

within some sedimentary units, so provide a local record of organisms that would not otherwise be preserved. Finally, they are a manifestation of behavior, so that their distribution through the stratigraphic column may be used as a basis for interpreting the evolutionary history of behavior.

Trace fossils are given latinized generic and species names in the same manner as body fossils. Although many trace fossils can be identified with the organism that produced them, it is clear that many other traces can not be identified even to phylum. Each trace fossil name is given to a particular geometry regardless of its biologic origin, which is almost always unknown at some taxonomic level. Fortunately, many — but certainly not all — are indicated by suffixes such as *-ichnus*, *-craterion*, *-ichnites*, *-opus*, etc. Trace fossil morphologies are named formally so that paleontologists and sedimentologists can communicate about them, although it must be kept in mind that many may actually represent more than one species, genus, or even phylum of organisms. Conversely, different activities of a single organism may produce different trace fossil morphologies.

The purposes of this exercise are:

- 1 to examine a variety of traces that represent different behavioral categories; and
- 2 to use traces as a key to environments in which the enclosing rocks were deposited.

17.2 CATEGORIES OF TRACE FOSSILS

Several different bases have been used for classification of trace fossils. Descriptive-genetic classifications are based on

recognition of such categories as tracks, trails, burrows, etc. Some classifications are based on preservation, while others are based on behavior. Classification by behavioral category is widely used, relatively straight-forward, and useful in interpretations of paleoenvironments. Therefore, behavioral category is used here as a means of organizing and interpreting trace fossils.

Seven behavioral categories exist to which trace fossils are assigned: resting or hiding, locomotion, dwelling, deposit feeding, surface grazing, escape following burial or exposure, and highly patterned structures that suggest some sort of farming or husbanding of environmental resources (Fig. 17.2, Table 17.1). Traces were originally made by organisms moving across, burrowing within, or stopping on or within the substrate. Traces within substrates may collapse if not back-filled with processed sediment or fecal pellets, or infiltrated by sediment from the substrate surface. Collapse is much more likely in highly aqueous clays than in silts and sands. Traces preserved at the sediment-water interface or at the interface between two layers of unconsolidated sediment were filled by sediment washing or flowing into them; splits along bedding planes therefore expose surfaces that are positives (original geometry preserved in the imprinted sediment) and negatives (surface of the infilling sediment).

Individual traces commonly reflect more than one behavior, such as dwelling burrows in which the organisms also feed, grazing traces that record the passage of an organism across an area, and so on. Usually, one behavior is dominant in generation of the trace so that its assignment to a particular category is based on the dominant behavior.

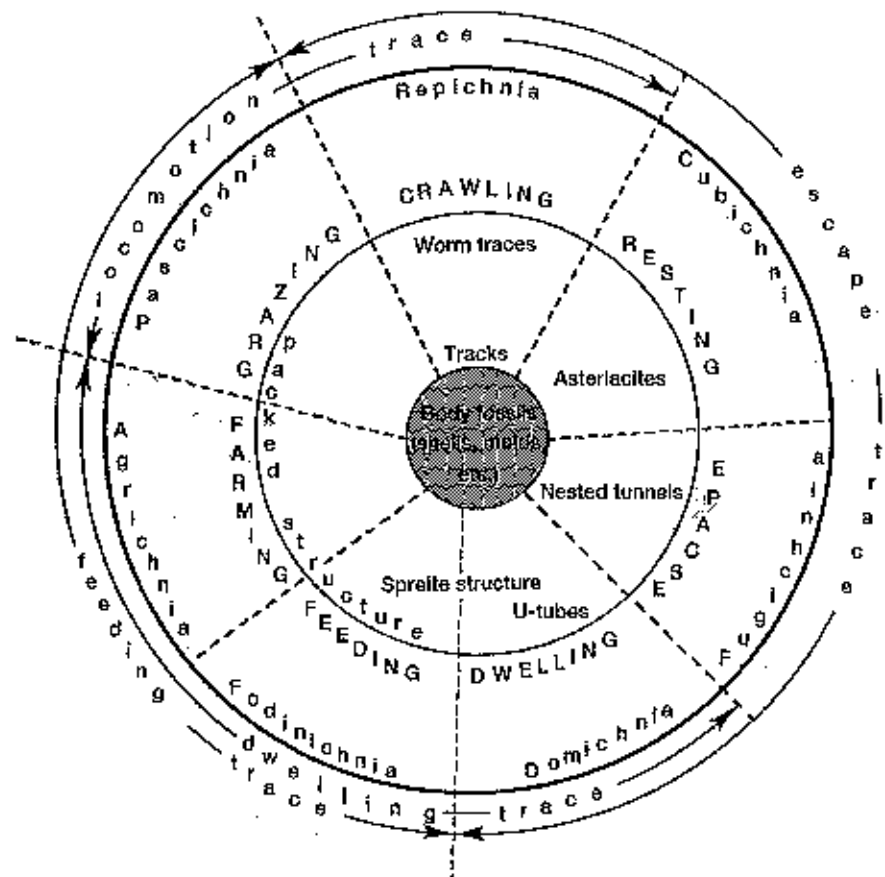


Fig. 17.2 Scheme of classification of the seven major categories of trace fossils, showing their relationship to body fossils and to one another; some generalized examples are incorporated in the middle ring. Adapted from Frey & Pemberton (1985) after Seilacher.

