THE HASHEMITE UNIVERSITY
Faculty of Natural Resources and Environment
Department of Earth Sciences and Environment
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Geological Field Techniques 111201391

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Recording palaeontological information

5.1 Introduction: Fossils are smart particles

Unlike many sedimentary particles, such as quartz grains, each fossil has a story to tell that goes beyond its composition and the way in which it was transported and deposited. A body fossil represents the remains of a once living organism that had a life history, a certain environmental tolerance, and a defined range in terms of its geographical and stratigraphic distribution. Body fossils may be large, as in the case of a complete mummified mammoth, or microscopic, such as a pollen grain. Trace fossils represent impressions that an organism made in sediment, such as a footprint, or the disturbance of sediment as the animal went about feeding, or burrowing to create a living space. Fossils can also provide evidence of their decay process (including post - mortem scavenger behavior), burial and tectonic history, all of which provide information on ancient environments. Moreover fossils occur in assemblages that may reflect predominantly life communities or processes of transport, deposition and decay that can also inform on past environmental conditions. Fossils are ‘ smart particles ’ .

5.1.1 Why are fossils important?

The occurrence of fossils in most sedimentary rocks, and more rarely in extrusive igneous rocks such as basalt lava flows and ash deposits, can be used to obtain stratigraphic, environmental and evolutionary information. Fossils can provide:

- a wealth of information on ancient life forms and thus are important in understanding the history of life on Earth and our place within it;
- data on ancient ecosystems and palaeoecology that have relevance to managing our planet today and in the future;
- qualitative and quantitative data on ancient climates, and a method of testing the applicability of climate models for a range of climatic modes;

• the basis of relative dating and correlation of rock units; some megafossils * are currently the only method by which rocks can be given a relative age in the field (other than superposition and cross - cutting);

• information on the biotic and chemical conditions following the death of the organism, at the time of burial and subsequently through its burial history – these data are important for determining, for example, the hydrocarbon potential of a rock unit.

5.1.2 Collecting fossil data

For fossils visible to the naked eye careful observation of morphology, preservation mode, orientation, context in terms of other fossils (assemblage characteristics), stratigraphic position and relationship to the entombing sedimentary deposits are all fundamental to successful palaeontological interpretations. The three - dimensional nature of both body and trace fossils often presents a challenge in recognizing the type of fossil. It is important to record the orientation and to become familiar with the characteristics of a variety of sections through the fossil. The best items of field equipment for recording fossils are:

• a notebook in which to make sketches;

• a hand lens to examine detail;

• a camera.

If you do need to collect you will need to consider the following.

• *Is the site protected by law?*

• *Is the site on publicly owned land?*

• *Can the fossil be removed safely with the tools to hand without destroying it or endangering the collector and those in the vicinity?*

• *Is collection really necessary to aid understanding?*

5.2 Fossil types and preservation

5.2.1 Body fossil classification

The chances are that in the field you will not be able to identify every fossil you find. Actually you don’t need to. A lot can be deduced about the organism in the field by careful observation and you can make up a working classification based on simple observation of, for example, symmetry (Figure A5.1). Even if we know nothing of the taxonomic identity of a fossil (which the case is often with newly discovered species)
we can infer a lot about its mode of life and palaeoenvironment by examination of its architecture and context within the entombing rock (e.g. Worked Example 5.1). Plants invariably fossilize as dispersed organs (leaves, fruits/ seeds, pollen/spores, trunks and roots) and most of the time we don’t know which parts belong together to make a specific extinct species. For this reason each organ has a Latin name of its own. Try to record as accurately as possible the morphology of each plant part including shape, size and ornamentation; in the case of leaves, margin details and venation are also important (Figure 5.1). Microscopic body fossils (microfossils) can rarely be identified in the field and collecting is often carried out without knowing if the sample will contain them.

5.2.2 Body fossil preservation

The way that a body fossil is preserved indicates a great deal about its transport, deposition and burial history as well as the chemical and tectonic history of the entombing sediment. Recognizing and recording the mode of preservation is important to understanding the processes during deposition and burial.

