency allowing sufficient time for burrow re-enforcements to be made.

Ichnogenus *Cylindrichnus* Howard, 1966

Cylindrichnus concentricus Howard, 1966

Pl. 5, fig. 1, 3, & 5; text fig. 14

C. concentricus Howard, 1966, p. 45, fig. 10; McCarthy, 1979, p. 361, P1.1, fig. 8; Pemberton and Frey, 1984, p. 289, fig 12b; Howard and Frey, 1984, p. 203, fig. 7.

Diagnosis: Relatively long, subcylindrical to subconical burrows, straight to gently curved, vertical to horizontal, having concentrically layered walls (Howard and Frey, 1984).

Description: Relatively large, deeply penetrating, vertical to subvertical, straight to gently curved, cylindrical burrows possessing a central core surrounded by a thick, downward tapering, concentric to slightly excentric laminary wall. Burrows occur either in solitary form, or more commonly comprise 2 or more (maximum 4) equally sized branches all extending to a common interface from a single parent stock; point of branching typically occurs 25 to 30 cm below the inferred aperatural interface; maximum recorded length for total structure is 50 cm.

Ichnogenus *Rosselia* Dahmer, 1937

Diagnosis: Conical to irregular bulbous structures, vertical to inclined, consisting of a small central burrow surrounded by broad, concentric, funnel-like laminae, tapering downward to a concentrically walled stem (Pemberton and Frey, 1982).

Remarks: At present, three ichnospecies of *Rosselia* are recognized, based on fabricational differences of the upper feeding structure: (1) *R. socialis* - formed by the outward laminary growth of a more or less stationary tube (Dalmer, 1937); (2) *R. rotatus* - formed by the back-filling of a tube which moved in a rotational pattern about a central axis (McCarthy, 1979); and (3) *R. chonoides* - a somewhat abberant form in which the sediment has been reworked in spreite-like helicoid swirls (Howard and Frey.

FIGURE 14

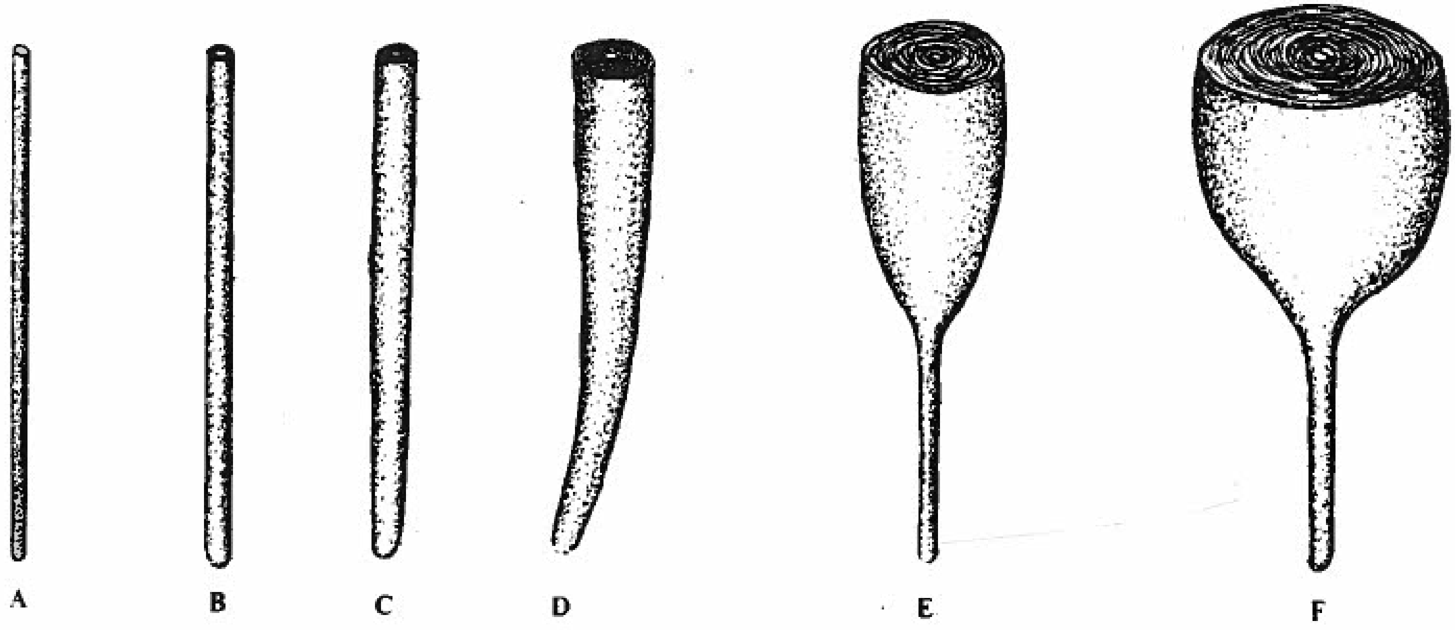
FIGURE 14. Diagram illustrating the morphologic intergradations and behavioral changes along an ichnospecific continuum from *Skolithos linearis* to vertically oriented *Cylindrichnus concentricus* and *Rosselia socialis.* Burrow A (unlined *S. linearis*) represents the temporary dwelling of an itinerent suspension feeder; development of a distinct wall lining in burrow B (still *S. linearis*) represents a step towards a more permenant inhabitance in which wall re-enforcement was of primary importance; development of a thin to moderately thick laminary wall in burrow C reflects, in addition to wall re-enforcement, the maintainance of an open domicile; infalling sediment being pressed directly into the burrow wall. Finally, burrows E and F (*R. socialis*) show the development of a highly expansive feeding cone, the laminae within which reflect primarily the outward reworking of sediment involved directly or indirectly in the process of feeiding; note downward gradation of funnels to a basal stem indentical in fabrication to burrow C (*C. concentricus*); burrow D (thickly lined, conically tapering *C. concentricus*) may overlap with this behavioral catagory.

Domichnia

(behavioural emphasis on dwelling and suspension feeding)

Fodonichnia

(behavioural emphasis or deposit feeding)



Skolithos linearis

Cylindrichnus concentricus

Rosselia socialis

Rosselia socialis Dahmer, 1937

Pl. 9, fig. 1-9; text fig 14

R. socialis. Dahmer, 1937, p. 532-533; Frey and Howard, 1970; Hautzschel, 1975, p. w101.

Diagnosis: Coniform to funnel-shaped *Rosselians*: central tube surround by concentric laminations of biogenically processed sediment.

Description: Relatively large, vertically oriented, bulbous, protuberant structures comprising (1) a simple, deeply extending, sharp walled, circular to subcircular core ranging in diameter from 6 to 12 mm; upper portion of core centrally encapsulated within (2) an upward expanding, coniform to funnel-shaped sediment body consisting of concentric laminae nested convexly downward; laminae consist dominantly of sideritized mud with thin, somewhat irregular interlaminations of less intensely sideritized sand; burrow core infilled with sand identical to host stratum. Funnel diameters range from 10 to 35 cm, with diameter/length ratios of 1:1-3. Downward, funnel structure (2) tapers to a thin, concentric wall lining, 1-5 mm, about the basal core.

Discussion: In addition to the basic solitary cone morphology, burrows commonly comprise a vertically stacked succession of two or more individual feeding cones (recorded maximum 4; Plate 9, fig. 1, 2, 4, & 6). These structures evidently reflect a post-storm burrow re-adjustment response on behalf of the tracemaker (see also earlier discussion).

Ichnogenus *Conichnus* Myannil, 1966

Ichnospecies Conichnus conicus Myannil, 1966

Pl. 7, fig. 2-6; text fig. 9F

C. conicus: Howard 1966, fig. 15; Frey and Howard 1970, fig. 8b; 1981, figs. 1A, 2A-E; Howard and Frey, 1984, fig. 7.

Diagnosis: Conical to acuminated subcylindrical structures, vertically oriented, thinly lined, having a smooth, sharply rounded basal apex (Howard and Frey, 1984).

Description: Large, vertically oriented, unlined, conical, plug-shaped burrows terminating downward in a smooth, well rounded base. Basal cross-sections are typically circular to subcircular, becoming increasingly oval and irregular towards the top of the structure; upper diameters range between 5 and 29cm, with corresponding lengths of 7 to 46 cm; width to length ratios vary from about 1:1.5 to 1:3. Burrows are infilled with sideritized sandstone in which fragments of petrified woody material are both ubiquitous and abundant, often rivalling the sand as the dominant infill constituent (see text figure 9F).

Discussion: The preferential siderite cementation causes the burrows to weather out from the surrounding weakly cemented host sand forming conspicuous nodular protuberances; the distinctive iron-red coloration and mere size of these structures adds to their prominence on the outcrop. *Conichnus conicus* evidently represents the resting-dwelling trace formed by itinerant anemone or anemone-like organisms.

Ichnogenus *Asterosoma* v. Otto, 1854

Asterosoma, v. Otto, 1854, p. 15; Hantzschel, 1975, p. W43; Fursich, 1974b, p. 38.

Diagnosis: Relatively large, fan to star-shaped burrows with bulbuous, spreitenless, outward tapering rays extending from a central shaft.

Asterosoma sp.