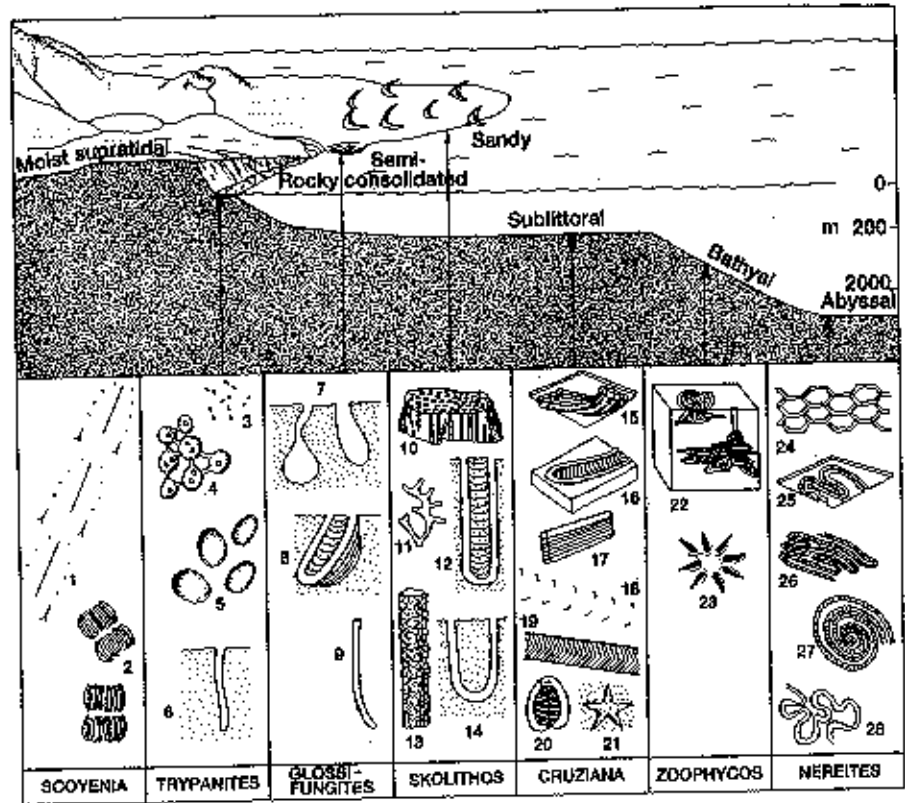


Fig. 17.3 Some of the common ichnofacies and examples of trace fossils that occur in them. (1) *Kouphichnium* (xiphosurid tracks); (2) *Isopodichnus*; (3) borings of *Polydora* (a polychaete annelid); (4) *Entobia* (boring of elionid sponges); (5) echinoid borings; (6) algal borings; (7) pholadid burrows; (8) *Diplocraterion*; (9) unlined crab burrow; (10) *Skolithos*; (11) *Thalassinoides*; (12) *Diplocraterion*; (13) *Ophiomorpha*; (14) *Arenicolites*; (15) *Phycodes*; (16) *Rhizocorallium*; (17) *Teichichnus*; (18) *Diplichnites* (trilobite tracks); (19) *Cruziana*; (20) *Rusophycus*; (21) *Asteriacites*; (22) *Zoophycos*; (23) *Lorenzina*; (24) *Paleodictyon*; (25) *Taphrohelminthopsis*; (26) *Helminthoidea*; (27) *Spirorhaphe*; (28) *Cosmorhaphe*. Adapted from Crimes (1975), Frey & Seilacher (1980), and Ekdale *et al.* (1984).

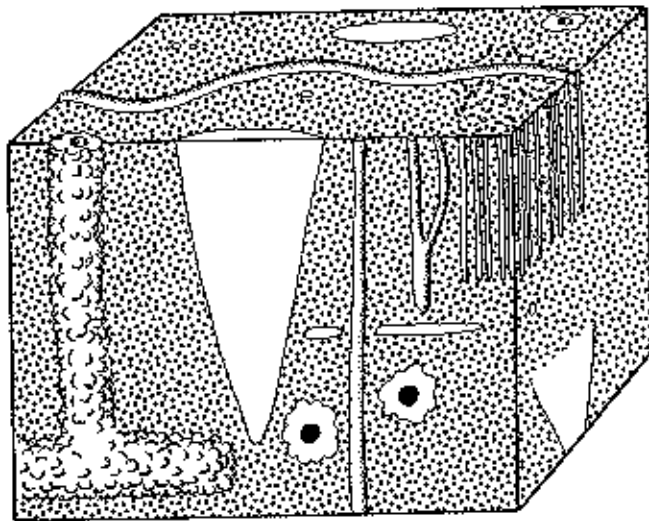


Fig. 17.4 Diagrammatic sketches of trace fossils that are common in the Pleistocene Ironshore Formation, Grand Cayman Island, British West Indies. Although these fossils are preserved in an ooid limestone, which is a carbonate rock, they are comparable to assemblages in similar-textured siliciclastic rocks. Based on photographic illustrations in Pemberton & Jones (1988).