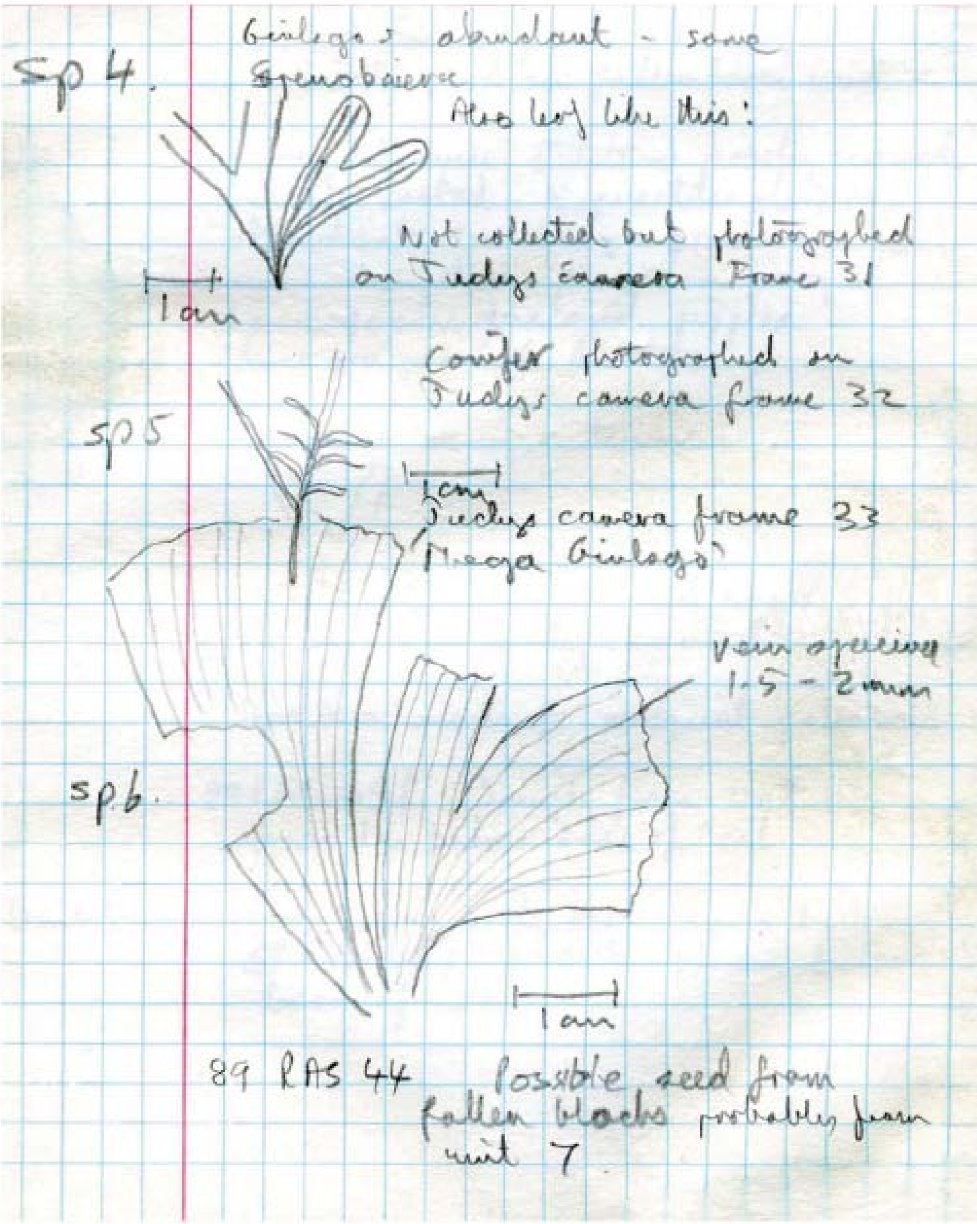


Figure 5.1 Part of a field notebook page showing sketches of leaves. Note scale, careful attention to venation and references to accompanying photographs, sedimentary units and specimen numbers. (Notebook of Robert A. Spicer, The Open University, UK.)

Worked Example 5.1 Using morphological observations to infer mode of life

(a) (b)

Figure 5.2 Two echinoid specimens with distinctly different morphologies. (a) *Archaeocidaris* (Robert A. Spicer, The Open University, UK) and (b) *Micraster* (specimen from Peter R. Sheldon, The Open University, UK).

In Figure 5.2 two echinoids are shown, one (taxon A) with a heavily armoured shell and another (taxon B) with a smoother and more streamlined shell. These morphological characteristics can be used to determine which of these is most likely to be infaunal (i.e. live within the sediment).

In the case of taxon A the possession of large spines would generate considerable drag if the organism were to attempt to burrow in sediment. It would be reasonable to surmise that taxon A was more likely to live on the surface of the sediment (epifaunal), while the smoother and more streamlined taxon B was more likely to burrow in the sediment (infaunal). This is not to say that all epifaunal organisms are heavily armoured with spines (some are smooth) but it is true to say that no burrowing organisms will have rigid projections that would impede passage through sediment. Similarly, fossils representing organisms that live in shallow water above the fair-weather wave base typically are more robust than those living in quieter conditions at depth.