Pl. 5 fig. 4, 6, & 7

Description: Relatively large, fan-shaped burrows comprising numerous (15 to 50) outward thickening, finger-like horizontal elements all radiating from a common vertically inclined shaft. All radial elements are morphologically alike, possessing cylindrical exteriors, and distinctly rounded distal terminations. In cross-section, individual elements are circular to horizontally elliptical, and consist of a central core 3 to 5 mm in diameter, mantled by a distally thickening, concentrically laminated wall 1 to 5 mm thick. Constituent elements are tangentially arrayed with minimal interpenetration occurring between neighboring elements. Distinct horizontal planes occur in most specimens, along which a small number of radial elements are aligned; elsewhere, constituent elements are distributed and stacked in a more irregular fashion. The axial shaft, preserved from a single specimen, extends an indeterminate distance both above and below the radial elements and possesses a circular 7 mm diameter core, surrounded by a 5 mm thick concentrically laminated wall; a slight horizontal shift of the axial shaft towards the radial fan, is inferred by the excentricity of the core.

Discussion: These burrows evidently represent combined feeding-dwelling structures formed by a vermiform organism which fed by systematically exploiting the substrate in a radial fashion about a vertically oriented tube (Chamberlain, 1971; Fursich, 1974). The tracemaker evidently possessed a strong phobotaxic behavioral sense, as evidenced by the tangential arrangement of individual feeding probes. These specimens, although clearly belonging to *Asterosoma* , resemble in size and overall plan geometry specimens of *Dactyloidites ottol* figured by Fursich and Bromley (1985), but differ by lacking the distinctive spreiten morphology of the radial elements.

N.ichnogenus A

Tentative Diagnosis: Large, distinctive sideritized spreiten structures formed through the combined lateral migration and outward concentric laminary growth of an unbranched, geometrically varied causative cylindrical tube.

Remarks: Based on the overall configuration of the causative burrow, taking also into account the morphology of the spreiten body, three new ichnospecies, tentatively referred to as A, B, and C, are herein proposed. Full intergradation between these forms can be expected to occur. Based on the nature of internal fabrication, *N. ichnogen. A* is interpreted as a combined feeding-dwelling structure. Although the biological affinities of the tracemaker have not as yet been positively determined, the intimate association between *N. ichnogen. A* and *O. borneensis* may suggest a genetic link.

n.ichnospecies A1

Pl. 8, fig. 7 - 9

Diagnosis: Essentially horizontal, broadly U-shaped forms; spreite can be either protrusive or retrusive.

n. ichnospecies A2

Pl. 7, fig. 1

Diagnosis: Causative burrow forms a relatively compact, inward and upward spiralling, more-less parallel armed "U"; successive whorls are nested inwards.

n. ichnospecies A3

Pl. 8, fig. 1-6

Diagnosis: Characterized by a solitary, upward and openly spiraling causative burrow; spreiten always protrusive.

Ichnogenus *Rhizocorallium* Zenker, 1836

Rhizocorallium Zenker, 1836, p. 219; Fürsich, 1974b, p. 18; Hantzschel, 1975, p. W101.

Diagnosis: U-shaped spreiten-burrows, parallel or oblique to bedding planes; limbs more or less parallel and distinct; ratio of tube diameter to diameter of spreite >1:5 (Pemberton and Frey, 1984)

Remarks: At present, the ichnogenus *Rhizocorallium* encompasses three ichnospecies; *R. jenense, R. irregulaire,* and *R. uliarense.* The first species, *R. jenense* is interpreted as the domichnia of a suspension feeder (see discussion below), where as the latter two forms, *R. irregulaire,* and *R. uliarense,* owing primarily to their distinctive plani - and trochispiral burrow configurations and preferred horizontal orientation, are best interpreted as fodonichnia (Fusich, 1974c).

Rhizocorallium jenense Zenker, 1836

Pl. 12, fig. 4 & 6 - 8

Description: Obliquely oriented , relatively narrow *Rhizocorallia* displaying discontinuous, step-like retrusive spreite; each successive retrusion displaces the vertex of the burrow, both vertically and horizontally, by up to 5 mm. All specimens are closely sized, with tube diameters ranging from 9 to 12 mm, and spreite varying between 3.5 and 5.5 mm in width. Maximum observed length was 30 cm. Burrows display smooth exterior wall surfaces; most of the internal characteristics, including wall structure and infill composition, were evidently distroyed in the sideritization process. The final causative U-tube, preserved in a single specimen, arches with parallel arms upward into the vertical; overall dimensions include a length of 20 cm, a width of 5 cm, and a constant tube diameter of 1.1 cm; this specimen also revealed the presence of a relatively thick (2 mm) laminary wall lining.

Discussion: The following morphological aspects combine to indicate that the *R. jenense* tracemaker was a suspension feeder rather than a deposit feeder (cf. Fursich, 1974):

(1) the oblique orientation and relatively short burrow length.

(2) the presence of a relatively thick laminary wall lining.

(3) the retrusive nature of the spreite, evidently reflecting an equilibrium response to an incrementally agrading substrate.

Rhizocorallium sp.

Pl. 12, fig. 1 - 3 & 5

Description: Horizontal, planiform, U-shaped, protrusive spreiten burrows up to 20 cm in length. Burrow arms, although relatively straight, diverge symmetrically towards the closed end of the structure resulting a gradual widening of the spriete in that direction [from 5 to 8 cm in one specimen]. U-tubes display circular cross-sections with constant along burrow diameters of 18 to 20 mm. Distinct external *Ophiomorpha* -like discoid, and hemi-spherical pellets (4-7 mm in diameter) were observed on all specimens, scattered about the upper spreite, although also somewhat obscured by diagenisis, do appear to conform with the curvature of the final U-tube.

Discussion: In addition to establishing a genetic link between *Rhizocorallium sp.* and the *Ophiomorpha* tracemaker, the presence of isolated pellets on the wall exterior indicates that the feeding process, rather than continuous, was periodically halted during which time minor wall re-enforcements of the causative burrow were made. Hence, these burrows are perhaps best interpreted as combined feeding dwelling structures, and along with *N. ichnogen A* , may represent opportunistic feeding responses of the *Ophiomorpha* tracemaker.

CONCLUSIONS

Progradational barrier island sequences are well represented from the geologic record, in particular from the Cretaceous System of the Western Interior of the North America (cf. Masters, 1967; Land, 1872; Cotter, 1975; Ryer, 1977; Rautman, 1978; Van Horn, 1979; Flores and Espenbeck, 1981; McLane, 1982; Lerand, 1983; Howard and Frey, 1984; Leckie, 1985; Madden, 1985; and Matheny and Picard, 1985). An excellent example, forming the basis of this study, occurs within the transitional strata of the Bearpaw and Horseshoe Canyon Formations exposed along the Red Deer River Valley near Dorothy, Alberta. Here, spectacular three dimensional outcrop exposures replete with a wide diversity of exceptionally well preserved trace fossils have provided ideal conditions from which to apply an integrated sedimentologic-ichnologic analysis in the interpretation of these deposits. The results, we hope, clearly demonstrate how trace fossils, when analyzed in concert with the physical characteristics of the rocks, can be used to strengthen a depositional interpretation.

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PLATE 1

PLATE 1

Trace Fossils of the Appaloosa Sandstone

Figures 1 - 8. *Diplocraterion parallelum* Torell, 1870 All specimens from bed X of section S.D.-1. **Figs. 1, 5 and 6** give an indication of tremendous burrow density. **Figs 7 and 8.** relatively small specimens showing pronounced sideways deflection. Scratch marked burrow exteriors can be found by closely examing figures 1,2,4,5 and 6.


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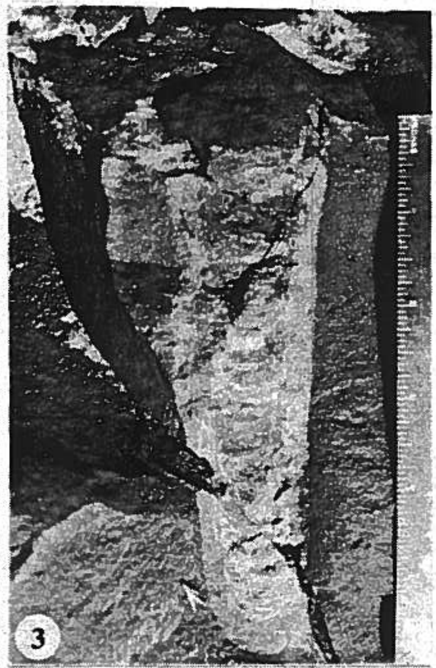
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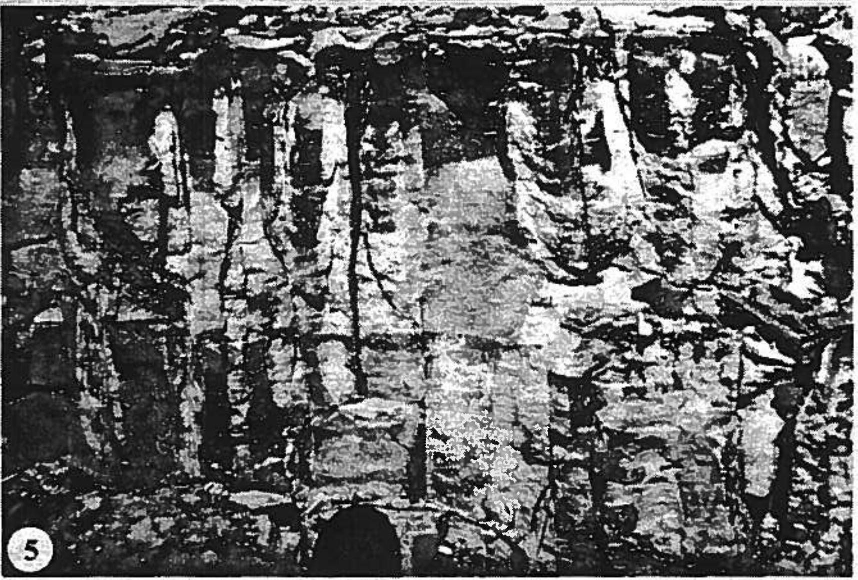
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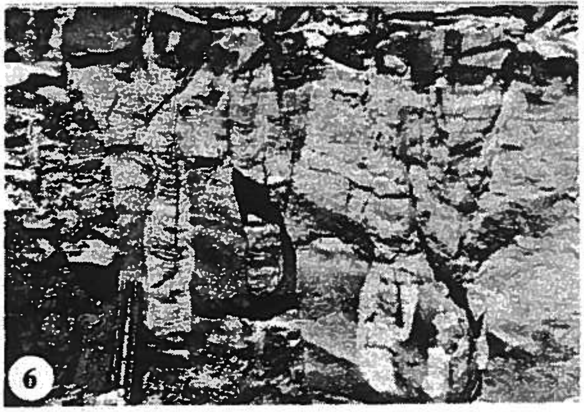
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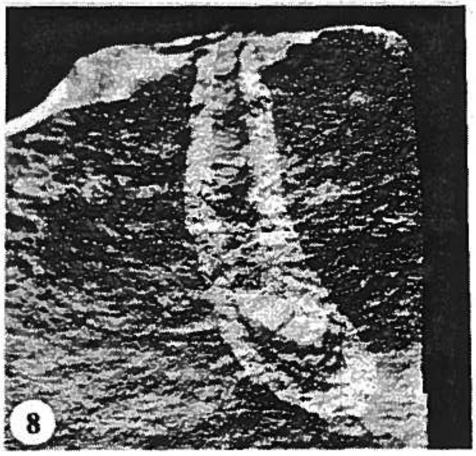
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PLATE 2