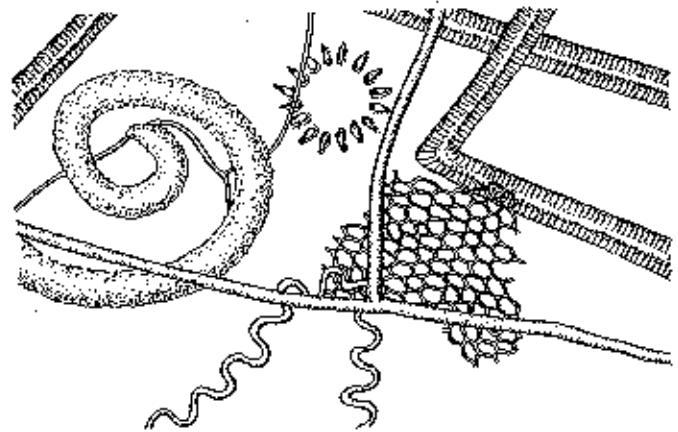


Fig. 17.5 Diagrammatic sketches of an assemblage of trace fossils that are parallel with bedding in the Mesozoic-Cenozoic flysch deposits of the Carpathian Mountains in Poland. Based on photographic illustrations in Kern (1980).

Table 17.2 (Continued)

	<p>some, developed mainly in response to substrate degradation, or aggradation (escape or equilibrium structures), forms of <i>Ophiomorpha</i> consisting predominantly of vertical or steeply inclined shafts</p> <p>Animals chiefly suspension feeders</p> <p>Diversity is low, yet given kinds of burrows may be abundant</p>
<i>Cruziana</i> ichnofacies	<p>Infralittoral to shallow circalittoral substrates</p> <p>Below daily wave base but not storm wave base, to somewhat quieter offshore-type conditions</p> <p>Moderate to relatively low energy, well-sorted silts and sands, to interbedded muddy and clean sands, moderately to intensely bioturbated</p> <p>Negligible to appreciable, although not necessarily rapid, sedimentation</p> <p>A very common type of depositional environment, including estuaries, bays, lagoons, and tidal flats, as well as continental shelves or epeiric seas</p> <p>Abundant crawling traces, both epi- and intrastratal, inclined U-shaped burrows having mostly downwardly extended spreiten (feeding swaths, soft-sediment <i>Rhizocorallium</i>)</p> <p>Forms of <i>Ophiomorpha</i> and <i>Thalassinoides</i> consisting of irregularly inclined to horizontal components</p> <p>Scattered vertical cylindrical burrows</p> <p>Animals may include mobile carnivores and both suspension and deposit feeders</p> <p>Diversity and abundance generally high</p>
<i>Zoophycos</i> ichnofacies	<p>Circalittoral to bathyal, quiet-water conditions, or protected epeiric sites; muds or muddy sands rich in organic matter but more or less deficient in oxygen</p> <p>Epeiric sites reflect somewhat stagnant waters</p> <p>Offshore sites are below storm wave base to fairly deep water, in areas free of turbidity flows or significant bottom currents</p> <p>Where relict or palimpsest substrates are present, especially if swept by shelf-edge or deeper-water contour currents, this ichnofacies may be omitted in the transition from <i>Skolithos</i> or <i>Cruziana</i> ichnofacies into the <i>Nereites</i> ichnofacies</p> <p>Relatively simple to moderately complex, efficiently executed grazing traces and shallow feeding structures</p> <p>Spreiten typically planar to gently inclined, distributed in delicate sheets, ribbons, or spirals (flattened forms of <i>Zoophycos</i> or, in pelitic sediments, <i>Phycostrophia</i>)</p> <p>Animals virtually all deposit feeders</p> <p>Low diversity, but given structures may be abundant</p>
<i>Nereites</i> ichnofacies	<p>Bathyal to abyssal, mostly quiet but oxygenated waters, in places interrupted by down-canyon bottom currents or turbidity flows (flysch deposits), or highly stable, very slowly accreting substrates</p> <p>In flysch or flysch-like deposits, pelagic muds typically are bounded above and below by turbidites</p> <p>In more distal regions, the record is mainly one of continuous deposition and bioturbation</p> <p>(The stable deep-sea floor is not universally bioturbated, however; at least not equally intensively at every site)</p> <p>Complex grazing traces and patterned feeding-dwelling structures, reflecting highly organized, efficient behavior</p> <p>Spreiten structures typically nearly planar, although <i>Zoophycos</i> forms are spiralled, multilobed, or otherwise very complex</p> <p>Numerous crawling-grazing traces and sinuous fecal castings (<i>Neonereites</i>, <i>Helminthoidea</i>, <i>Cosmorhaphis</i>), mostly intrastratal</p> <p>Animals chiefly deposit feeders or scavengers, although some may have farmed microbe cultures within their more or less permanent, open domiciles (<i>Paleodictyon</i>)</p> <p>Diversity and abundance significant in flysch deposits, less so in more distal regions</p>

17.1 INTRODUCTION

Trace fossils are remnants of the activities of live organisms, but do not include the body or body parts of the organisms themselves (Fig. 17.1). Trace fossils (also referred to as *Lebensspuren* or *ichnofossils*) include such phenomena as tracks, burrows, coprolites (fossil dung), and scratches in sand made by live seagrasses waving on a beach. They do not include shells, molds of dead organisms, the track of a carcass washed across a sand flat, nor scratches in sand made by dead seagrasses waving on a beach. Sedimentary structures that were not produced by organisms, but that look superficially as if they were, are called *pseudofossils*. With a little experience, body fossils, trace fossils, and pseudofossils can be distinguished in most instances. However, occasionally a

structure may be difficult or impossible to assign to one of these three categories. For example, the traces of dead and live grass tips are impossible to distinguish.