5.2.3 Trace fossils

Although the body parts of organisms that make trace fossils are almost always missing, the trace shape and context can tell us a lot about environmental conditions at, and after, the time the trace was made. Trace fossils have the advantage over body fossils in that they cannot be reworked, although they can be disrupted or destroyed by later trace fossils. Trace fossils fall into several categories based on behavior. Trace fossils do not occur randomly but are repeatedly found in recognizable associations with particular sediment types. These associations form ichnofacies that can indicate a lot about the conditions under which sediment was deposited. In the field, using photographs and sketches, record the following:

• the size distribution;

• geometries (including working out which are different cross - sections through the same type of trace fossil);

• associations with other trace fossils;

• characteristics of the sedimentary deposits;

• frequency and density;

• presence/absence of burrow wall linings (e.g. made up of organic matter, shell fragments or different sediment types, etc.) – the infilling of burrows is also important to note in

•respect of sediment type(s) compared with the sediment burrowed, and any geometries associated with the infill (simple collapse versus structures that indicate deliberate backfilling by the organism);

• look for tiering, i.e. the pattern of trace fossil types vertically in the sediment, in relation to a given horizon marking a change in sedimentation – some burrows are typically formed in shallow sediment depths while others penetrate deeper, and loss of shallow tiers can indicate erosion;

• cross - cutting relationships indicating successive colonizations of the sediment and changing conditions through time.

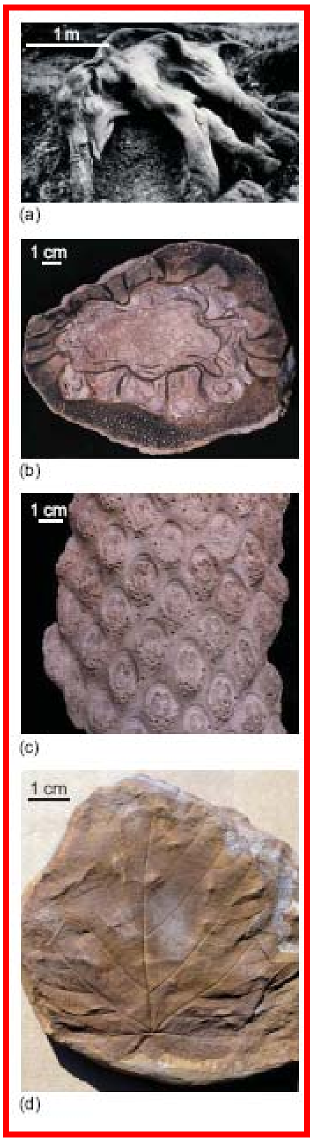


Figure 5.3 Modes of fossil preservation: (a) Mummified body of a young mammoth found in Siberia; (b) polished transverse section of a permineralized (petrified) tree fern stem; (c) cast of a tree fern trunk; (d) leaf impression from the north slope Alaska. (a–d: Robert A. Spicer, The Open University, UK.)

5.3 Fossil distribution and where to find them

Initially the best way to look for fossils is to examine loose pieces of rock material ('float ') derived from the exposure. Float has the advantage of exposing a large number of bedding surfaces that can be examined for fossils. If fossils are visible the next step is to try and relate the lithology of the fossil - bearing float to lithologies that are in place, for example, in the adjacent cliff face. This lithology can then be examined for *in situ* fossil material. If fossils are not obvious on the float bedding surfaces, expose further bedding planes by splitting the blocks parallel to the bedding using a chisel or the chisel end of a hammer.

• *Carbonate fossils:* Body fossils composed of carbonate tests or shells, as well as bones, are most likely to be found in carbonate - rich rocks such as limestones and chalks. They can also be found in siliciclastic rocks provided that they have not been in acidic conditions during deposition and subsequent burial.

• *Siliceous fossils:* Fossils with silica tests or frustules (diatoms and radiolarians for example) survive best in low pH (acidic) environments because silica is soluble under high pH (alkaline) conditions. It is therefore unlikely that diatoms and radiolaria will be found in carbonate – rich rocks; but note that even in chalk it is common to get localized variations in chemistry at the time of deposition, leading to the preservation of silica - rich fossils (e.g. sponge spicules in flint).

• *Colour:* Colour changes can also be a clue to finding fossils. Look at reduction spots (typically grey or green spots in otherwise red/brown sedimentary deposits) as these indicate locally oxygen - poor conditions and may be associated with organic remains or their derivatives.

• *Change in sedimentation rate:* Changing grain size and/or an increase in sedimentation rate can also be a clue to finding fossils. Post – mortem (an examination of the body made after the death) oxygen exclusion is related to the speed of sedimentation. For example leaves accumulating on the fine - grained sedimentary deposits at the bottom of a lake will often be destroyed by invertebrates, fungi and bacteria unless buried quickly. In such cases, look for fossils just below increases in grain size or other indicators of rapid sediment deposition.

• *Hydraulic equivalence:* In situations where water is flowing (streams, rivers and marine tidal flow environments) an important clue as to where to find fossils is the concept of hydraulic equivalence. Hydraulic equivalence associates the hydraulic characteristics (settling velocity, velocity of entrainment, etc.) of a fossil to that of a quartz grain. So, for example, a large dinosaur bone or waterlogged tree stem are broadly hydraulically equivalent to a large quartz pebble or small boulder. It is no surprise then that such fossils are commonly found in the basal lags of river channels. Similarly, leaves commonly occur in fine – grained fluvial siltstones.