PLATE 2

Trace fossils from the Appaloosa Sandstone

Figures 1 - 5 *Diplocraterion parallelum* Torell, 1870. **Figs. 1 and 2.** specimens from base of Appaloosa at EC-4. Here burrows subtend from the transgressive surface, and are excavated into a back-barrier coal seam evidently exhumed during transgressive shoreface erosion. **Figs 3, 4** capping R1 deltaic sequence at Little Big Coulee; here burrows subtend from the transgressive surface defining the R 1 - R2 boundary.

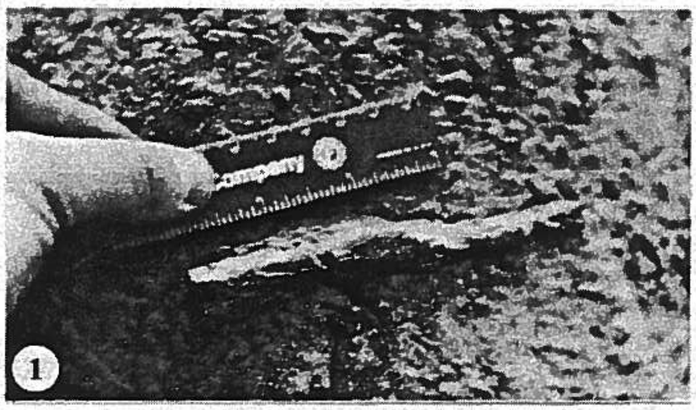
PLATE 3

PLATE 3

Trace fossils from the Appaloosa Sandstone

Figures 1 - 4. *Teichichnus rectus* Seilacher, 1955. **Fig. 2.** plan view of interpenetrating burrows. **Figs. 1, 3, and 4** of vertical outcrop faces; **Fig. 3.** dense profusion of burrows. **Fig. 4.** exceptionally well preserved specimen showing full U-structure including aperatural arms.

Figures 5 - 8. *Gyrocorte comosa* Heer, 1865. **Fig. 5.** epichnial specimens from BC-1 preserved on upper surface of a Swaley X-stratified storm sand: note tremendous size variation. **Figs 6 - 8.** hypichnial specimens from L.B.C.-1 preserved on the base of a resistant parallel laminated storm sand.



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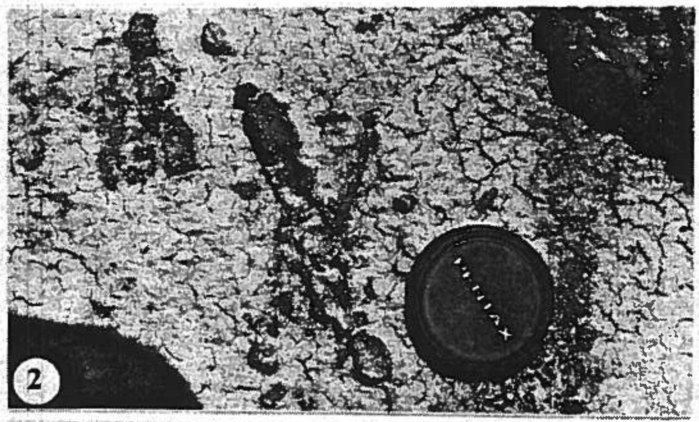

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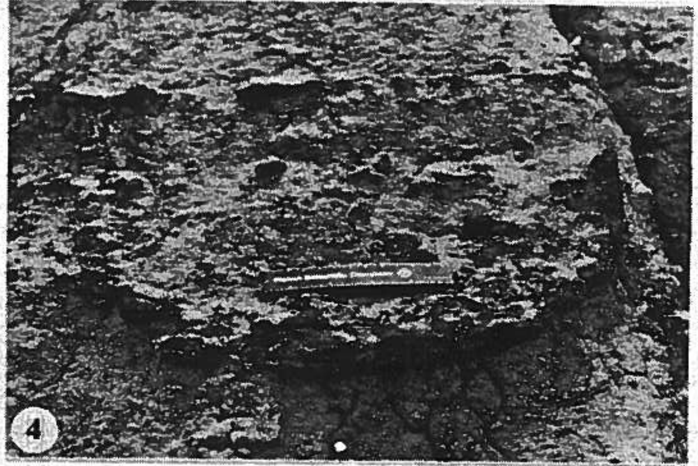

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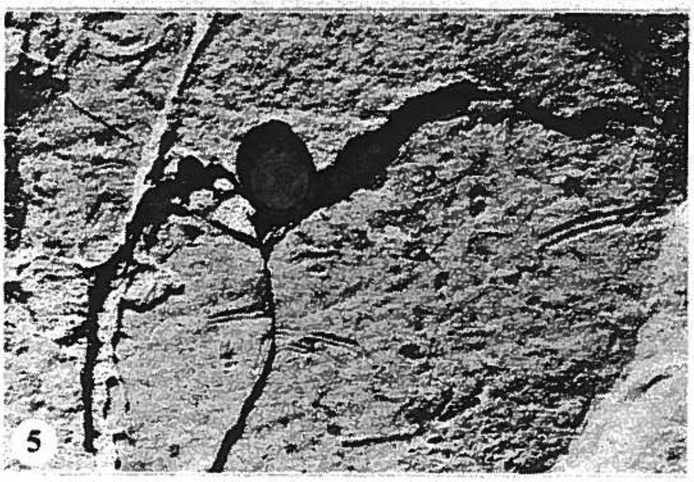

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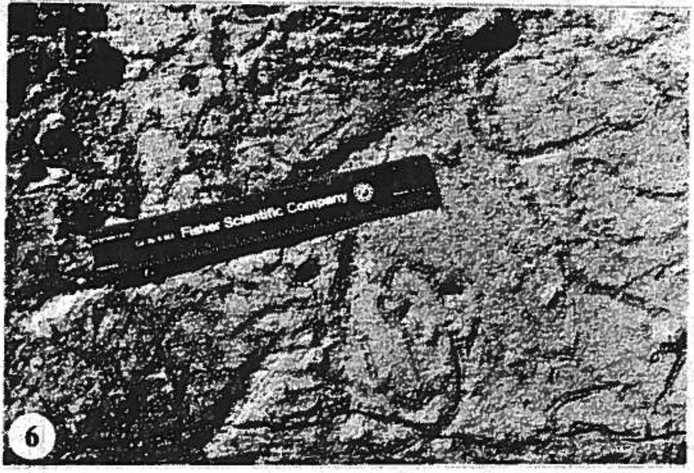

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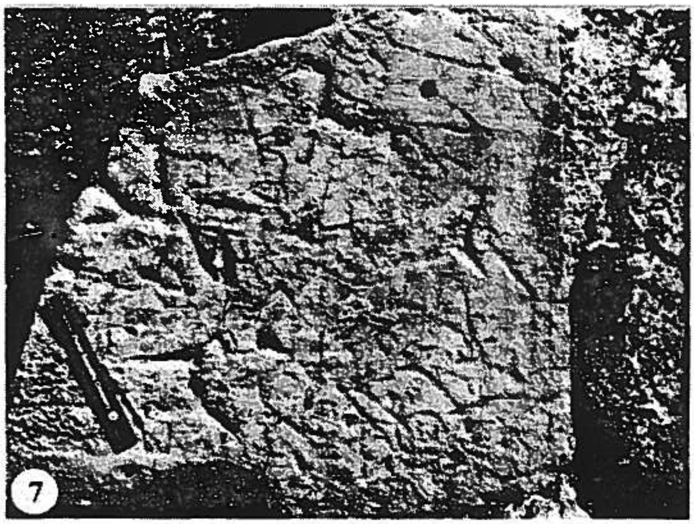

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PLATE 4

PLATE 4

Trace fossils from the Appaloosa Sandstone

Figures 1 - 7. *Ophiomorpha borneensis* Kiej, 1965. **Fig. 1.** oblique view of well-preserved "maze like" system within uppermost storm sand of Unit 1B at S.D.-1. **Fig. 2.** side view of complexly interwoven three dimensional "boxworks" within ammalgamated storm sands near OH-1. **Fig. 3.** plan view of gently meandering tunnel with well preserved double pellets. **Figs. 4-6.** vertical rock faces displaying burrows in cross-section as they might appear in core. **Fig. 6.** oblique view of partially exposed system; note *Teichichnus* - like retrusive spreiten migration of tunnel situated above ruler. **Fig. 7.** "triple tunnel junction" from Unit 5 at DOR-1; note characteristic enlargement of burrow at point of branching.


