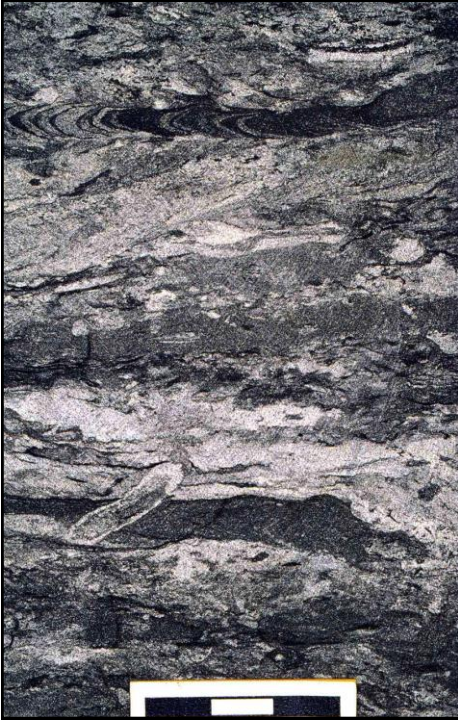




LECTURE 3 – APPLICATIONS OF ICHOLOGY

Ichnology

Introduction to Ichnology

Identification of Trace Fossils in Core

Grazing Structures (pascichnia)

Deposit-Feeding and Dwelling Structures (fodinichnia
& domichnia)

Other (including fugichnia)

Ichnology

Introduction to Ichnology

Identification of Trace Fossils in Core

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Other (including fugichnia)

What is Ichnology?



Ichnos = Track

Logos = Study

Ichnology is the study of the **traces left by animals that lived on or in the sediment.**

Consider them as **Biogenic Sedimentary Structures.**

Why Do Ichnology?

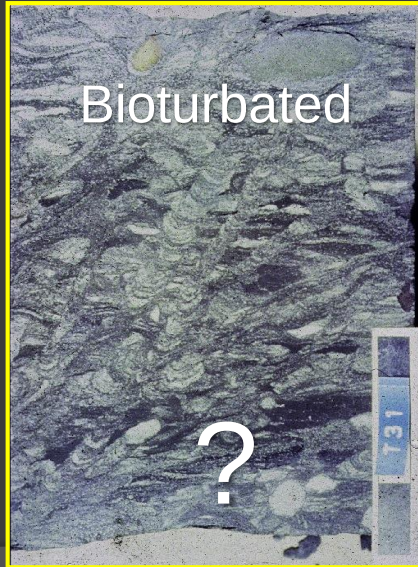
Burrowed

Bugs?

Squiggles

Churned

?



????

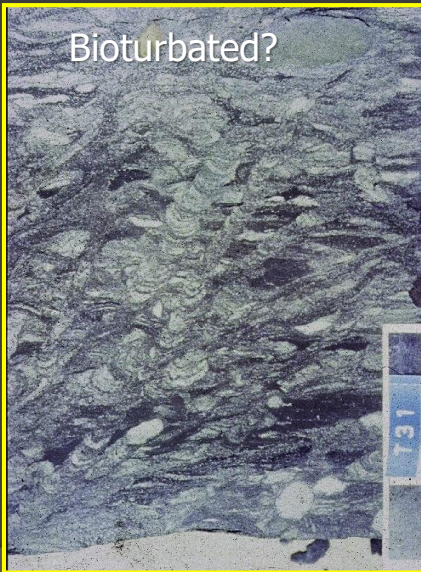
Biogenic Structures

Traces

Vandalized
Sediment

Why Do Ichnology?

Bioturbated?



A monospecific suite of robust *Teichichnus*, indicative of rapid, continuous sedimentation.

Such conditions are commonly associated with marine delta-front environments.

Application of Ichnology



Animals are sensitive to such things as:

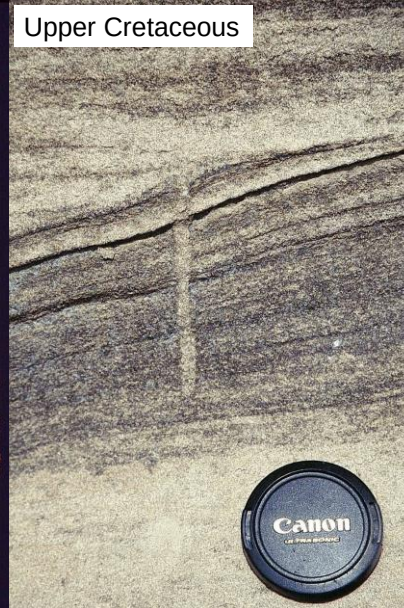
- sedimentation rates
- uniformity vs. episodicity of deposition
- water turbidity
- water salinity
- substrate consistency
- primary productivity (food availability)
- oxygenation, etc.

General Ichnological Principles

Cambrian



Upper Cretaceous



Trace fossils are *temporally long-ranging*; ichnological suites are **useful throughout the Phanerozoic**.

Trace fossils are **facies controlled**, and many **ichnogenera have narrow facies ranges**: ichnological suites impart information about the original depositional environment.

General Ichnological Principles

Trace Fossils result from the activities of soft-bodied organisms that are generally not preserved

Image courtesy of S.G. Pemberton

Most environments are dominated by the so-called “Minor Phyla”



Rosselia



Terebellid Polychaete

Phylum	Approx. # Species	Ecology	Fossil Record
Nemertini	800	M, T	Jurassic – Recent
Nematoda	500,000	F, T, M	Cambrian – Recent
Nematomorpha	250	F, (one M)	Eocene – Recent
Sipuncula	320	M	?Cambrian – Recent
Echiura	135	M	Cretaceous – Recent
Pognophora	100	M	Nil
Priapulida	9	M	Nil
Phoronida	15	M	Cambrian – Recent
Hemichordata	100	M	Nil
Cephalochordata	3	M	Cambrian – Recent
Chaetognatha	60	M	Nil
Urochordata	2,000	M	Cambrian – Recent
Onychophora	120	M, T	Cambrian – Recent
Annelida	8,750	F, M, T	Cambrian – Recent

The So-Called “Minor” Phyla

Data from Laverack and Dando (1979) and Briggs and Crowther (1990)

Phylum	Approx. # Species	Ecology	Fossil Record
Nemertini	800	M, T	Jurassic – Recent
Nematoda	500,000	F, T, M	Cambrian – Recent
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Priapulida	9	M	Nil
Phoronida	15	M	Cambrian – Recent
Hemichordata	100	M	Nil
Cephalochordata	3	M	Cambrian – Recent
Chaetognatha	60	M	Nil
Urochordata	2,000	M	Cambrian – Recent
Onychophora	120	M, T	Cambrian – Recent
Annelida	8,750	F, M, T	Cambrian – Recent

General Ichnological Principles

The so-called “Minor Phyla” includes organisms like:



Sea Anemones

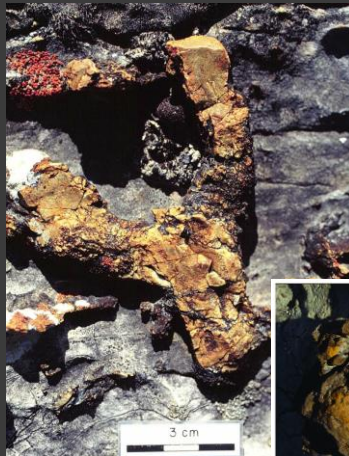


Sipunculids & Nematodes



Polychaetes

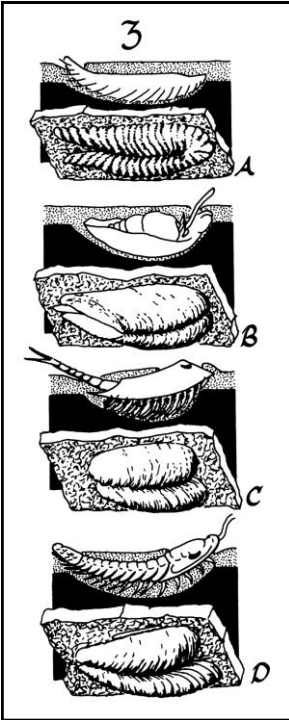
General Ichnological Principles



Trace fossils are generally enhanced by diagenetic conditions that destroy body fossils. Commonly are the **only preserved record of fauna**.