5.4.1 Sampling for biostratigraphic or evolutionary studies

For biostratigraphy and/or evolutionary studies a succession of samples collected vertically through the deposit usually takes precedence over investigating lateral variations (compare Figure 5.8 a with 5.8 b and 5.8 c). Over geological time different fossils are important for biostratigraphy (Figure A5.5). Many studies incorporate more than one fossil group. In addition the sampling strategy needs to be appropriate for the type of biozonation that is used for the fossil group or period of geological time. It is important with microfossils to limit the risk of contamination. The two types of sampling are spot and continuous.

• *Spot sampling* can be performed at regular distance intervals and/or targeted to different lithologies. The advantage of spot sampling is that it is relatively quick and minimizes the amount of material collected.

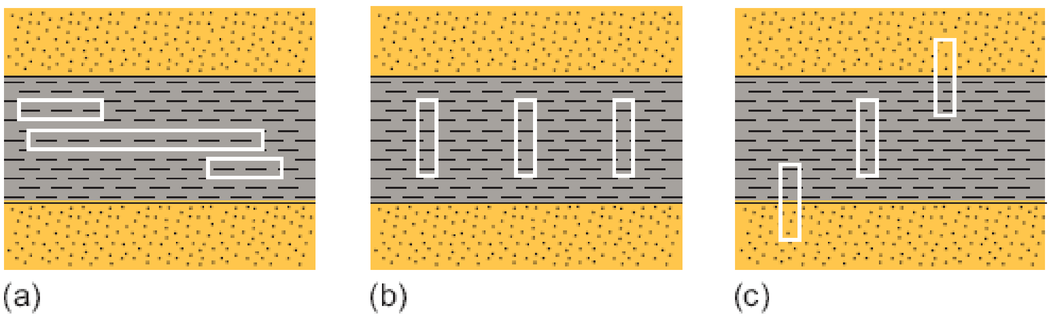


Figure 5.8 Three different patterns of continuous or channel sampling. (a) Overlapping samples parallel to bedding. (b) Repeat samples at right angles to bedding within a lithology. (c) Samples at right angles to bedding representing the stratigraphy, with short overlaps for cross-correlation purposes.

• *Continuous sampling,* sometimes known as channel sampling, has advantages over spot sampling for high resolution studies if resources allow.