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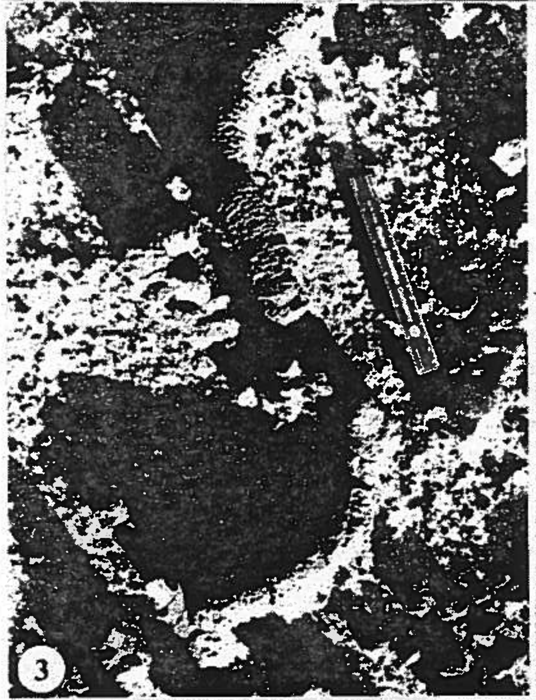
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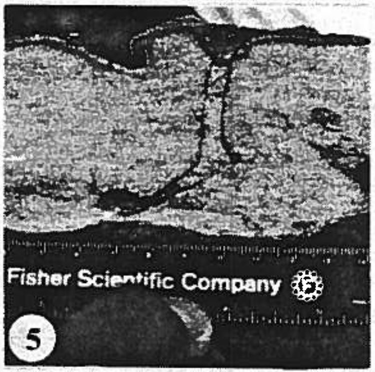
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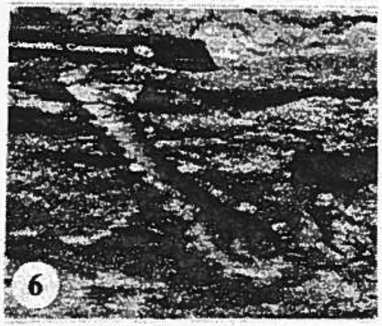
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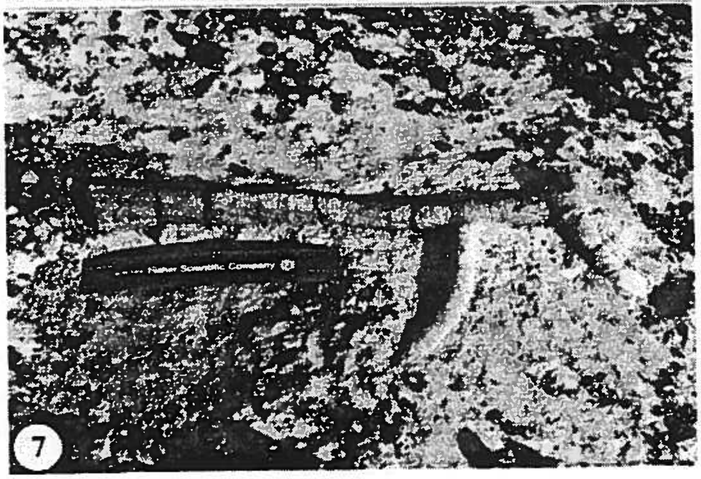
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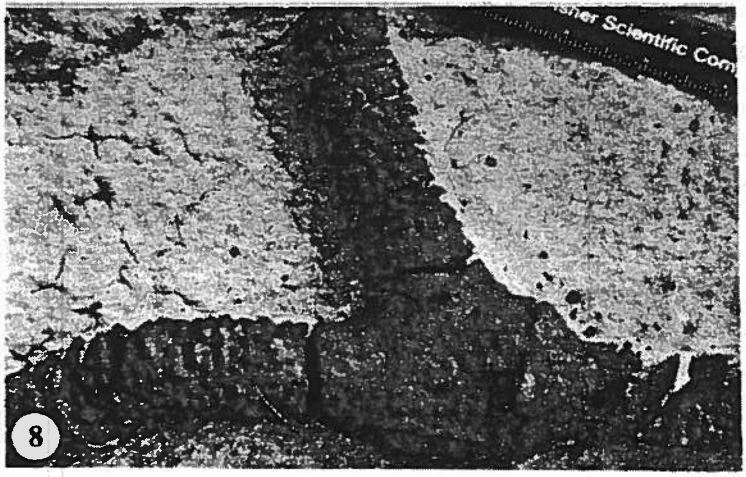
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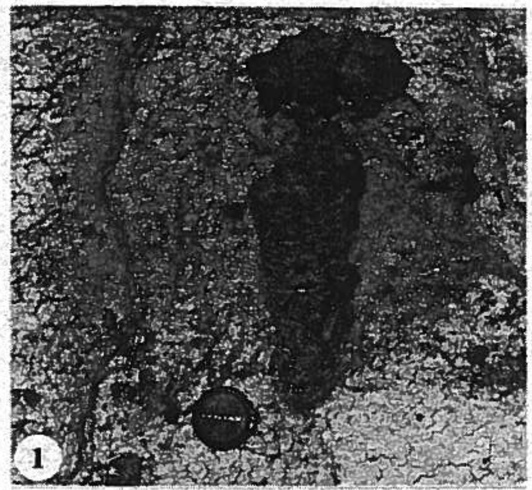
PLATE 5

PLATE 5

Trace Fossils from the Appaloosa Sequence

Figures 1, 3 & 5. *Cylindrichnus concentricus* Howard, 1966. **Figs. 1 and 3.** specimens from Unit 4 at DOR-1 displaying upward branching of basal stock into 2 and 3 separate elements. **Fig. 2.** top view of specimen in figure 5. **Fig. 3.** multiple specimens within lower shoreface at EC-5.

Figures 4, 6 & 7. *Asterosoma sp.* **Fig. 7.** plan view of specimen from unit 4 at DOR-1: note concentrically laminated central shaft. **Fig. 4.** x-section of specimen in figure 6: note tangential arrangement of radial elements. **Fig. 6.** specimen showing characteristic outward branching of radial elements.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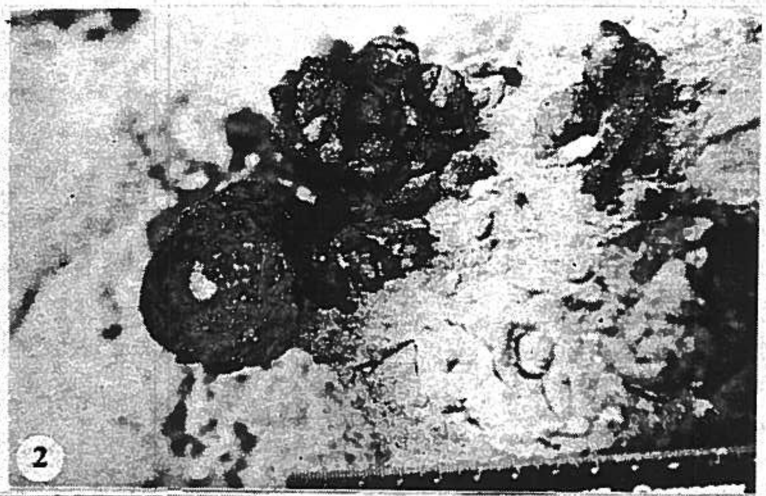
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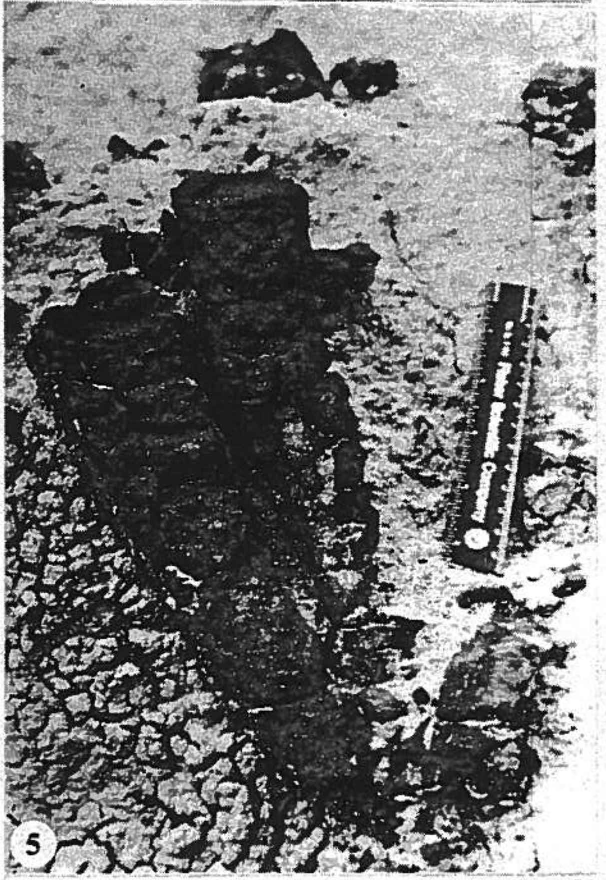
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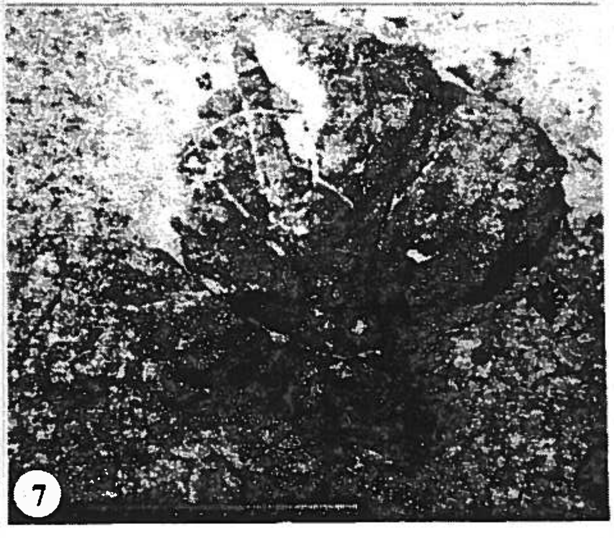
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PLATE 6