Although extensive and systematic studies of trace fossils have been undertaken only during the past 30 years, such fossils are extremely important for paleontology and sedimentology. Their most important use up to now is based on the observation that traces being formed at present are organized into distinct environmental assemblages, and these assemblages appear to have been stable over long periods of evolutionary time. Many trace fossils are records of organisms that were soft-bodied and therefore had low preservation potential as body fossils. Trace fossils were almost always formed in the place where they are found and were not transported. Trace fossils are the only type of fossils preserved

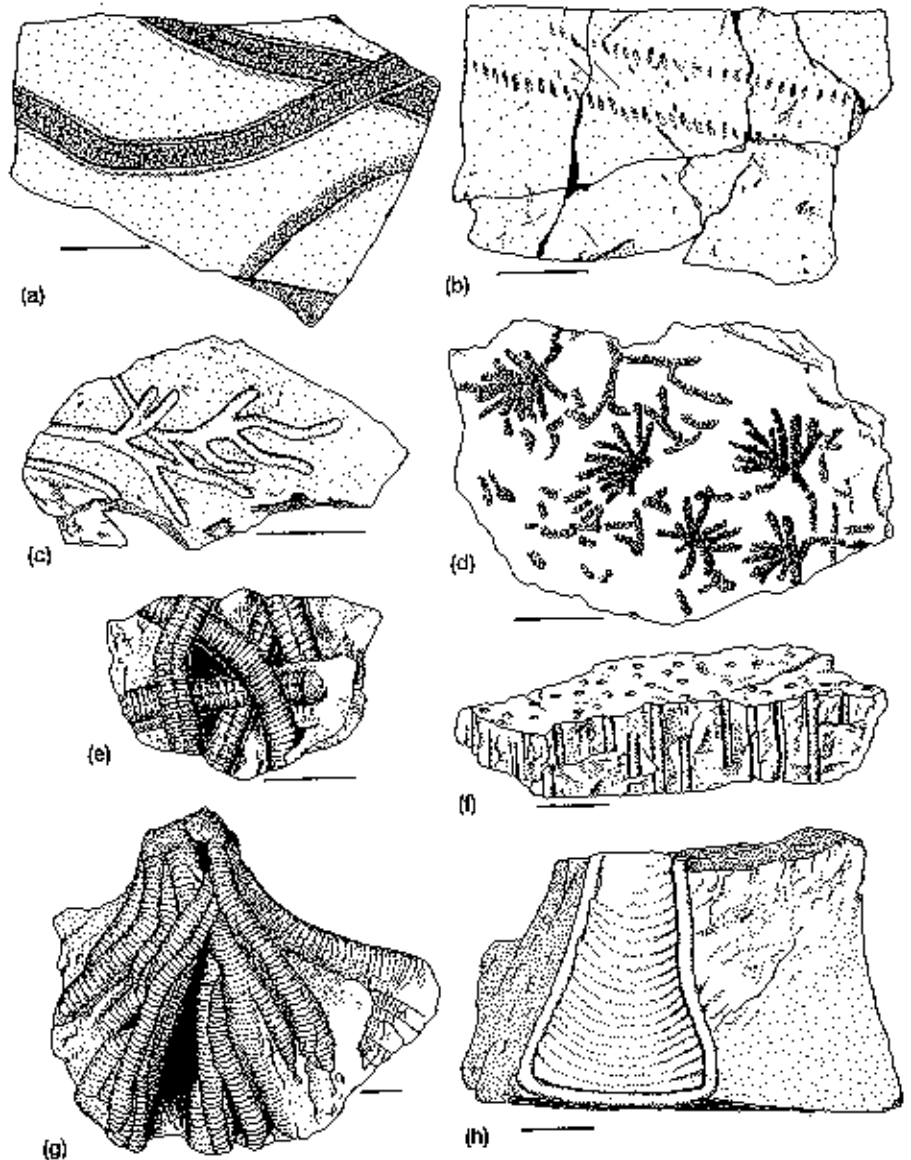


Fig. 17.1 Various trace fossils, progressing from traces parallel with to traces perpendicular to bedding. (a) Trail of unidentified freshwater arthropod, Pennsylvanian; (b) *Diplichnites*, Ordovician; (c) *Chondrites*, Ordovician; (d) *Oldhamia*, Mississippian; (e) *Arthropycus*, Silurian; (f) *Skolithos*, Silurian; (g) *Phycodes*, Silurian; (h) *Diplocraterion*, Ordovician. Scale bars equal 25 mm.