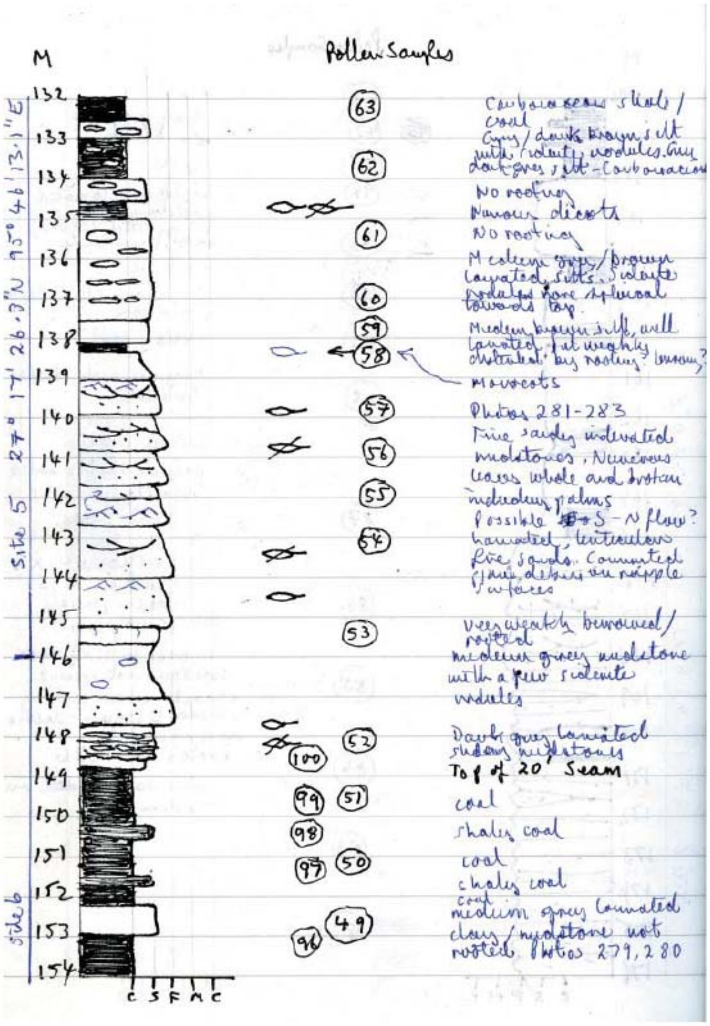
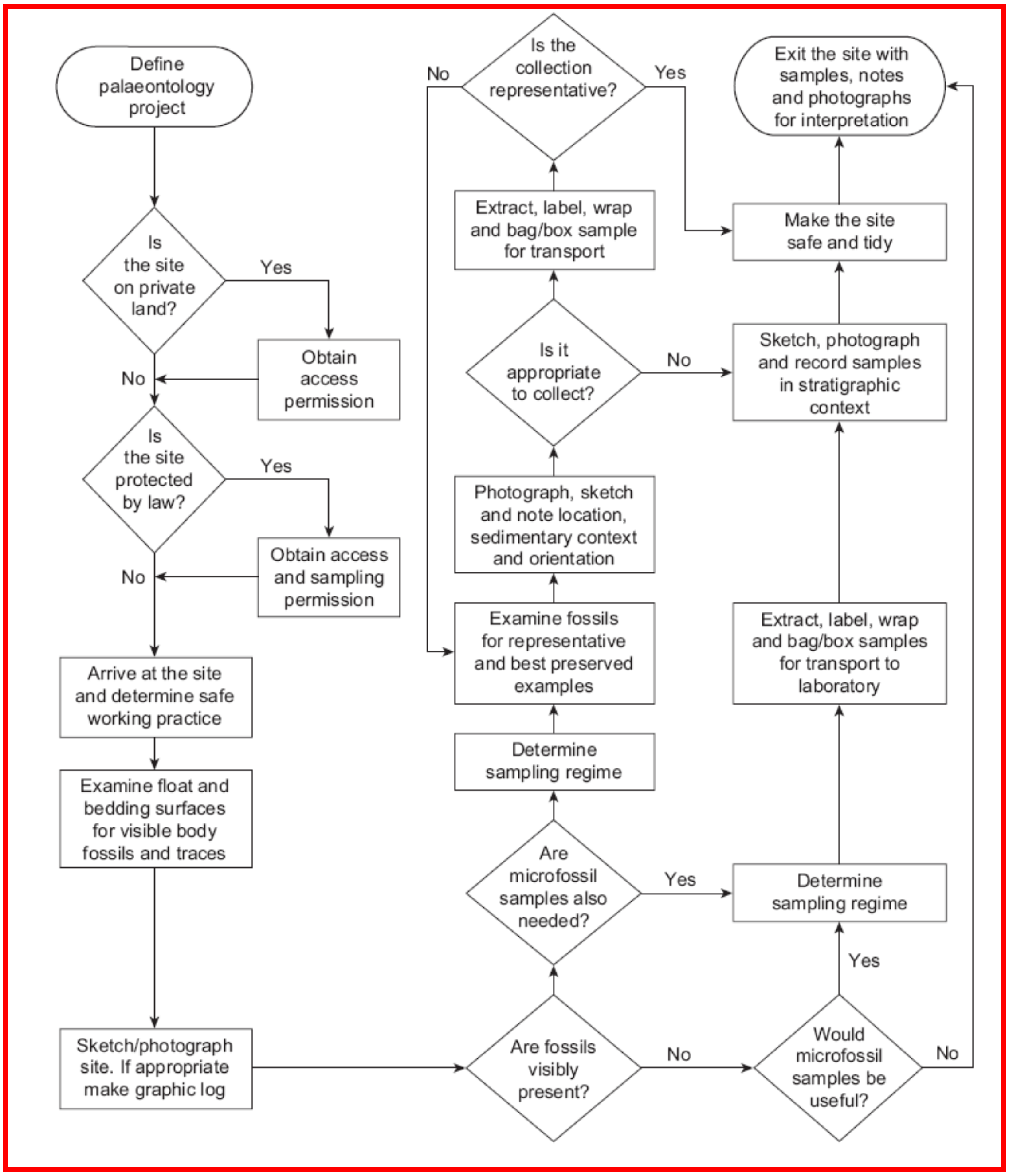


Figure 5.10 Example of a field notebook page showing the position of fossiliferous layers and pollen samples on a graphic log. The log and samples are for a section in Assam, India. (Notebook of Robert A. Spicer, The Open University, UK.)


Define palaeontology project
Is the site on private land?
Yes
Obtain access permission
No
Is the site protected by law?
Yes
Obtain access and sampling permission
No
Arrive at the site and determine safe working practice
Examine float and bedding surfaces for visible body fossils and traces
Sketch/photograph site. If appropriate make graphic log
Are fossils visibly present?
No
Would microfossil samples be useful?
No
Yes
Determine sampling regime
Are microfossil samples also needed?
Yes
Determine sampling regime
Examine fossils for representative and best preserved examples
Photograph, sketch and note location, sedimentary context and orientation
Is it appropriate to collect?
No
Sketch, photograph and record samples in stratigraphic context
Extract, label, wrap and bag/box sample for transport
Is the collection representative?
No
Yes
Make the site safe and tidy
Extract, label, wrap and bag/box samples for transport to laboratory
Exit the site with samples, notes and photographs for interpretation