Few trace fossils are susceptible to resedimentation. In general, **trace fossils are *in situ***.





General Ichnological Principles

Polychaete: *Aphrodite*

Nassid Snail

Rusophycus

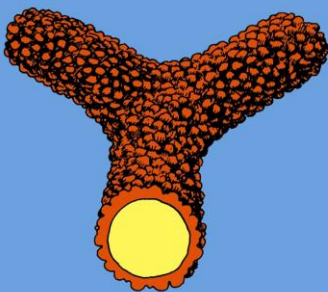
Crab: *Goneplax*

Trilobite

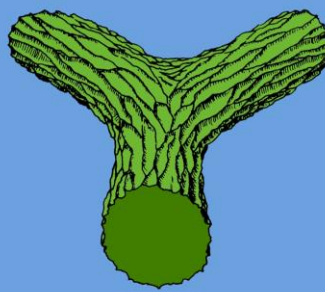
Multiple
architects may
produce the
same structure!

after Ekdale et al., 1984

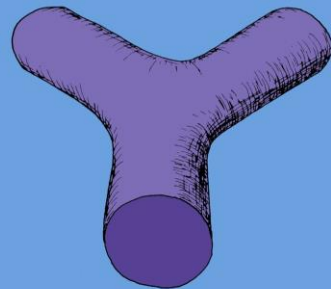
Taxonomic Classification



Ophiomorpha nodosa



Spongeliomorpha iberica



Thalassinoides suevicus

after Ekdale et al., 1984

Taxonomic Classification of trace fossils is based on the morphology of the structure, governed by the International Commission on Zoological Nomenclature (ICZN), addressed in Supplement W of the Treatise of Invertebrate Paleontology.

Trace fossils are named in the context of **ichnogenera** and **ichnospecies**, though not at higher levels. *Remember, though, trace fossils are NOT the animals themselves!*

Phylogenetic Classification of Trace Fossils



Ophiomorpha



Thalassinid Shrimp

Phylogenetic Classification of Trace Fossils



Palaeophycus



Polychaete: *Nereis*

Phylogenetic Classification of Trace Fossils



Conichnus



Sea Anemone

Ethological Classification of Trace Fossils



Locomotion



Resting



Escape



Dwelling



Farming/Grazing



Feeding

Ichnological Analysis is More Than Trace Fossil Identification

Proper Ichnological Analysis Includes:

- Determination of the Trace Fossil Suite
- Relative Proportions of Ichnological Elements
- Ethological Assessment of Recurring Elements
- Bioturbation Intensity (Bioturbation Index)
- Uniformity of Bioturbation
- Diversity of the Suite
- Size of the Ichnogenera (relative to archetypal expressions)
- Assessing Departures from Archetypal Ichnofacies
- Integration with Sedimentological Characteristics of the Facies

Bioturbation Intensity: Using Bioturbation Index (BI)

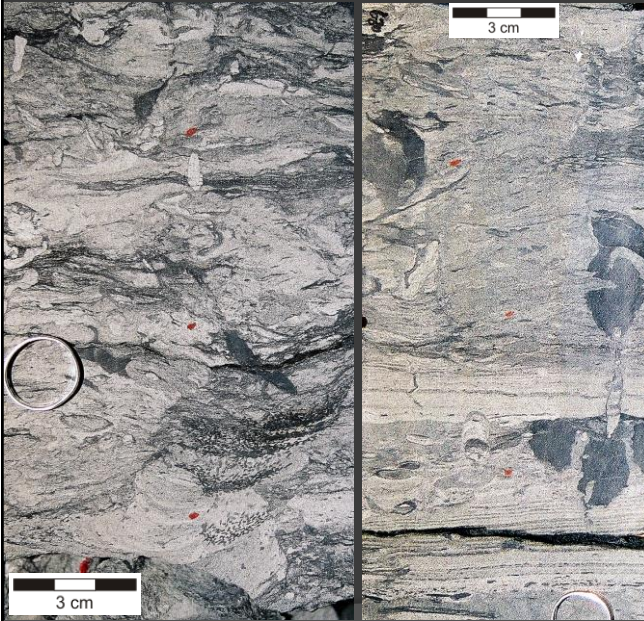
KEY TO BIOTURBATION INTENSITY			
BI	Characteristics	Mudstone Facies	Sandstone Facies
0	Bioturbation absent		
1	Sparsely bioturbation, bedding distinct, few discrete traces		
2	Uncommon bioturbation, bedding distinct, low trace density		
3	Moderate bioturbation, bedding boundaries sharp, traces discrete, overlap rare		
4	Common bioturbation, bedding boundaries indistinct, high trace density with overlap common		
5	Abundant bioturbation, bedding completely disturbed (just visible)		
6	Complete bioturbation, total biogenic homogenization of sediment		

Assessing Bioturbation Intensity is based on Bioturbation Index (BI), a semi-quantitative assessment.

In routine outcrop and core description, charts such as these are employed to assign quantitatively based “grades” of bioturbation to rocks, similar to the way that we evaluate sediment sorting.

Modified from Bann *et al.* (2008)

Uniform vs. Sporadically Distributed Bioturbation



Burrowing uniformity is controlled by relative deposition rates and degree of episodic sedimentation.

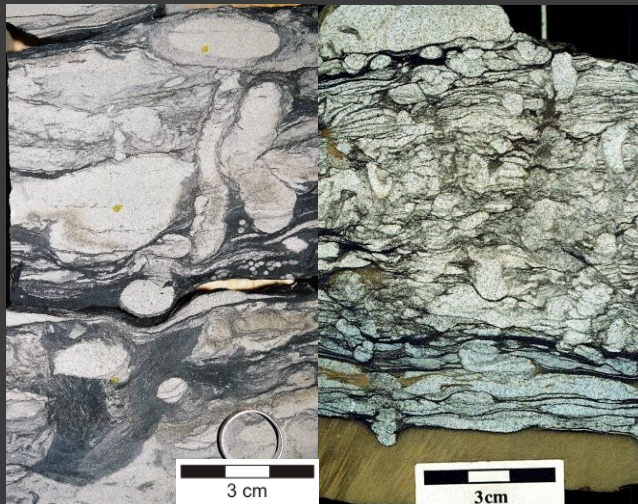
Uniform burrowing is typical of **slow continuous deposition**.

Sporadic bioturbation generally reflects **episodic deposition** (e.g., event beds).

Sporadically burrowed intervals yield suites that:

- 1) record event bed colonization (**event suites**)
- 2) record ambient conditions (**fairweather suites**).

Assemblage Diversity: Recognizing Impoverishment



Diversity indicates how stressful the environment is to infauna.

Diverse suites = **less stressful settings**. Favorable to infaunal communities.

Low-diversity suites = **more stressful environmental conditions**. Dominated by simple structures.

Low-diversity suites are dominated by traces produced by organisms **tolerant of environmental stress**. Such elements are regarded as "**facies-crossing**" forms.