Table 17.1 Behavioral classification of trace fossils and their general characteristics. Largely after Frey (1973) and Ekdale *et al.* (1984). The following format is followed for each category:

- 1 Behavioral category
 - 2 Typical morphologies
 - 3 Location with respect to bedding
 - 4 Examples
-
- 1 Resting or hiding traces (Cubichnia)
 - 2 Shallow depressions that may reflect ventral morphology of the generating organism
 - 3 Bedding planes
 - 4 *Rusophycus*
 - 1 Locomotory traces (Repichnia)
 - 2 Evidence of movement on or through sediment; generally linear or slightly curved, continuous succession of marks; continuous structures are commonly annulated; characteristically linear, because the organism was traveling from one point to another
 - 3 Bedding planes or typically horizontal within beds
 - 4 *Cruziana*, *Diplichnites*, *Kouphichnium*
 - 1 Dwelling traces (Domichnia)
 - 2 Elongated burrows or deep excavations that served as residences (domiciles) for the generating (and commonly subsequent) organisms; unbranched or bifurcated cylindrical burrows originally near-vertical, or U-shaped burrows; commonly perpendicular, inclined at various angles to bedding, or with vertical and horizontal components; burrow walls typically lined
 - 3 Within beds
 - 4 *Diplocraterion*, *Skolithos*
 - 1 Deposit feeding traces (Fodinichnia)
 - 2 Originally three-dimensional burrows of sediment-feeders; horizontal, U-shaped or inclined but seldom only vertical, may be multi-branched or other complex geometries; seldom lined by mucous
 - 3 Within beds
 - 4 *Chondrites*, *Phycodes*, *Spirrophyton*
 - 1 Grazing traces (Pascichnia)
 - 2 Primarily two-dimensional traces; usually horizontal with regular geometric pattern, such as coiled or sinuous but seldom linear, that rarely crosses itself and is unbranched
 - 3 Most common on bedding planes
 - 4 *Helminthoidea*
 - 1 Escape structures (Fugichnia)
 - 2 Various traces modified in response to deposition or erosion so that equilibrium depth is restored with respect to surface of sediment; relatively slow changes reflected in vertically nested spreiten; rapid deposition reflected in vertical shafts; intergrades with traces of other types
 - 3 Within beds
 - 4 Some *Diplocraterion*, *Corophioides*
 - 1 Apparent farming traces (Agrichnia)
 - 2 Regularly patterned horizontal burrow systems; permanent dwelling and feeding (farming or trapping) are presumed; particularly characteristic of fine-grained, pelagic or hemipelagic deposits
 - 3 Horizontal, either within beds or on bedding planes
 - 4 *Casmarhaphis*, *Paleodictyon*

Some grazing, feeding, and dwelling behaviors involve repetitious activities within a small area so that each excursion of the animal from a starting point partially overlaps and is parallel or subparallel with the previous excursion. These behaviors result in overlapped to slightly divergent filled structures that are referred to as spreite (plural, spreiten). See examples in Fig. 17.1 (g and h).

(Question 1)

17.3 TRACE FOSSIL ASSEMBLAGES

Similar trace fossils may be generated by diverse organisms that:

- 1 have similar overall shapes (or just similar profiles as they pass through or move across the substrate); and
- 2 engage in roughly similar behavior.

Although behaviors can develop only within the range of possibilities allowed by the phylogenetic history of an organism, any given behavior is developed in response to environmental factors, such as sediment texture, location and concentration of food, substrate stability, avoidance of predation, etc.

Therefore, most trace fossils do not accurately mirror species evolution. But, because various organisms respond with similar behaviors to a given environment, particular assemblages of trace fossils through much or all of the fossil record are typically associated with particular environments (Fig. 17.3, Table 17.2). The assemblages are not necessarily related to depth *per se*, but are responses to substrate composition, stability, and nutrient content, each of which may be influenced by depth-related processes. Trace fossil assemblages therefore currently have an increasing importance in paleoenvironmental reconstruction and in paleoceanography. (Questions 2 and 3)

Table 17.2 Environments represented by ichnofacies (sediments and rocks containing certain trace fossil assemblages) and (inset) the trace fossils that characterize them. From Frey & Pemberton (1985).

Scoyenia ichnofacies

Moist to wet, pliable, argillaceous to sandy sediments at low-energy sites, either very shallowly submerged lacustrine or fluvial deposits periodically becoming emergent, or waterside subaerial deposits periodically becoming submergent

Intermediate between aquatic and nonaquatic, nonmarine environments

Small, horizontal, lined, back-filled feeding burrows

Curved to tortuous, unlined feeding burrows

Sinuuous crawling traces

Vertical, cylindrical to irregular shafts

Tracks and trails

Invertebrates mostly deposit feeders or predators

Vertebrates are grovellers, predators, or herbivores

Invertebrate diversity very low, yet some traces may be abundant

Vertebrate tracks may be diverse and abundant around water bodies

Trypanites ichnofacies

Hard surfaces consisting of consolidated marine littoral and sublittoral omission surfaces (rocky coasts, beachrock, hardgrounds, reefs) or organic substrates (beds of shell, bone)

Bioerosion is as important as, and accelerates, physical erosion of the substrate

Intergradational with the *Glossifungites* ichnofacies, somewhat intergradational with a woodboring ichnofacies that is not described here

Cylindrical to vase-, tear-, or U-shaped to irregular domiciles of endoliths, oriented normal to substrate surfaces, or shallow anastomosing systems of borings (sponges, bryozoans), excavated mainly by suspension feeders or passive carnivores

Raspings and gnawings of algal grazers, etc. (chitons, limpets, echinoids)

Diversity moderately low, although borings or scrapings of given kinds may be abundant.