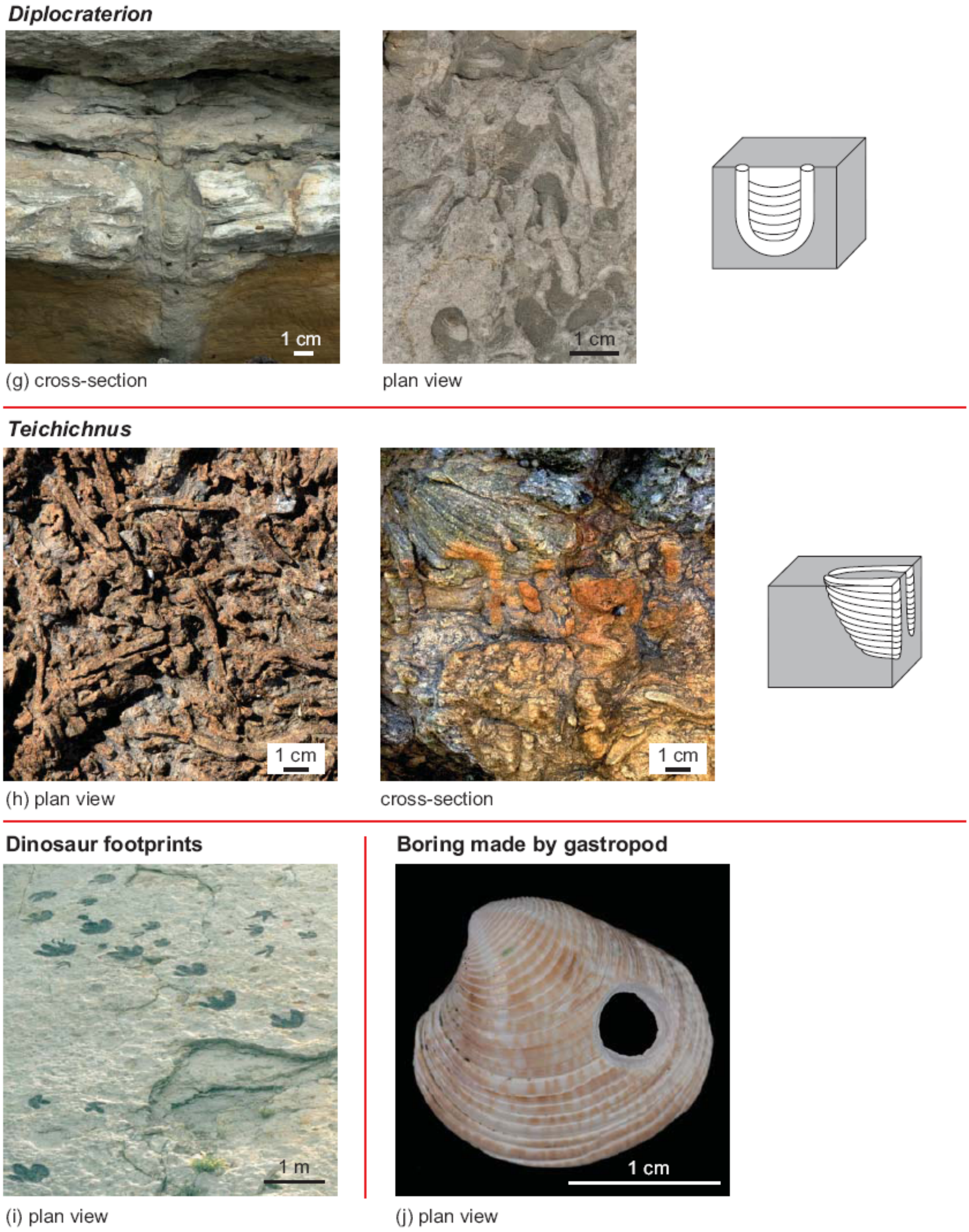


Figure A5.3 *Continued*

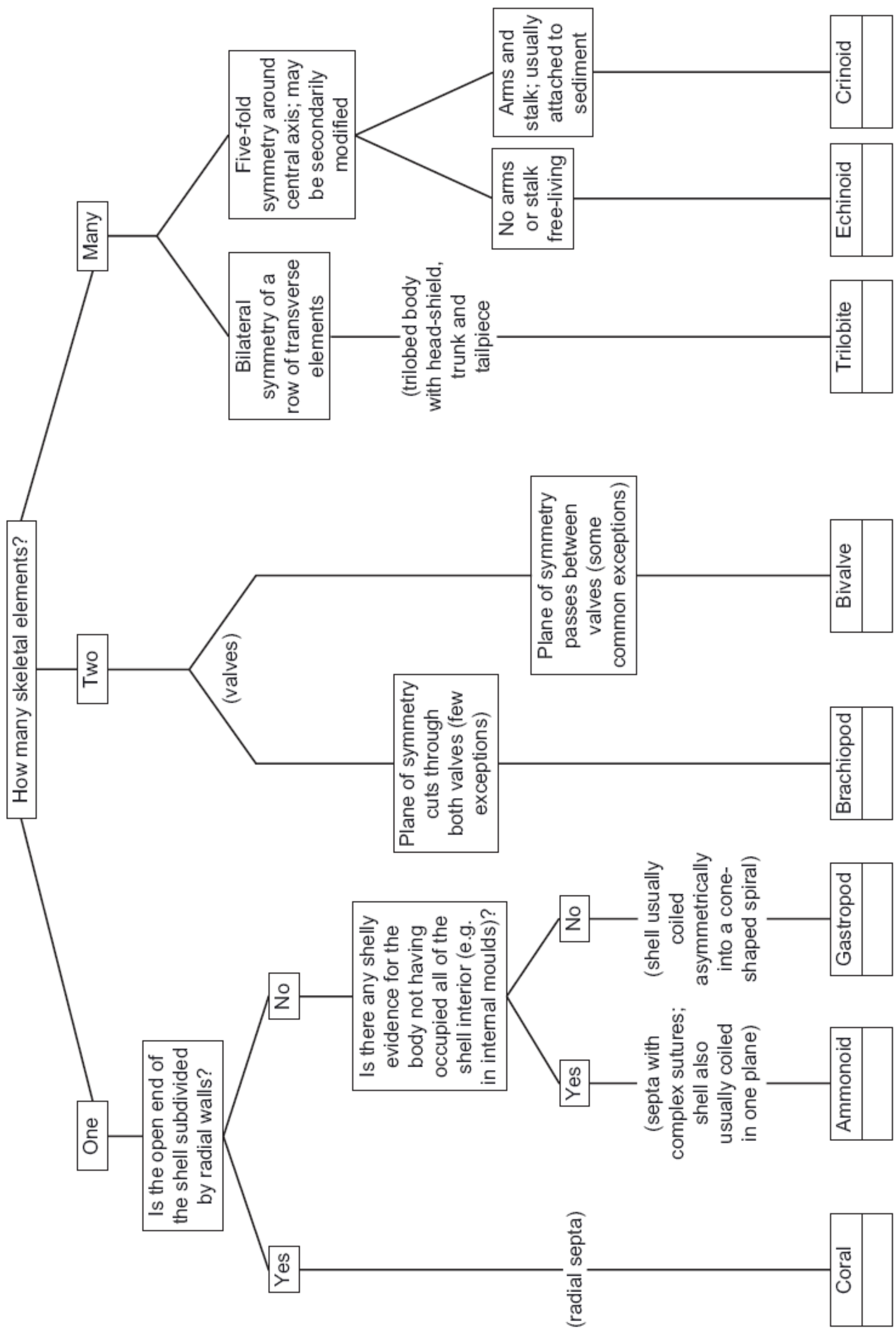


Figure A5.1 A simple scheme for the identification of invertebrate fossils based on symmetry.