Assemblage Diversity: Recognizing Impoverishment



Diversity: 14 ichnogenera
BI 3 (moderate dep. rate)



Diversity: 2 ichnogenera
BI 5 (slow deposition)

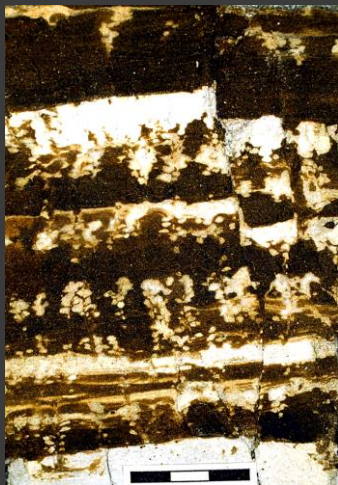
Trace intensity $\neq$ Trace Diversity

High-diversity suites are typical of **ambient (unstressed) settings**.

Low-diversity suites record **environmental (physico-chemical) stress**.

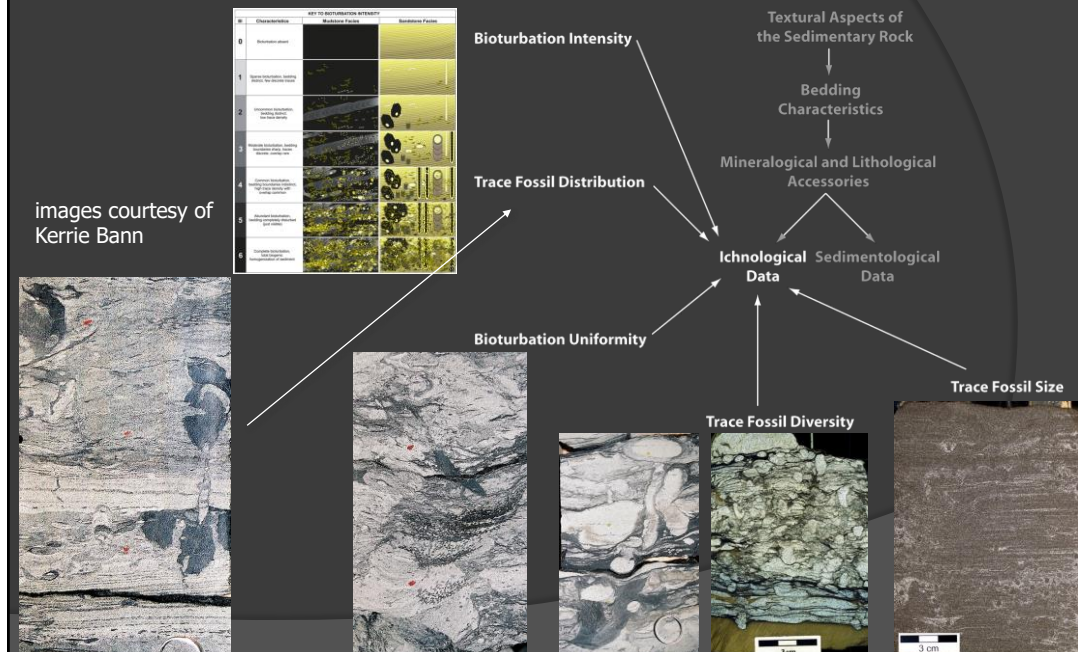
Bioturbation *intensity* is more often an **indicator of deposition rate**.

Applications of Ichnology to Facies Analysis

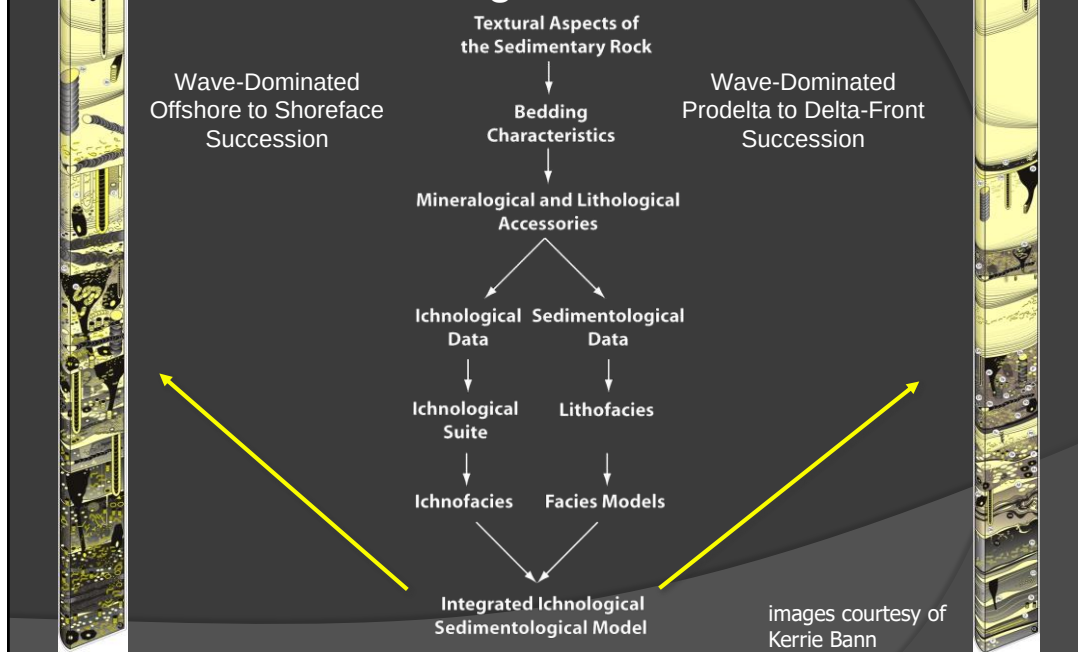


Trace fossils can be used to ascertain non-sedimentological parameters, including: **salinity, deposition rates, temperature, oxygenation, and water turbidity**.

Ichnological Data for Facies Analysis



The Rise of Integrated Facies Models



Ichnology

Introduction to Ichnology

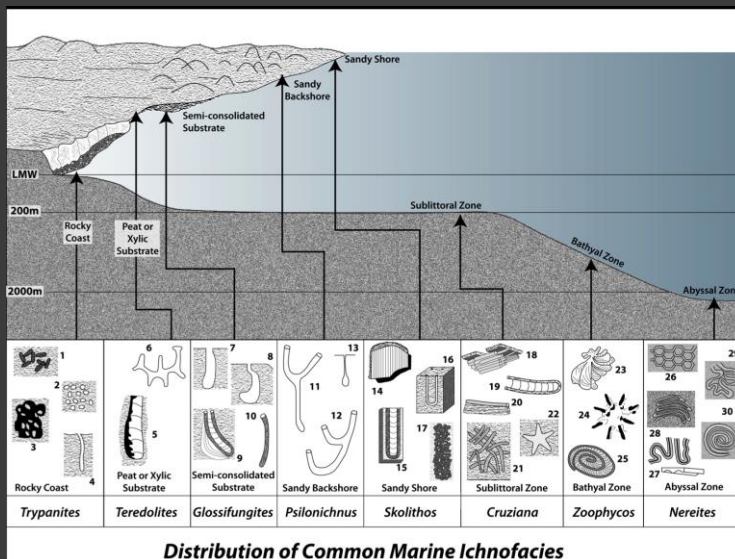
Identification of Trace Fossils in Core

Grazing Structures (pascichnia)

Deposit-Feeding and Dwelling Structures (fodinichnia & domichnia)

Other (including fugichnia)

Trace Fossil Identification



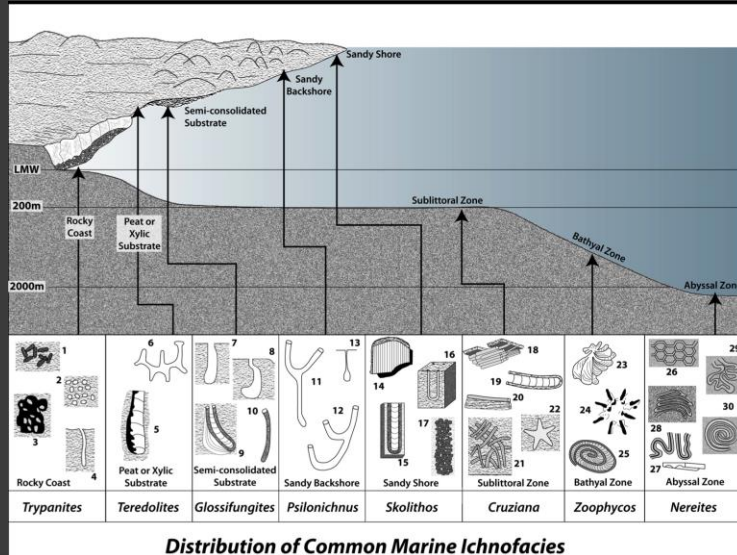
Distribution of Common Marine Ichnofacies

after MacEachern *et al.*, 2007

Trace fossils are named using genus and species, similar to animals, but always remember - **they are NOT animals**, they are structures left by the activity of animals.