Glossifungites ichnofacies

Firm but un lithified marine littoral and sublittoral omission surfaces, especially semiconsolidated carbonate firmgrounds, or stable, coherent, partially dewatered muddy substrates either in protected, moderate-energy settings or in areas of somewhat higher energy where clastic, semiconsolidated substrates offer resistance to erosion

Final sedimentary record typically consists of a mixture of relief features and palimpsest features (which erase and reconfigure the surface)

Vertical cylindrical, U- or tear-shaped borings or boring-like structures, or sparsely to densely ramified dwelling burrows

Downwardly extended spreiten in some, developed mostly through growth of animals

Fan-shaped *Rhizocorallium* and *Diplocraterion*

Many intertidal species (e.g. crabs) leave the burrows to feed

Others are mainly suspension feeders

Diversity typically low, but given kinds of structures may be abundant

Skolithos ichnofacies

Shifting sediments in lower littoral to infralittoral, moderate to relatively high energy conditions

Slightly muddy to clean, well-sorted sediments subject to abrupt erosion or deposition

(Higher energy increases physical reworking and obliterates biogenic sedimentary structures, leaving a preserved record of physical stratification)

Vertical, cylindrical, or U-shaped dwelling burrows, downwardly and also upwardly extended spreiten in

FURTHER READING

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QUESTION 1

Several named trace fossils are provided. Describe the traces, the sediment in which they are preserved, and assign each to the appropriate behavioral category.

1 Name: _____ Sketch: _____

Description: _____

Sediment: _____

Behavioral category: _____

2 Name: _____ Sketch: _____

Description: _____

Sediment: _____

Behavioral category: _____

3 Name: _____ Sketch: _____

Description: _____

Sediment: _____

Behavioral category: _____

4 Name: _____ Sketch: _____

Description: _____

Sediment: _____

5 Name: _____ Sketch: _____

Description: _____

Assemblage to which the group belongs: _____

Probable environment: _____

Names of trace fossils in Fig. 17.5:

 _____ / _____

Assemblage to which the group belongs: _____

Probable environment: _____

QUESTION 3

If a group of trace fossils is provided in the laboratory, identify the rock type in which each is preserved, name each type of trace, determine the category of trace to which each belongs, assign the group to its proper assemblage, and give the estimated environment in which it probably formed.

Rock type in which assemblage occurs: _____

Trace fossil name: _____ Category: _____

Trace fossil name: _____ Category: _____

Trace fossil name: _____ Category: _____

Trace fossil name: _____ Category: _____

Trace fossil name: _____ Category: _____

Trace fossil name: _____ Category: _____

Trace fossil name: _____ Category: _____

Assemblage to which the group belongs: _____

Probable environment: _____

Dinosaur Track Activity

Introduction: Dinosaur tracks can tell us a lot about extinct animals; not only where they lived and what they did but also, what kind of dinosaur made them, how big they were and how fast they were moving. These activities will explore some of the principles behind the methods used by palaeoichnologists (people who study fossil trackways) to determine the size and speed of animals trackmakers. We will start with what we know best and then you will be supplied with a dinosaur footprint primer - a quick reference guide to the different types of tracks that exist and how to figure out their speeds.

Organisation of the activity

There are two parts to this exercise. In the first part students measure the foot length, hip height and overall height of every person in the room to investigate if there is a correlation between the two. The correlation of FL to h is used in dinosaur trackway studies to determine the size of the trackmaker and hence the speed. In the second part students measure the stride length and speed of one or more people in their group (of known foot length and hip height) to find the correlation between these two variables. The strong relationship between stride length and speed common to many different types of animals has been used to estimate the speeds of dinosaurs. Students are provided with worksheets for data recording.

Objective: Students will be able to measure, plot on a graph, and interpret data that they have collected to understand the correlations between foot length, hip height and speed in dinosaurs and other animals

Background

Several different equations are applied to dinosaur footprints to find out more information about the trackmaker such as size, leg length and speed. Footprint length (FL) is most often used as a basis for the estimation of the size of the trackmaker. It is advisable to measure FL on the best preserved footprint in a trackway. If no footprint is very well preserved it is best to measure them all and take the average.

Form of the trackway

Several measurements may be taken from the trackway which indicate not only the size of the trackmaker but also the layout - these include **pace length** (PL), **stride length** (SL), **trackway width** (TW) and **pace angulation** (ANG).

Pace length is the distance between two successive footprints, e.g. left hind foot to right hind foot (Figure 2.5). Stride length is the distance between two successive footprints of a single foot (Figure 2.5). In the trackway of a quadrupedal dinosaur the stride lengths of manus and pes must be roughly equal although the pace lengths may differ considerably (Figure 2.5). Needless to say these measurements should be taken from the same point on each footprint. This is usually the tip of digit III as it is most often clearly defined. The choice of reference points affects other trackway measurements, notably pace angulation.