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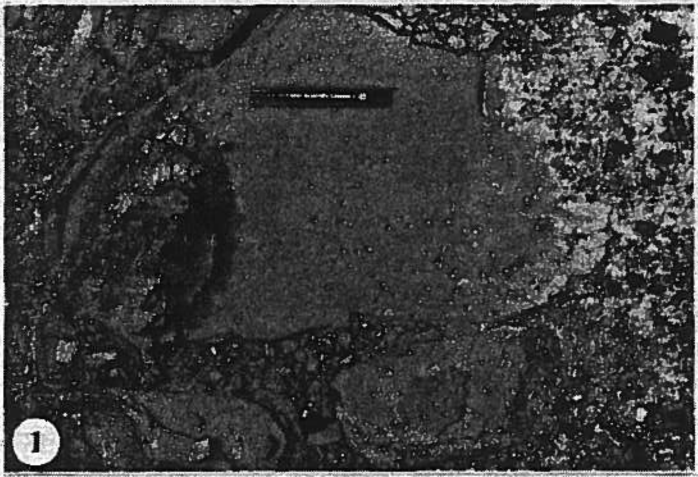
Trace fossils from the Appaloosa Sandstone

Figures 1 - 4. *Skolithos linearis* Halderman, 1840. **Fig. 1.** bedding plane profusion on upper surface of H.C.S. sand bed in Unit 1B at S.D.-1. **Fig.2.** bedding view of solitary specimen displaying thin mud wall-lining. **Fig. 3.** specimen displaying thick lining of clean agglutinated sand. **Fig. 4.** x-sectional view of specimens occurring within laminated-rippled facies of lower shoreface sands at Boot Coulee.

Figures 5 - 8. *Arenicolites variabilis* Fürsich, 1974. All photos of upper bedding surfaces. **Fig. 5, 6 and 8.** unlined specimens; individual opening preserved as conspicuously paired epichnial bumps. **Fig. 7.** specimens preserved near top of Appaloosa sequence at EC-4; note size differential of individual openings comprising paired associations.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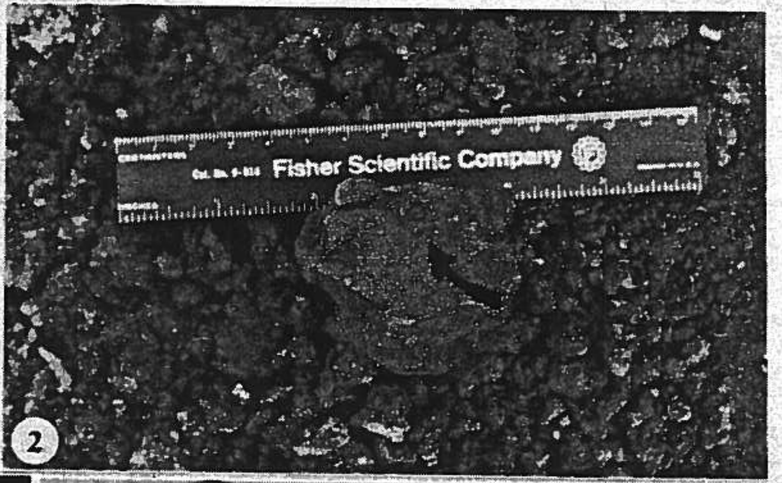
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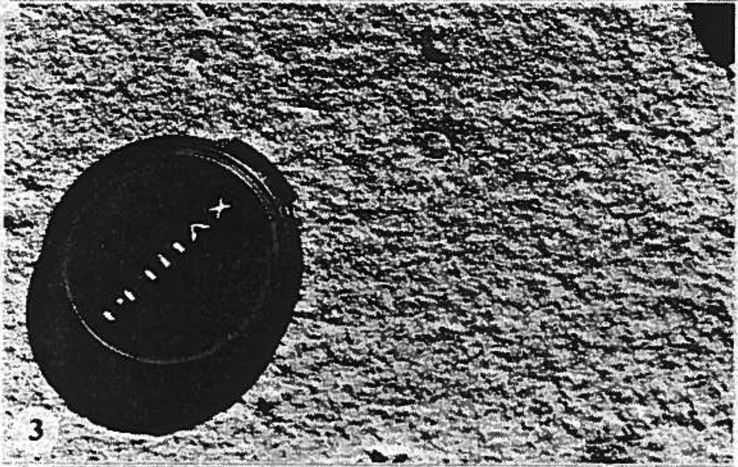
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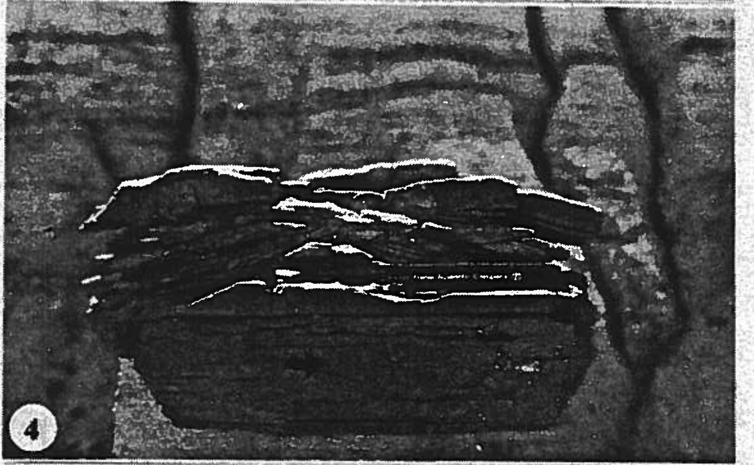
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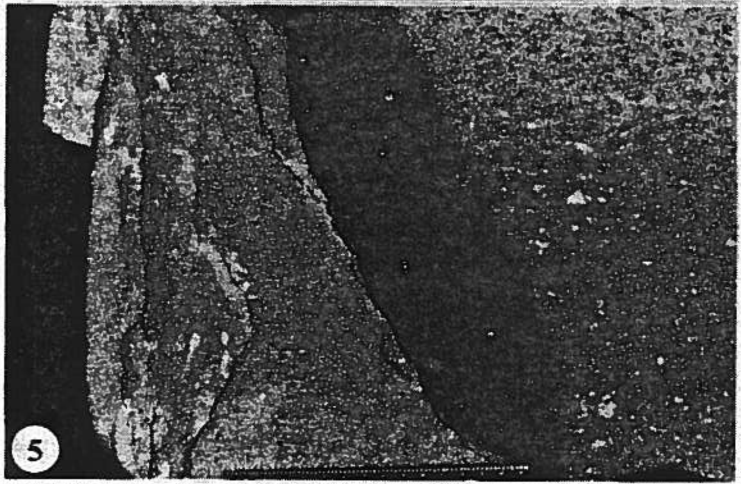
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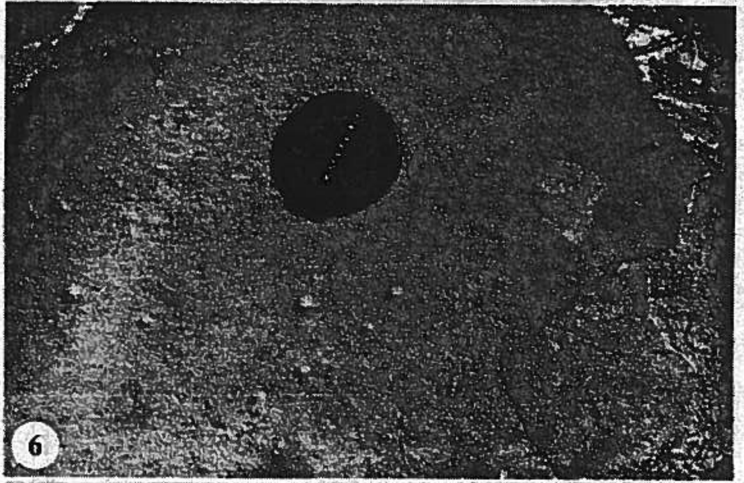
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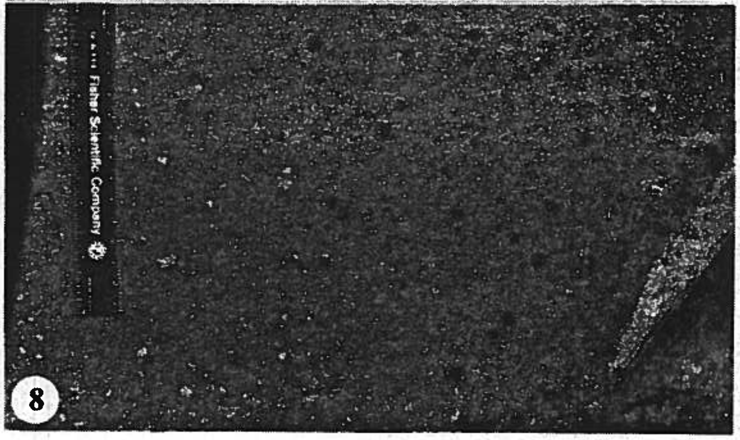
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PLATE 7