Trace fossils are identified on the basis of their **morphology**.

Trace Fossil Identification



In core, we must **make educated guesses** about their 3-D shapes from oblique transects.

In general, we can identify 4 main groupings in routine core study:

Grazing (pascichnia)

Deposit-Feeding (fodinichnia)

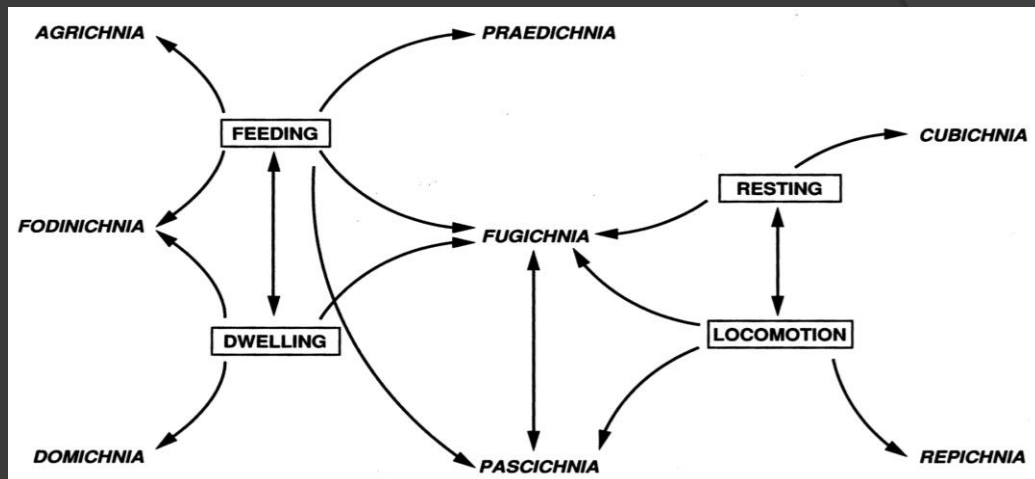
Permanent Dwelling (domichnia)

Escape (fugichnia)

Distribution of Common Marine Ichnofacies

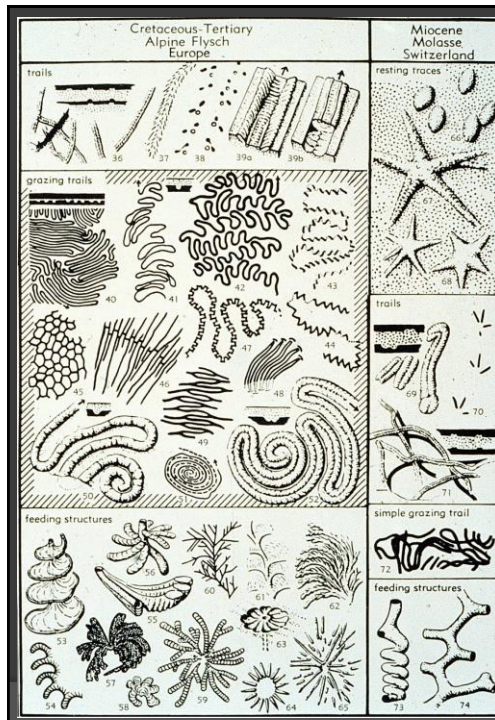
after MacEachern et al., 2007

Ethological Classification



Ethological Classification of trace fossils is concerned with interpreted organism behaviours.

There are a **variety of behaviours** recognizable in the ancient record, though many are intergradational and overlap.



Grazing Structures: Pascichnia

Produced by mobile **detritus** and **deposit-feeders**.

Includes: mobile surface grazing, foraging and sediment ingesting structures. **Typically restricted to the sediment-water interface.**

Most structures are **cored with fecal material** = black, organic mud infill.

Bedding planes may display geometric arrangements of structures.

Representative of **very low energy depositional conditions**: settings dominated by suspended sediment deposition.

after Seilacher, 1955

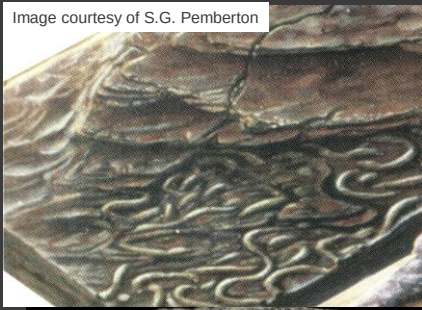
Image courtesy of S.G. Pemberton



Helminthopsis / Helminthoida



Image courtesy of S.G. Pemberton

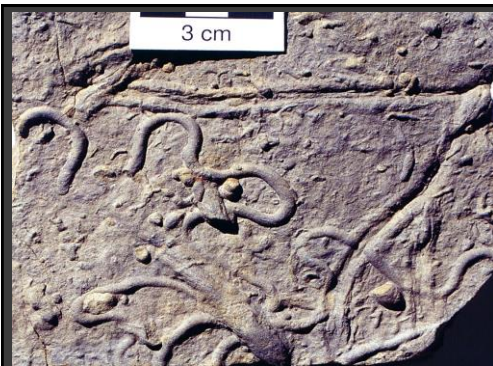


Helminthopsis / Helminthoida

Horizontally oriented tubes **consisting of fecal strings**, yielding a black, organic mud infill.

Bedding planes may display a meandering pattern.

Structures lack a halo of silt or sand.



Cosmorhapha



image from A. Wetzel

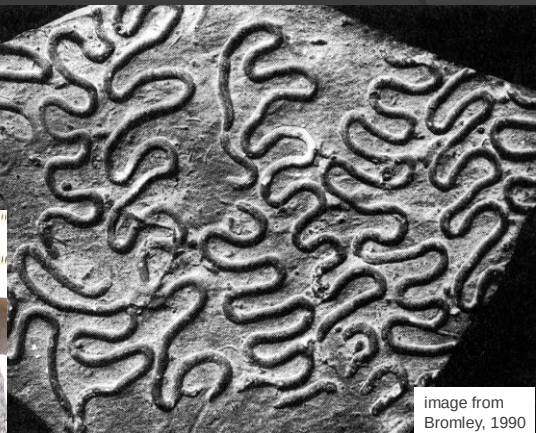
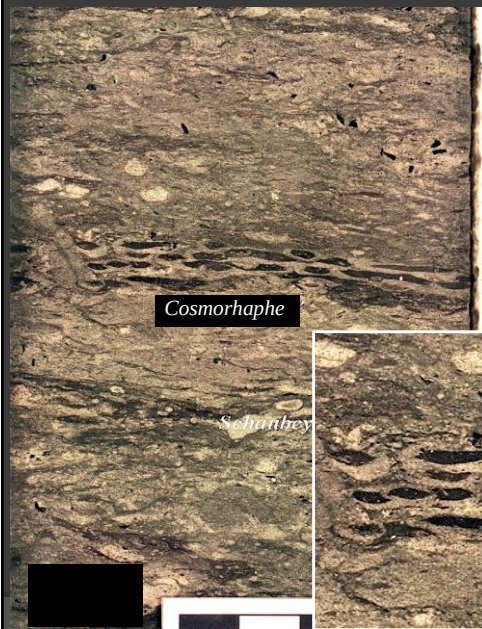