Trackway width may be measured directly from the trackway. Trackway width is usually taken to mean **external trackway width**, i.e., between the outer edges of the footprints, but the **internal width** (between the inner edges of left and right footprints) may also be measured (Figure 2.5). In addition there is the **angulation trackway width** - the width of the angulation pattern - which is calculated from the angulation pattern.

The angulation pattern (Figure 2.5b) may also be measured directly from the trackway but it is often easier, especially with larger trackways, to calculate it from the pace and stride lengths, as follows:

$$\cos ANG = \frac{(PLa)^2 + (PLb)^2 - (SL)^2}{2 \times (PLa) \times (PLb)}$$

In the trackways of quadrupedal dinosaurs, pace angulation may be considerably different for the forefeet and the hindfeet.

Size of the trackmaker

With regard to dinosaur footprint data, **height at hip (*h*)**, is probably the most useful measure of body size. "Skeletal hip height" (Thulbom and Wade, 1984) is a similar dimension defined as the height above the ground of the hip joint in a dinosaur skeleton.

Methods of predicting *h*

A good general rule of thumb used by paleontologists is that the hip height of a dinosaur is four to five times its footprint length. However, this does not take account of variations in limb structure between different groups of dinosaurs.

Morphometric ratios

Simple equations based on the limb proportions of the two major types and sizes of bipedal dinosaurs.

Small theropods (<i>FL</i> < 25 cm):	<i>h</i> = 4.5 <i>FL</i>
Large theropods (<i>FL</i> > 2.5 cm):	<i>h</i> = 4.9 <i>FL</i>
Small omithopods (<i>FL</i> < 25 cm):	<i>h</i> = 4.8 <i>FL</i>
Large omithopods (<i>FL</i> > 25 cm):	<i>h</i> = 5.9 <i>FL</i>
Small bipedal dinosaurs in general (<i>FL</i> < 25 cm):	<i>h</i> = 4.6 <i>FL</i>
Large bipedal dinosaurs in general (<i>FL</i> > 25 cm):	<i>h</i> = 5.7 <i>FL</i>

Relative speeds

Equations which calculate relative speed of dinosaurs from their footprints assume that the faster the animal moved, the longer were its strides.

Relative stride length (*RSL*) is defined as stride length divided by leg length. For the purposes of calculating the speeds of dinosaurs, leg length is taken as being the same as the height at the hip (*h*) above.

$$RSL = SL/h$$

Dinosaurian gaits can be defined in terms of relative stride lengths:

Walk: $SL/h < 2.0$

Trot: $SL/h = 2.0 - 2.9$

Run: $SL/h > 2.9$

Walking is defined as a gait where each foot is on the ground for more than half the time so that there are times when both feet are on the ground. For quadrupeds this means that there are stages when both forefeet or both hindfeet are on the ground at the same time. In running each foot is on the ground for less than half the time so that there are periods when neither foot is on the ground - the **unsupported** phase. For dinosaurian purposes a trot is assumed to be an intermediate gait.

Trotting gaits are very rarely recorded from dinosaur trackways and this may be because it is an energetically inefficient gait.

It is not possible to calculate absolute speed from dinosaur trackways without making assumptions about how quickly they moved their legs.

Absolute Speeds

Alexander (1989) published a graph relating relative stride length to dimensionless speed. Using this graph it is possible to translate dimensionless speed into absolute speed, although this estimate of speed is necessarily a rough one.

From observations of various living animals, as diverse as small mammals, birds, humans, horses and elephants, Alexander (1976) derived the following equation to calculate absolute speeds from trackways:

$$SL/h = 2.3(V^2/gh)^{0.3}$$

In this equation, all linear measurements are in metres, the animals speed (V) is expressed in metres per second and g represents the acceleration due to gravity. This general relationship holds for large and small animals, quadrupeds or bipeds, at gaits from walk to run and it does not seem to be seriously affected by variations in substrate consistency.

Alexander *et al.* (1977) refined the above equation after observing fast moving African ungulates, to derive an equation better suited to fast moving animals.

$$SL/h = 1.8(V^2/gh)^{0.39}$$

Alexander (1976) rearranged the first equation in order to estimate the speeds of dinosaurs

$$V = 0.25g^{0.5}SL^{1.67}h^{-1.17}$$

Thus absolute speeds of dinosaur trackmakers may be calculated if SL can be measured from the trackway and h can be estimated from FL . Speeds estimated in this way are generally seem rather low; this method may underestimate moderate speeds and overestimate high ones.

To calculate the speeds of running dinosaurs Thulborn and Wade (1984) rearranged

The second equation:

$$V = [gh(SL/1.8h)^{2.56}]^{0.5}$$

The speeds of dinosaurs that used a trotting gait (SL/h between 2.0 and 2.9) may be calculated as the mean of the two estimates.

The observant amongst you will have noted that there has so far been no discussion of FL/H ratios of quadrupedal dinosaurs. This is because until fairly recently not many of them had been found and even now they are still vastly outnumbered by the number of tridactyl bipedal tracks known. The little research that has been done indicates that $5FL$ is a good estimate for sauropod (and probably stegosaur) tracks, and that $4FL$ seems to work for ankylosaur and ceratopsian tracks. FL here refers to the length of the **back** footprint. The only ceratopsian tracks known are from a single site at Golden!