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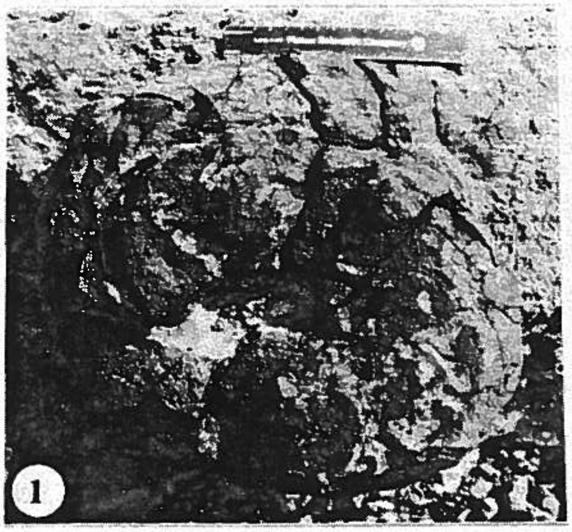
Figure 1. *N. ichnogenus A sp A2* plan view of type specimen from Unit 1B at S.C.-1: note characteristic upward and inward nature of coiling; although resembling *Rhizocorallium* in overall geometry (see Fürsich, 1974), this burrow is made distinct by the presence of a thick laminary wall structure.

Figure 2-6. *Conichnus conicus* Myannil, 1966. Protuberant sideritic specimens from Unit 1 at Sundance Coulee. **Fig. 3.** cluster of relatively small specimens, indicating the trace maker, at least during juvenile stages of development, exhibited "gregarious" behaviour -- a characteristic common amongst certain species of modern Anemones. **Fig. 6 .** large specimen (note scale at base of photo) showing characteristic rounding of basal apex.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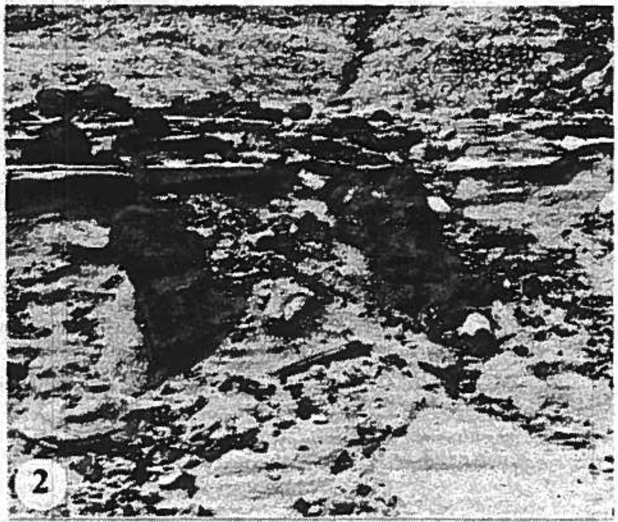
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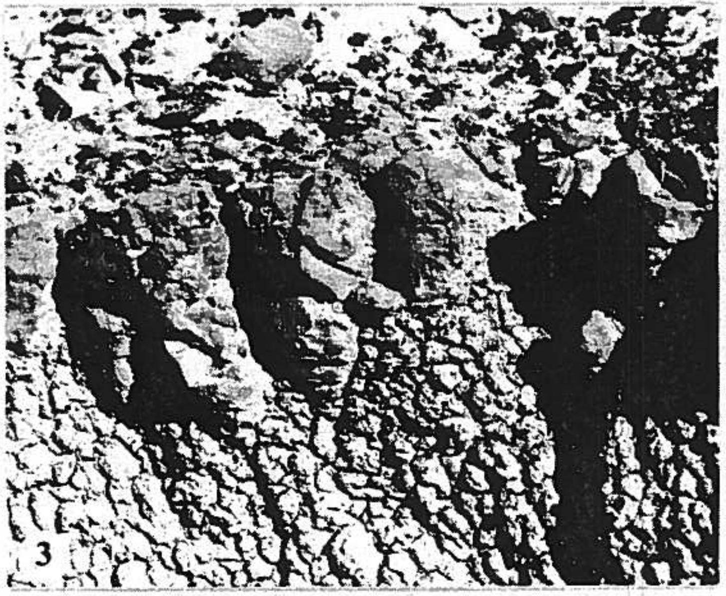
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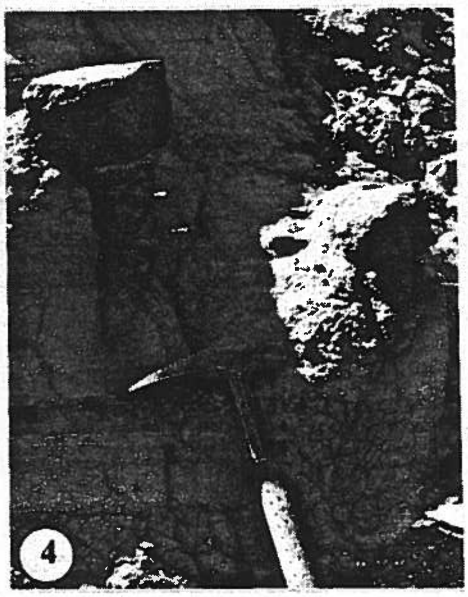
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PLATE 8

PLATE 8

Trace fossils from the Appaloosa Sandstone

Figures 1 - 6 . *N. ichnogenus A sp. A3* Specimens from unit 5 at DOR-1 **Fig. 1.** oblique view of type specimen showing three successive levels within spiral: see figure 2 for top view of this specimen. **Figs. 3 - 6.** side views of specimens showing the range of possible morphological variation.

Figures 7 - 9. *N. ichnogenus A. sp A1* **Fig. 7.** partially preserved specimen from Unit 5 at DOR-1. **Fig 8.** photo (taken later) showing internal structure of specimen in Figure 7; note sand filled tube coursing through centre of structure and overall similarity in mode of fabrication between these burrows and *R. socialis.*


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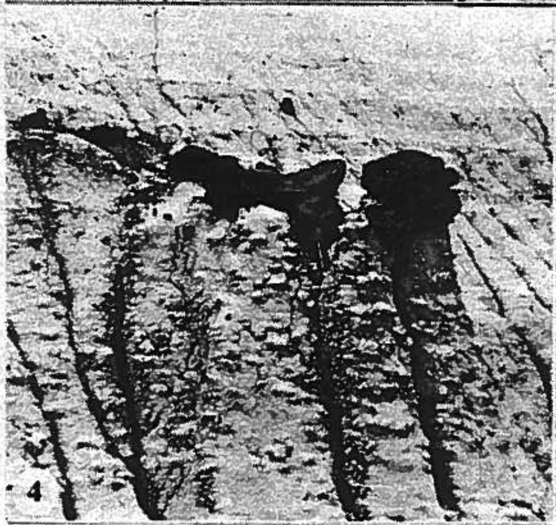
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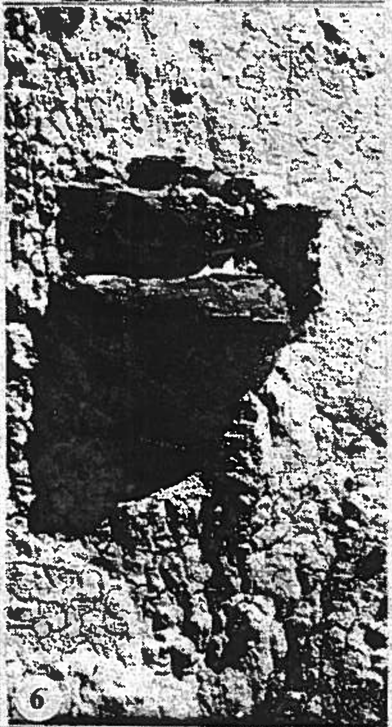
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PLATE 9

PLATE 9

Trace fossils from the Appaloosa Sandstone

Figures 1 - 9. *Rosselia socialis* Dalmer, 1937. All specimens from Boot Coulee (DOR-1, units 4 and 5). **Fig. 1.** outcrop photograph of Unit 4 at DOR-1 showing specimen with well developed second feeding cone reflecting a post-storm re-equilibriation response of the tracemaker. **Fig. 2.**close-up of specimen in figure 1. **Figs 3 and 9.** longitudinal sections of specimens showing central sand filled tube and internal nature of laminae comprising feeding cone. **Figs 5 and 7.** specimens with basal stock preserved. **Fig. 6.** outcrop view of specimens elucidating concealed bedding surfaces; see figure 4 for close-up of double-funnel in centre of photo. **Fig 8.** top view of relatively large specimen.