image from
Bromley, 1990

Cosmorhapse



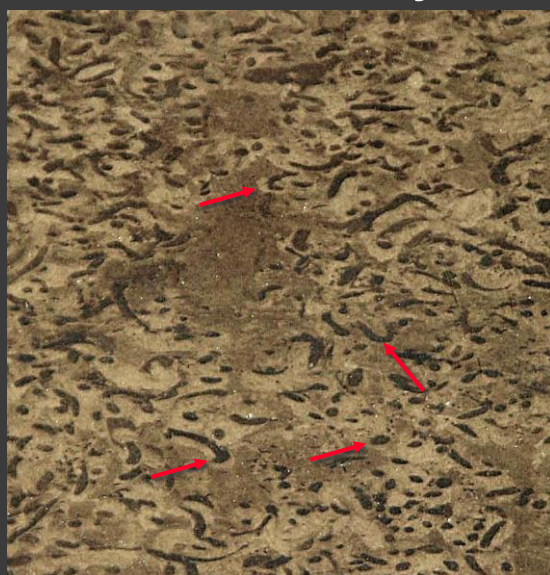
Typically **large-diameter grazing tubes**, largely horizontal.

May have halo of disrupted sediment around the fecal string.

Fecal string may contain pellets or meniscae



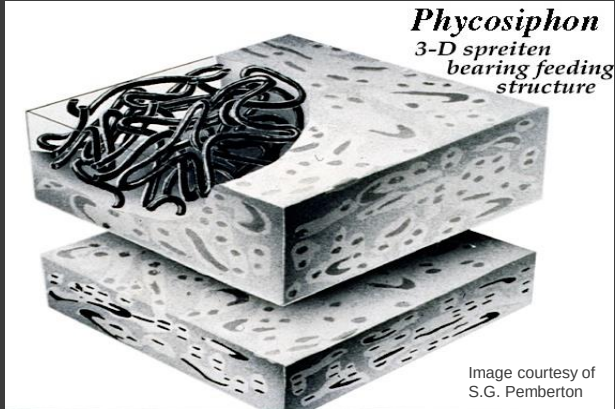
Phycosiphon



Small-diameter fecal **cored tubes**, with light-coloured halos and **hook-like shapes**.



Phycosiphon



Small-diameter fecal **cored tubes**, with light-coloured halos and **hook-like shapes**.

Displays horizontal and vertical orientations, indicating structures are penetrative and Not confined to sediment-water interface.



Phycosiphon



Recognition of Grazing Structures



Low-angle or horizontal, small-diameter tubes, typically of uniform dimension.

Black (organic-rich) structureless fill. Some burrows may be backfilled (rare).

In core, mainly appear as undulatory or curvilinear, black ovals, hooks, or tubes.

Commonly occur in large numbers, and uniformly distributed.

Bedding planes may display geometric arrangements.

Ichnology

Introduction to Ichnology

Identification of Trace Fossils in Core

Grazing Structures (pascichnia)

Deposit-Feeding and Dwelling Structures (fodinichnia & domichnia)

Other (including fugichnia)

Deposit-feeding structures: fodinichnia



Mobile and sessile deposit-feeding structures are developed near to, but generally **below the sediment-water interface**.

Mobile deposit-feeding structures (e.g., *Planolites* and *Macaronichnus*) reflect the activity of sediment-ingesting organisms.

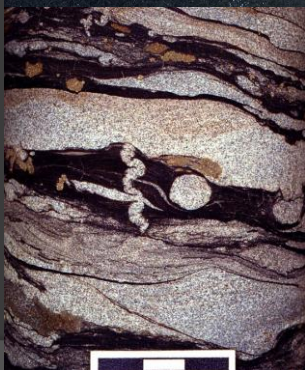
Sessile deposit-feeding structures, include:

temporary, stationary burrows (e.g., *Chondrites*) produced when animals probe deeply into the substrate for food; and, the dwelling structures of inferred deposit feeders and carnivores (e.g., *Thalassinoides*, *Palaeophycus*, *Asterosoma*, etc.)

Mobile Deposit-Feeding Structures: *Planolites*



Image courtesy of S.G. Pemberton



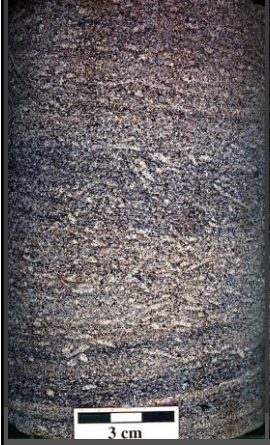
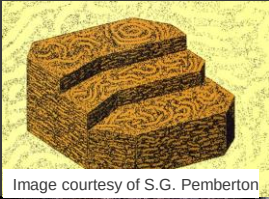
Horizontal to inclined, generally **unbranched** tubes.

Active sediment processing: **infill contrasts with the host strata**.

Burrow generated by organisms while moving through the sediment - **no meniscae or spreiten**.

Structures are **unlined**.

Mobile Deposit-Feeding Structures: *Macaronichnus*



Horizontal to inclined, but rarely vertical, unbranched tubes.

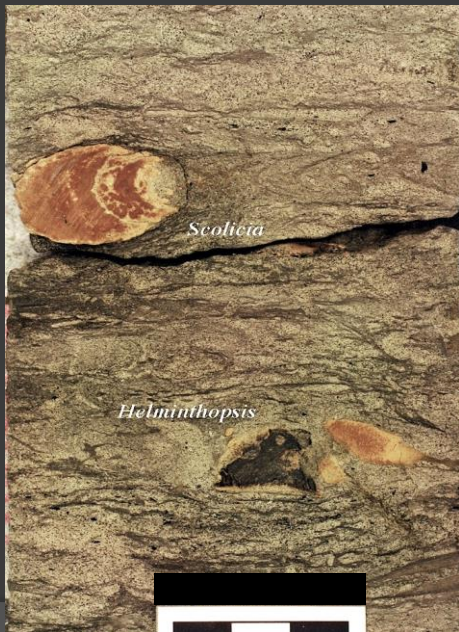
Active sediment processing: infill contrasts with the host strata.

Burrows generated by organisms while moving through the sediment - no meniscae or spreiten.

Structures are unlined, but shifting of mafic and ferromagnesian grains to burrow margin can give the appearance of a lining.

Burrows typically do not interpenetrate or cross one another.

Mobile Deposit-Feeding Structures: *Scolicia*



Horizontal to inclined, unbranched tubes.

Well-developed meniscate fill (back-filled), commonly with broad, rounded chevron shapes.

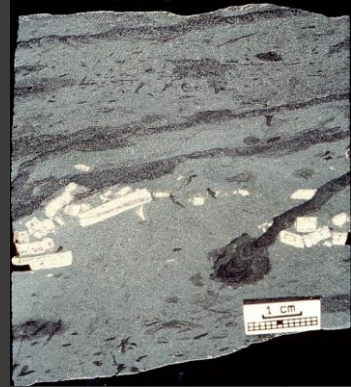
Tubes typically bi-lobed and ovoid in cross-section.

Sessile Deposit-Feeding Structures: *Zoophycos*



Deep Sea Zoophycos

Image courtesy of S.G. Pemberton



Horizontal to inclined bands, typically several in an interval.

Bands contain chevron-shaped spreiten.