Trackmaker size and speed activity

First make sure you have read the above background information. Variables, such as those you will be measuring are used in footprint analysis to glean more information from fossil trackways. This activity allow students to measure similar data to better understand the reason behind all the equations.

Method: Divide into groups of four or five. All measurements in this activity, as in all others, should be in metric. Some footprint equations do not work in Imperial. You will be working out speeds in metres per second.

Part 1. Measure the foot, hip height and overall height of everyone in the room, and record the data on the worksheet provided. Hip height is measured from the ground to where the top of the femur (thighbone) joins the pelvis (to find this spot, lift a leg so the femur is parallel to the ground; it is now easy to see where the top of the femur joins the pelvis). When you have collected all the data plot foot length against hip height and total height. Answer the following questions:

1. Is there a strong correlation between the two?
2. If there is not why do you think that might be the case?
3. If you measured the feet and hip heights of animals do you think the correlation would be weaker or stronger? Why?
4. If you wanted to determine the speeds of fossil mammals from their tracks could you just use the dinosaur equations or would you have to work out some new ratios? Explain.
5. Do you now feel confident about the method of determining dinosaur size from tracks?

Part 2. Measure out a course and use tape to mark the beginning and end of it. 20 metres is a good length. One student will run and walk the length of the course while other students in the group will time, measure, and record his progress. In each group, one student will complete the course (**guinea pig**), and the other three will be the **timer**, the **measurer**, and the **recorder**. Each group member will have the opportunity to perform each activity. Group members will do the following:

Recorder: Enters data on to the worksheet. Also assists the measurer to determine stride length.

Timer: Stands at the finish line with a stopwatch, says "Go!" when the student is at the starting line, and times how long it takes for the student to first walk, then run the length of the course.

Measurer: (with the help of the recorder) determines the stride length for the walking and running trials by counting strides and dividing the length of the course by number of strides.

All students in the group should rotate through all positions until every student has walked and run the course. Additional data sheets are provided if you want to also try slow and fast walking or jogging, if time permits.

To determine students' speed divide the length of the course by the time (in seconds). This will give a speed in meters per second to be entered in the appropriate column.

Plot the relationship between stride length and speed on a scatter graph. Answer the following questions:

1. Is there a strong correlation between the two?
2. If there is not why do you think that might be the case?
3. If you combined your data with that of the whole class do you think that would strengthen or weaken the correlation?
4. After carrying out this experiment how do you feel about the accuracy of this method, and its application to dinosaur tracks?
5. Do you now feel confident you could apply the same methods to dinosaur trackways?

Everyone's favorite.... Grad Pac Appts! Here's the list of needers for Spring. I'll take care of the vita-collecting (unless you happen to have one), if you could please start wrangling up letters? If the box in the letter column is empty, we need a letter, otherwise I'll just need your signature. Holler if you have questions, changes, or just want to object in general. Thanks, Casey

Term	AU	CrseSubj	Fac Type	Instructor	Appt Status	Vita in FSC?	Letter from Prog?	Program Signature?
20071	D1	CPCE	L	ADDISON, SHEILA M.	Limited	Yes		
20071	D1	ECE	L	RUDKIN, JENNIFER A.	Expired	Yes		
20071	D1	ECE	L	SPERRY, LAURIE A.	Expired	Yes	n/a	
20071	D1	BPSY	L	BOEKHOFF, GAIL I.		Yes	Yes	
20071	D1	IT	L	MARLATT, J. KEVIN				
20071	D1	IT	L	SWITZER, SCOTT H.	Expired	Yes		
20071	D1	IPTE	T	ESPINOZA, MANUEL		Yes		
20071	D1	IPTE	L	FRANCKOWIAK, CHRISTINE				
20071	D1	IPTE	L	HELFRICH, SARA R.		Yes		
20071	D1	IPTE	L	HOGLE, MARY JO (JODI)		Yes		
20071	D1	IPTE	L	MC INTYRE, MARILYN J.	Expired	Yes		
20071	D1	IPTE	L	PERA, ANGELA M.				
20071	D1	IPTE	T	PITTMAN, MARY E	Expired	Yes	n/a	
20071	D1	IPTE	L	SAHLING, NANCY J.	Expired	Yes	n/a	
20071	D1	LLC	L	GALLEGOS, PAULA M.				
20071	D1	LLC	L	HALOIN, MARCIE B.				
20071	D1	LLC	L	KAEHNY, SHEILA MARY	Expired	Yes		
20071	D1	LLC	L	KOWAL, CONNIE B.	Expired	Yes		
20071	D1	LLC	L	STEPHENSON, JUDY C.		Yes		
20071	D1	LLC	L	THOMPSON, TERRI S.		Yes		
20071	D1	LLC	L	WATSON, NATALIA V.	Expired	Yes		
20071	D1	REM	L	LARSEN, SUSAN E.	Expired	Yes		
20071	D1	SECE	L	KIRTLEY, KARMEN		Yes		
20071	D1	SPED	L	OLIVER, PATRICIA	Expired	Yes		
20071	D1	SPSY	L	VOLKERT, SARAH S.				