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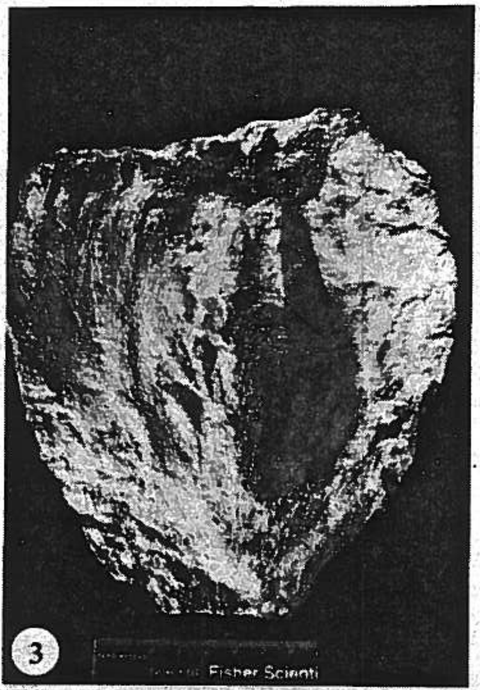
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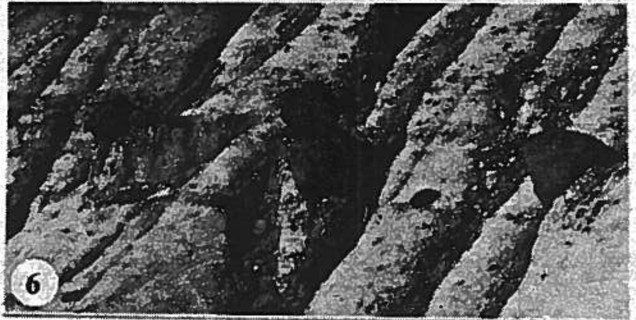
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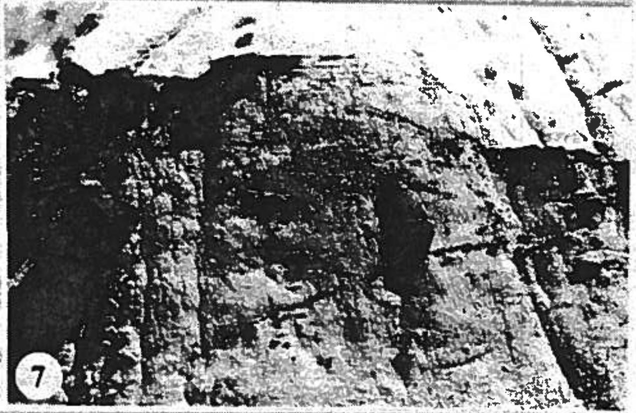
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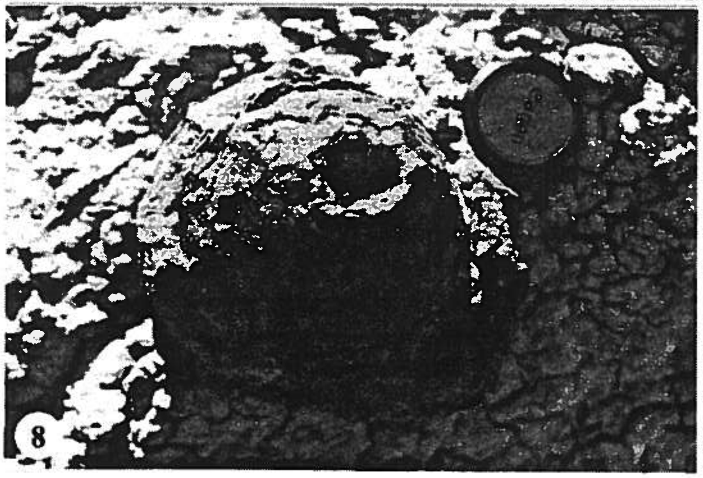
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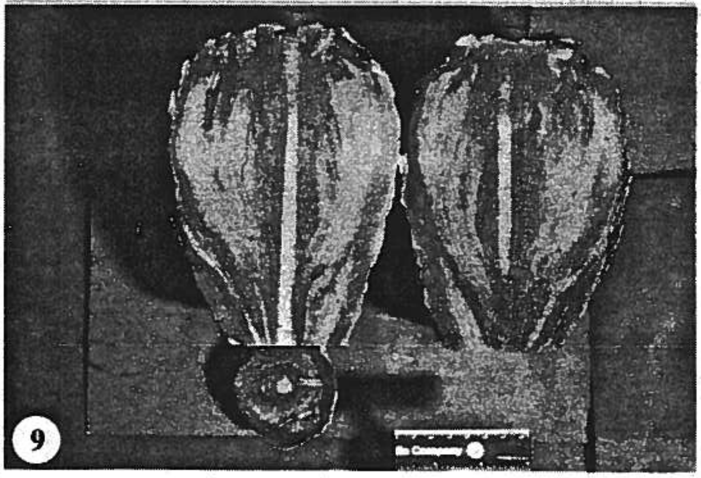
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PLATE 10

PLATE 10

Trace fossils from the Appaloosa Sandstone

Figures 1-6 & 8. *Macaronichnus segregatis* Clifton and Thompson, 1978. **Figs. 1,2,4,6, and 8.** Profusely burrowed bedding surfaces displaying characteristic "random avoidance" pattern of burrowing; in all figures, forms intergradational between *M. segregatis* and *M. spiralis* can be seen. **Figs 3 and 5.** intensely burrowed vertical faces: note preferential concentration of burrows along certain bedding planes in figure 5.

Figures 7, 9 &10. *Macaronichnus spiralis* , n. ichnosp. bedding surface views of specimens displaying distinctive spiral configuration. **Fig. 9.** well developed near circular tightly coiled spiral. **Figs. 7 and 10.** specimens showing distinctive, but less well developed spiral configurations; bar in figure 7 one cm.


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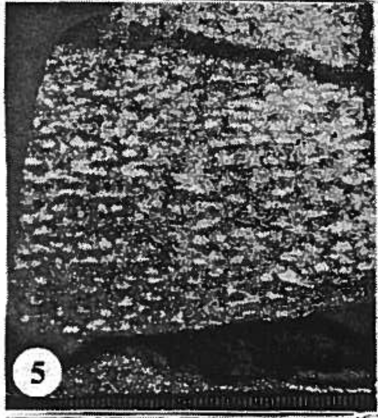
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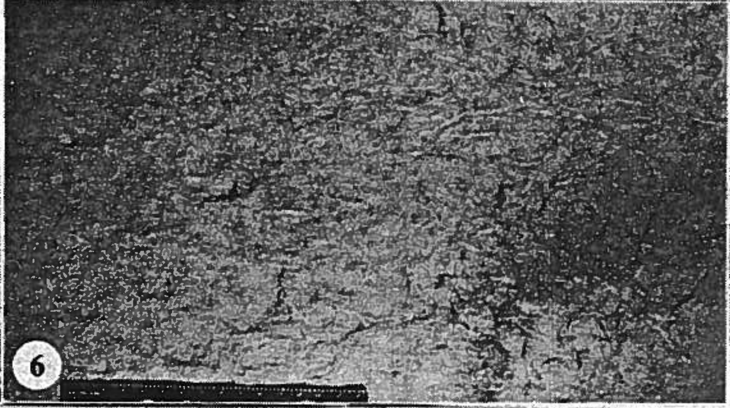
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PLATE 11

PLATE 11

Trace fossils from the Appaloosa Sandstone

Figures 1-5 & 7. *Planolites sp.* **Figs. 3 and 7.** specimens displaying characteristic randomly interpenetrating pattern of burrowing; all bedding views. **Fig. 4.** epichnial specimens occurring on upper surface of storm sand in Unit 1B at S. D. -1; note distinct parting lineation.

Figures 3, 6 and 7. *Palaeophycus tubularis* Hall, 1847. **Fig. 6.** side view of endichnial specimen displaying relatively thick mud lining: note similarity between infill and matrix. **Figs. 3 and 7.** epichnial specimens co-occurring with *Planolites sp* ; both bedding views.