Sessile Deposit-Feeding Structures: *Chondrites*



after Bromley, 1990



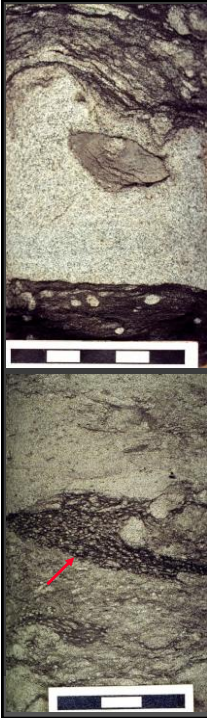
Downward branching structures.

Individual systems do not interpenetrate earlier branches.

Core expression: horizontal, vertical, and inclined equidimensional tubes in clusters.

Fill is mainly silt or very fine-grained sand; fill contrasts with host strata.

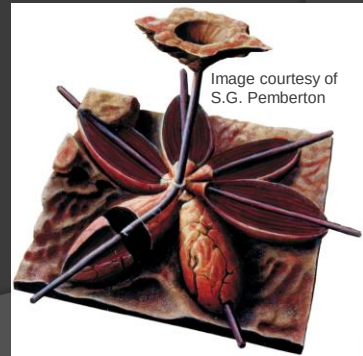
Sessile Deposit-Feeding Structures: *Asterosoma*



Horizontal mud lobes radiating from a central dwelling tube in sandy or muddy substrates.

Mud lobes typically display a central tube reflecting the probings of the tracemaker.

Mud lobes may be reburrowed after burial by *Chondrites* or other deep-tier structures



Sessile Deposit-Feeding Structures: *Rosselia*



Vertical cone of mud or silty mud in a sandy substrate

Lined or unlined dwelling subtends from the mud ball.

Dwelling tube passively filled, generally contrasts with host strata.



Image courtesy of S.G. Pemberton

Dwellings of Inferred Deposit-Feeders: *Thalassinoides*



Image courtesy of S.G. Pemberton



Mainly horizontal branching systems

Margins are unlined; deeply penetrate muddy substrates.

Burrow dimensions may pinch and swell.

Fill is generally passive, though back-filling may occur to produce meniscae.

Branches may form Y-shapes or T-shapes.

Dwellings of Inferred Deposit-Feeders: *Ophiomorpha*



Image courtesy of S.G. Pemberton



Vertical, horizontal and inclined branching burrow networks.

Tube margins lined with fecal pellets.

Branches typically occur in Y-shapes.

Burrow diameters may pinch and swell, related to turn-around positions, brood chambers, etc.

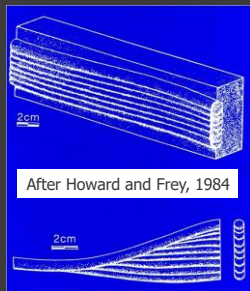
Fill typically passive, though locally may show meniscate backfill.



Dwellings of Inferred Deposit-Feeders: *Ophiomorpha*



Dwellings of Inferred Deposit-Feeders: *Teichichnus*



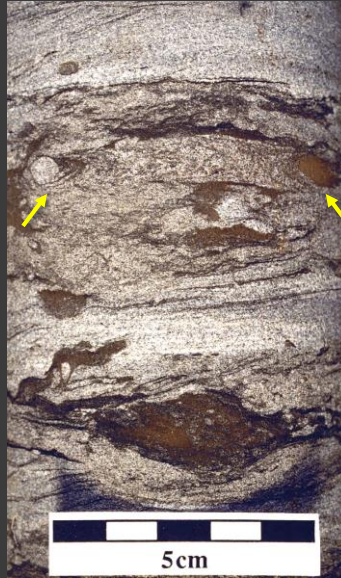
Horizontal unlined tube, never branching, locally horse-shoe shaped.

Upward OR downward shift of structure results in preservation of spreiten either below (most common) or above (very rare) the final tube position.

No discrete wall margins along spreiten.

Final tube typically filled passively.

Dwellings of Inferred Deposit-Feeders: *Rhizocorallium*



Horizontal, U-shaped burrow, tube diameters typically uniform.

Incremental shift of U-tube during organism growth produces spreiten between the tube's arms.

Core expression shows passively filled tubes, with a band of spreiten between them.

Spreiten are parallel to the inside margin of the U-tube.

Dwellings of Inferred Surface Deposit-Feeders: *Gyrolithes*

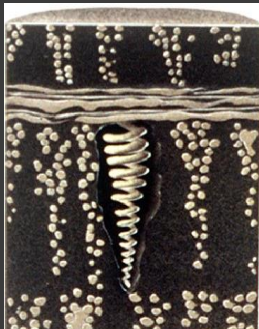
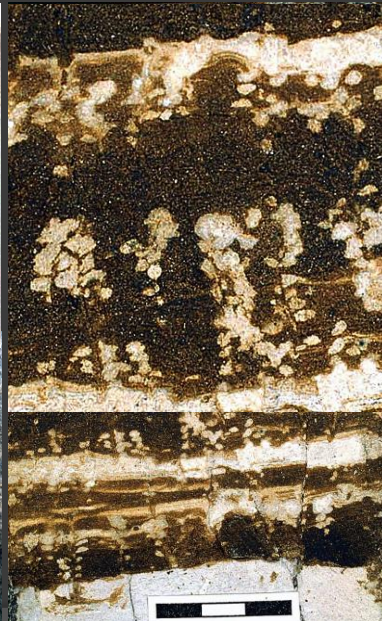


Image courtesy of S.G. Pemberton



Image courtesy of S.G. Pemberton



Vertical, corkscrew-shaped dwelling tube, may be lined.

Corkscrew diameter generally tapers downward; burrow diameter constant.

Burrow is passively filled, typically contrasts with host strata; commonly clay filled.

Appearance in core: cluster of grapes, due to offset of burrow intersections.

Dwellings of Inferred Surface Deposit-Feeders: *Cylindrichnus*



Image courtesy of S.G. Pemberton

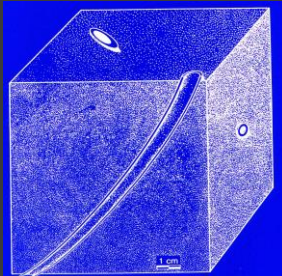


Vertical to inclined, locally gently curved, single entrance, downward tapering shafts.

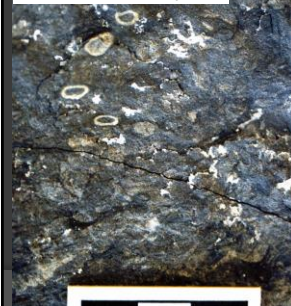
Tube margins lined with concentric layers of silt and clay.

May be intergradational with *Rosselia*.

Dwellings of Inferred Passive Carnivores: *Schaubcylindrichnus freyi*



After Howard and Frey, 1984



Horizontal to inclined, commonly taper slightly downwards.

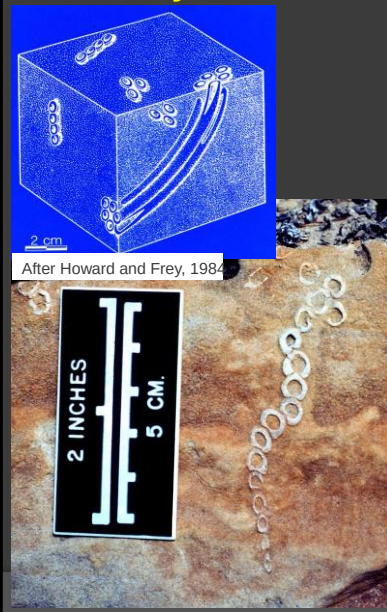
Tube margins lined with agglutinated silt.

Tubes isolated, commonly small diameter.

Tubes thinly lined, and occur in muddy substrates; commonly compacted to form "squashed doughnuts"

Dwellings of Inferred Passive Carnivores:

Schaubcylindrichnus coronus



Horizontal to steeply inclined, commonly tapers slightly downward.

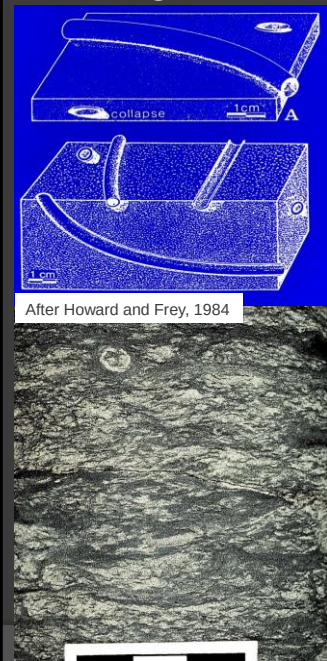
Tube margins thickly lined with agglutinated sand or silt.

Tubes in colonial groupings, commonly large diameter.

Tubes mainly occur in sandy substrates; normally not strongly compacted.



Dwellings of Inferred Passive Carnivores: *Palaeophycus*



Horizontal to inclined, typically large and uniform in diameter.

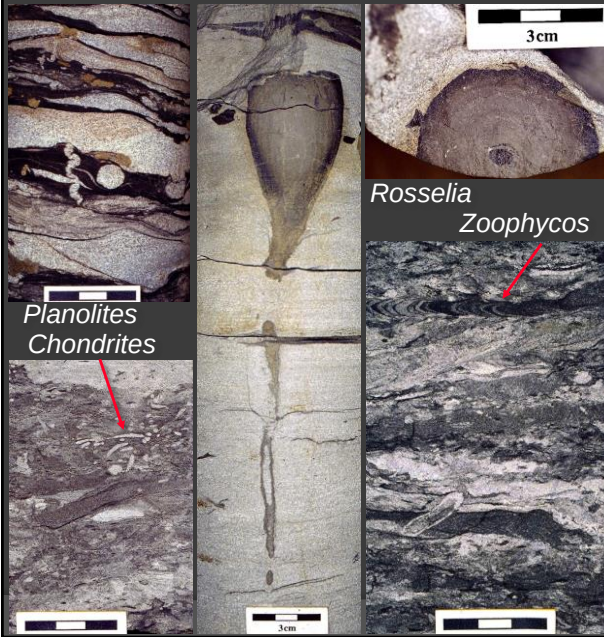
Tube margins lined with agglutinated silt or sand (e.g., *P. heberti*) or dark organic linings (e.g., *P. tubularis*).

Tubes are isolated, and passively filled; rarely contrast with host strata.

Tubes may be heavily lined and occur in sandy substrates; generally show little compaction.



Recognition of Deposit-Feeding Structures



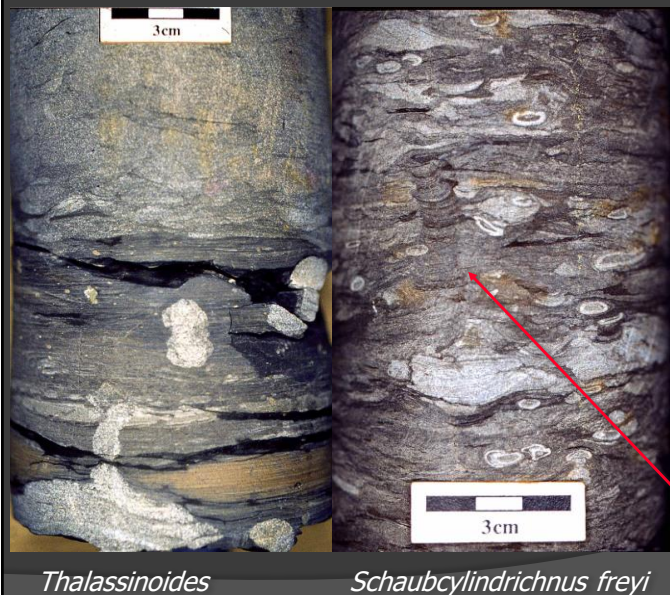
Mobile Deposit-Feeding Structures:

- horizontal to inclined tubes
- unlined
- fill contrasts with host sediment
- lacks spreiten

Sessile Deposit-Feeding Structures:

- horizontal to inclined tubes, possibly branching (e.g., Chondrites)
- generally unlined
- may contain a biogenic "deposit" (e.g., Rosselia).
- may contain spreiten (e.g., Zoophycos).

Recognition of Deposit-Feeding Structures



Dwelling structures of deposit-feeders and carnivores:

- horizontal to inclined tubes
- lined; agglutinated sand/silt or black organic linings, typically in muddy substrates.
- may contain spreiten
- tube infill is passive and therefore similar to host sediment.

Teichichnus

Dwellings of Inferred Suspension-Feeders: Domichnia



Image courtesy of S.G. Pemberton

More or less **permanent domiciles** that penetrate deeply into **sandy substrates**. Reflects high-energy settings.

Dominated by **vertical or inclined shafts** of inferred suspension-feeding organisms.

Includes **U-shaped shafts**, may have **spreiten**.

Includes **branched, heavily lined tubes**.

Includes **lined dwelling tubes** of inferred passive carnivores **in sandstones** (e.g., *Palaeophycus* and *Schaubcylindrichnus*; see previous descriptions).

Dwellings of Inferred Suspension-Feeders: *Skolithos*



Image courtesy of S.G. Pemberton

Vertical to steeply inclined, single entrance non-tapering tubes.

Tube margins may or may not be lined with "mud".

Burrow diameters generally remain **constant**.

U-Shaped Dwelling Structures: *Arenicolites*



Vertical to inclined, double entrance non-tapering U-shaped tubes.

Tube margins may or may not be lined with "mud".



U-shape may vary from narrow to very broad.

No spreiten between the shafts.

U-Shaped Dwelling Structures: *Diplocraterion*

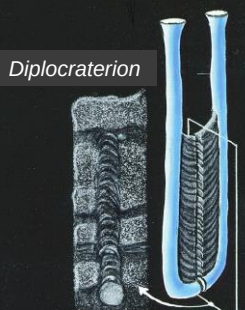


Image courtesy of S.G. Pemberton



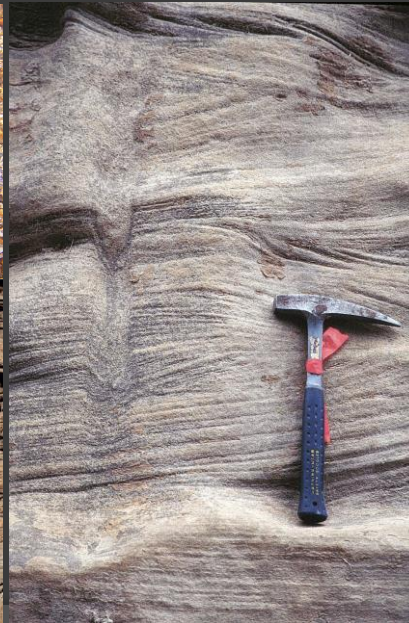
Vertical to inclined, double entrance U-shaped tubes.

Tube margins may or may not be lined with "mud".

Incremental shift of U-tube downward (sediment removal or organism growth) results in preservation of spreiten between the shafts.

Incremental shift of U-tube upward (deposition) results in preservation of spreiten beneath the shaft.

Dwellings of Inferred Suspension-Feeders: *Conichnus*

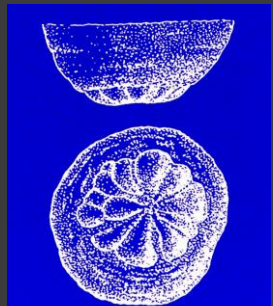


Vertical cone-shaped dwelling / resting structure, with underlying collapse features (associated with extraction of trace-maker from substrate).