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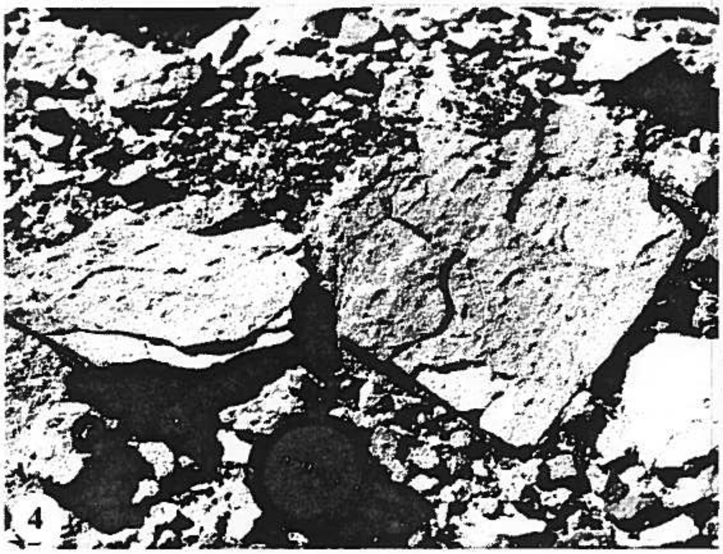
PENTAX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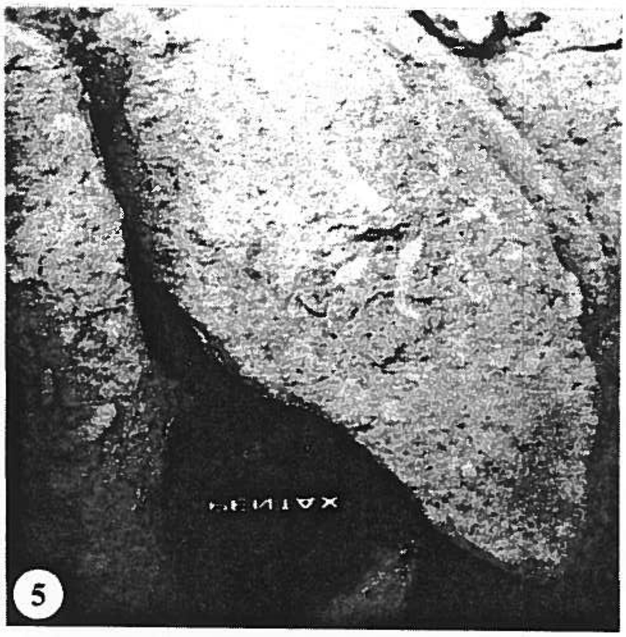
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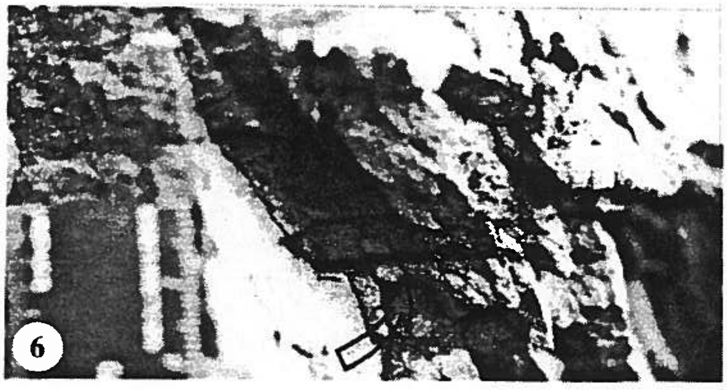
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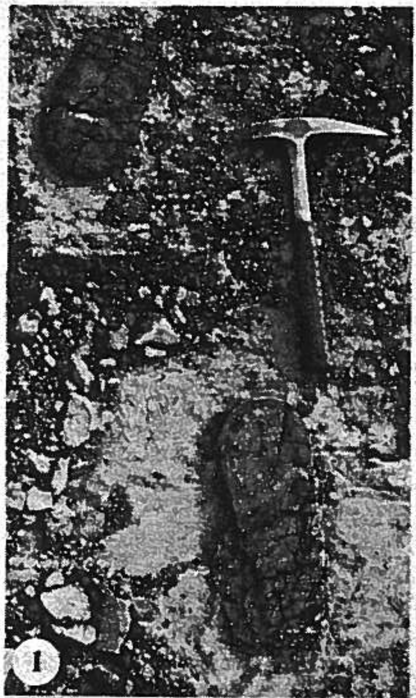
PLATE 12

PLATE 12

Trace fossils from the Appaloosa Sandstone

Figures 1-3 & 5. *Rhizocorallium sp.* Bedding views of specimens co-occurring at top of unit 1B storm bed at Sundance Coulee; note single *Ophiomorpha* - like pellets scattering the surfaces of all specimens.

Figures 4 & 6-8. *Rhizocorallium jenense* Zenker, 1876. Specimens from Unit 4 at DOR-1 showing characteristic step-like retrusive spreite. **Fig. 4.** side view of specimens shown below in Figure 6. **Fig 8.** oblique view of specimens co-occurring with *R. socialis.*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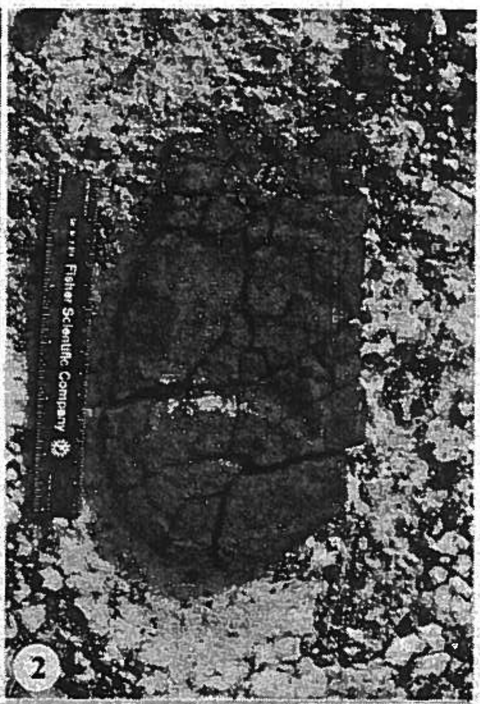
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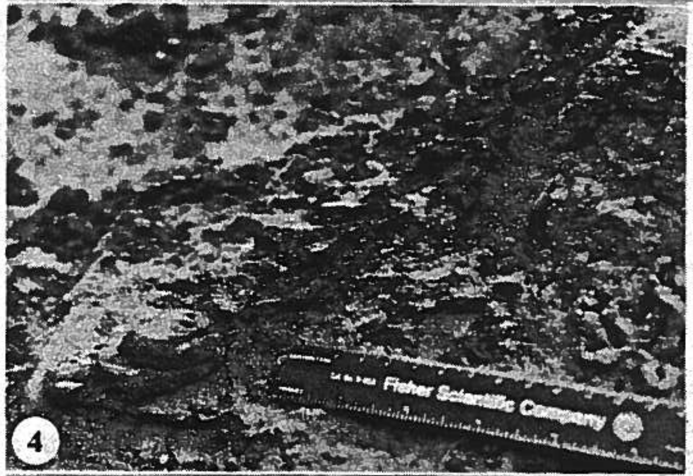
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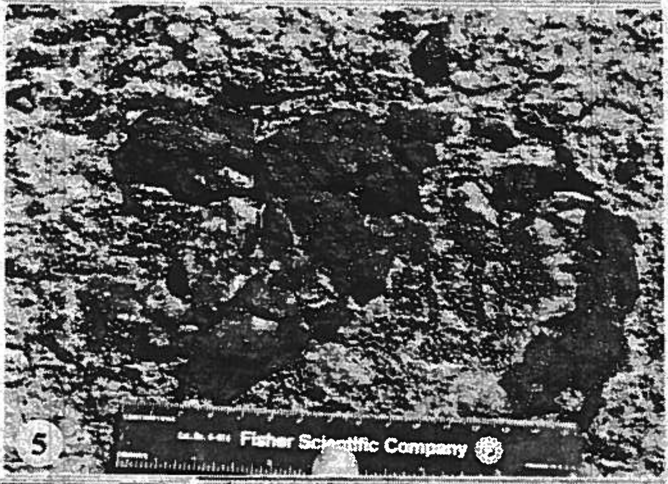
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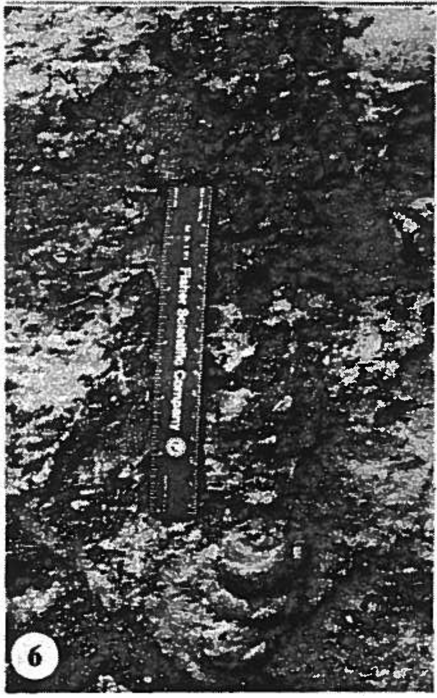
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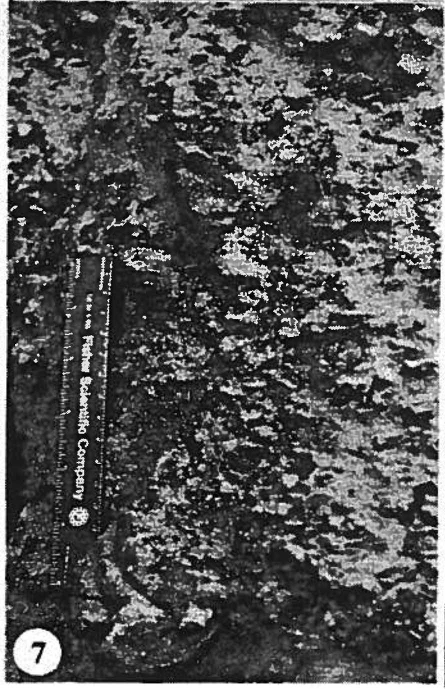
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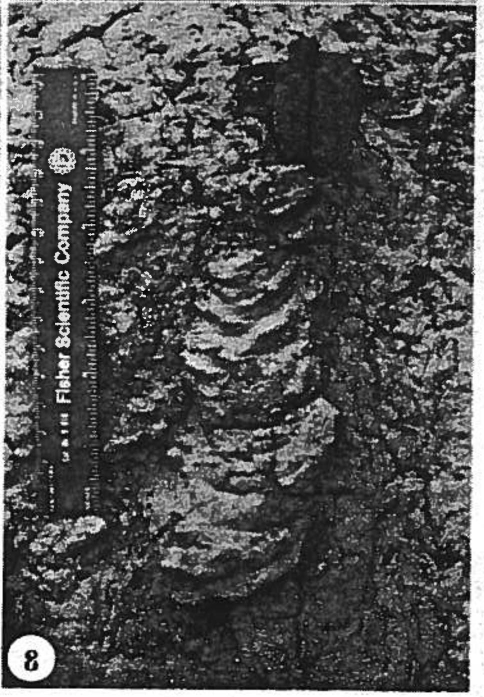
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