Underlying collapse has appearance of fugichnia (escape)

Upper margin of *Conichnus* can be lined, typically with an organic-rich “mud”.

Dwellings of Inferred Suspension-Feeders: *Bergaueria*



Images courtesy of S.G. Pemberton



Simple plug-shaped depressions, locally with complex central zone reflecting point of attachment by trace-maker (an actinian anemone).

Preservation generally as a cast from overlying unit (passive infill).

Most commonly seen on bedding planes of overlying sandstones.

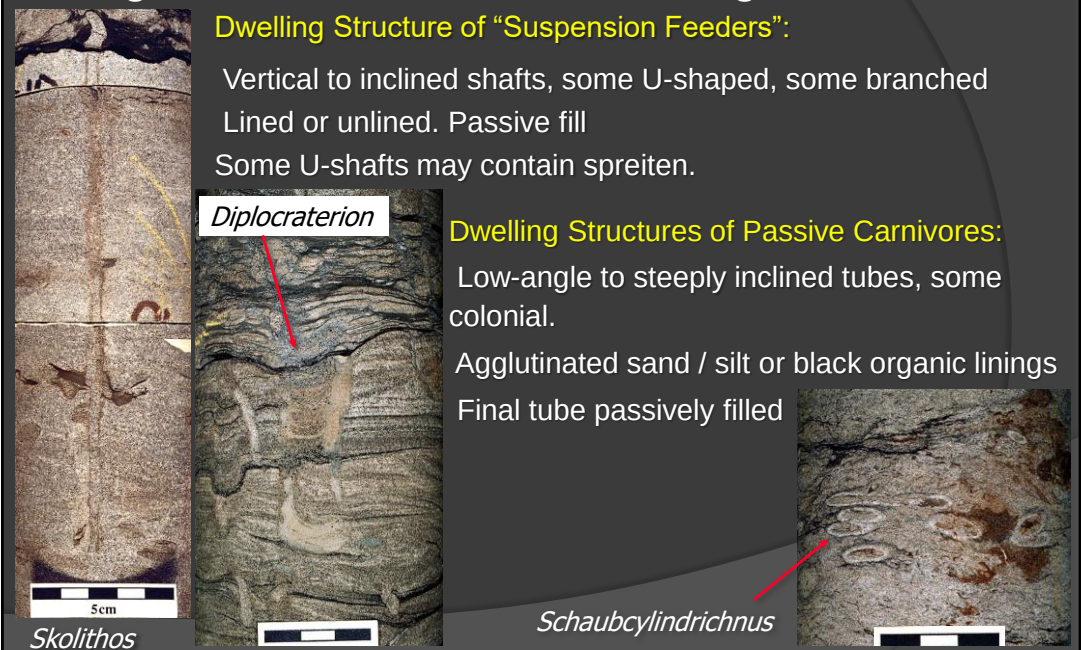
In core, easily confused with gutter casts. Gutter casts are more common (should be default interpretation).



Dwellings of Inferred Suspension-Feeders: *Siphonichnus*



Recognition of Permanent Dwelling Structures



Ichnology

Introduction to Ichnology

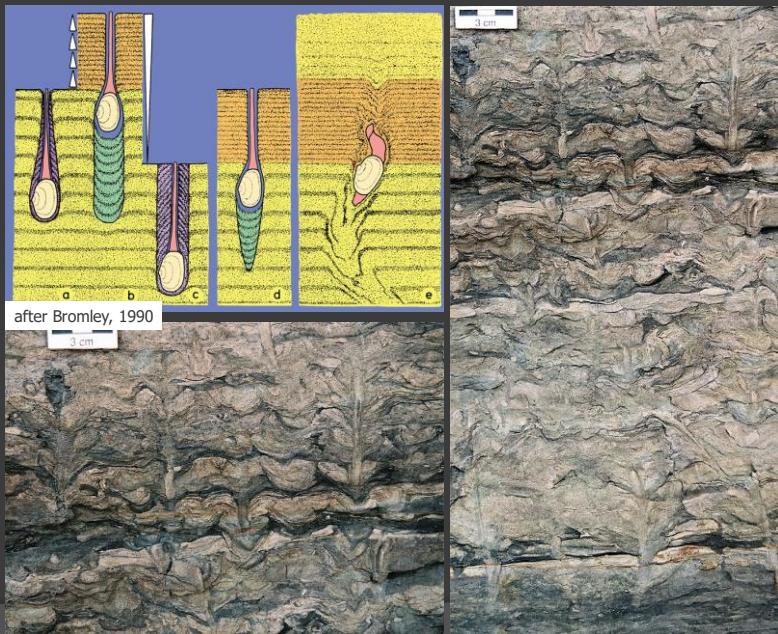
Identification of Trace Fossils in Core

Grazing Structures (pascichnia)

Deposit-Feeding and Dwelling Structures (fodinichnia & domichnia)

Other (including fugichnia)

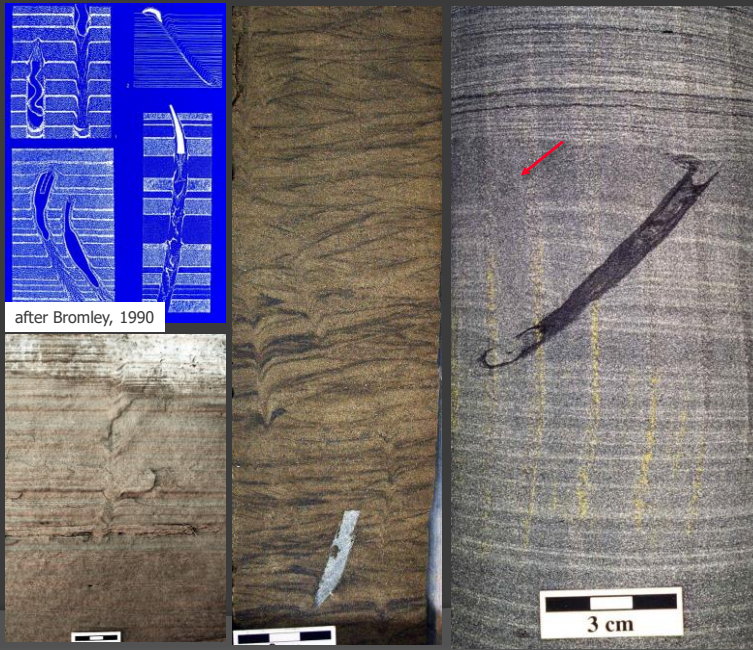
Equilibrium-Adjustment Structures: *Lingulichnus*



Generally **vertical orientations** of disrupted stratification.

Cone-shaped multiple adjustments typically in sandstone associated with position modification of bivalves.

Fugichnia: Escape Structures (No Genus Names Assigned)



Generally **vertical orientations** of disrupted stratification.

Laminae totally disrupted or display downward deflections associated with upward movement of organisms entrained in or buried by the flow.

Summary: Ichnological Structures

1. Identification and interpretation of **biogenic structures** yield essential data on *physico-chemical conditions* of the environment – many of these are not readily discerned using physical sedimentary structures alone.
2. **Intensity of Bioturbation (BI)** is commonly used to assess depositional rate.
3. **Uniformity of Burrowing** is a good indication of depositional episodicity in the environment.
4. **Diversity of the Suite** is useful for assessing a range of environmental stresses, both energy and chemical (e.g., salinity, turbidity, oxygenation, substrate consistency).
5. **Ethological (behavioural) assessment** of the suite is useful for investigating animal-sediment responses to the paleoenvironment.
6. Other aspects, such as diminution (reduced size), tiering position (occupation levels in the substrate), and cross-cutting relations can be critical for evaluating the paleoecology of the environment.