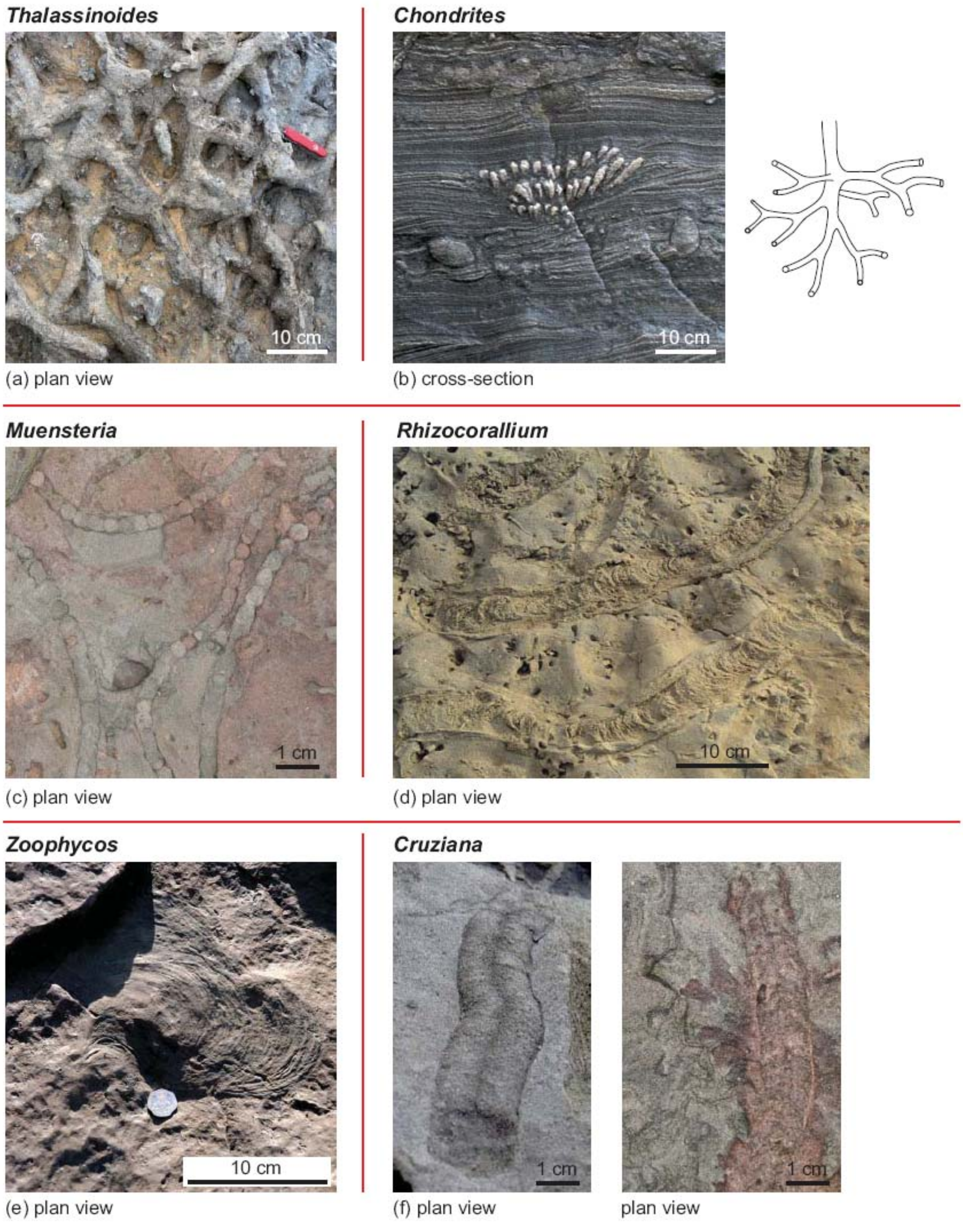


Figure A5.3 Illustrations of some common trace fossils. ((a)–(j) Angela L. Coe, The Open University, UK. Except (f) plan view; Fiona Hyden, Open University Associate Lecturer, UK.)

Table A5.2 There has been a plethora of categories for classifying trace fossils. One such classification is based on the interpretation of what the animal was doing. Note that many of these are not mutually exclusive.

Category	**Explanation**	**Examples**
Grazing (*Pascichnia*)	Traces left as an organism moves over a sediment surface. The substrate may be either soft or hard. Often movement over a surface is associated with feeding as well as locomotion	*Nereites, Spirorhaphe*
Feeding (*Fodinichnia*)	These traces are left as organisms move through sediment as they feed. They are usually three dimensional	*Chondrites, Muensteria, Teichichnus, Rhizocorallium, Zoophycos*
Dwelling (*Domichnia*)	Structures resulting from an organism's living space	*Thalassinoides, Ophiomorpha, Diplocraterion* (also *Fodinichnia*)
Resting (*Cubichnia*)	Formed by the impression of an organism in soft sediment	*Rusophycus, Asteriacites*
Moving (*Repichnia*)	Formed by normal locomotion as distinct from feeding	*Cruziana*
Predation (*Praedichnia*)	Predatory traces such as drill holes in shells or bite marks	*Entobia, Gastrochaenolites, Trypanites*
Gardening (*Agrichnia*)	Formed as organisms create (usually complex) burrows or structures to capture or cultivate other organisms such as bacteria or fungi for food	*Paleodictyon*

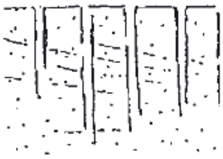
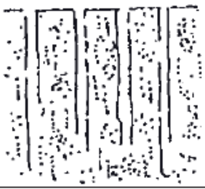
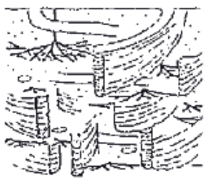
Example	Observations	Implications	Environment
1 	Single colonization with clearly visible primary structures	Initial colonization of, for example, an event bed by a low diversity biota	Most likely an unstable high sedimentation rate environment, e.g. estuarine
2 	Successive colonization without an increase in biotic diversity	Gradual/moderate sedimentation in stressed environments	Possibly longer intervals between events than in examples 1 or 3 but with low diversity biota
3 	Simple tiering by increasingly diverse biota	A wide range of environments associated with event beds	Moderate sedimentation rates, but perhaps longer intervals between events than in example 1
4 	Complex tiering	Gradual aggradation	Stable environment with low sedimentation rates
5 	Gradual overlap	Low sedimentation	Gradual environmental change
6 	Omission and possible truncation of burrows	Sudden facies change, perhaps with the development of a firmground or even hardground	Period of non-deposition and condensation

Figure A5.4 Examples of tiering of burrows and their implications. (Modified after Goldring 1991.)

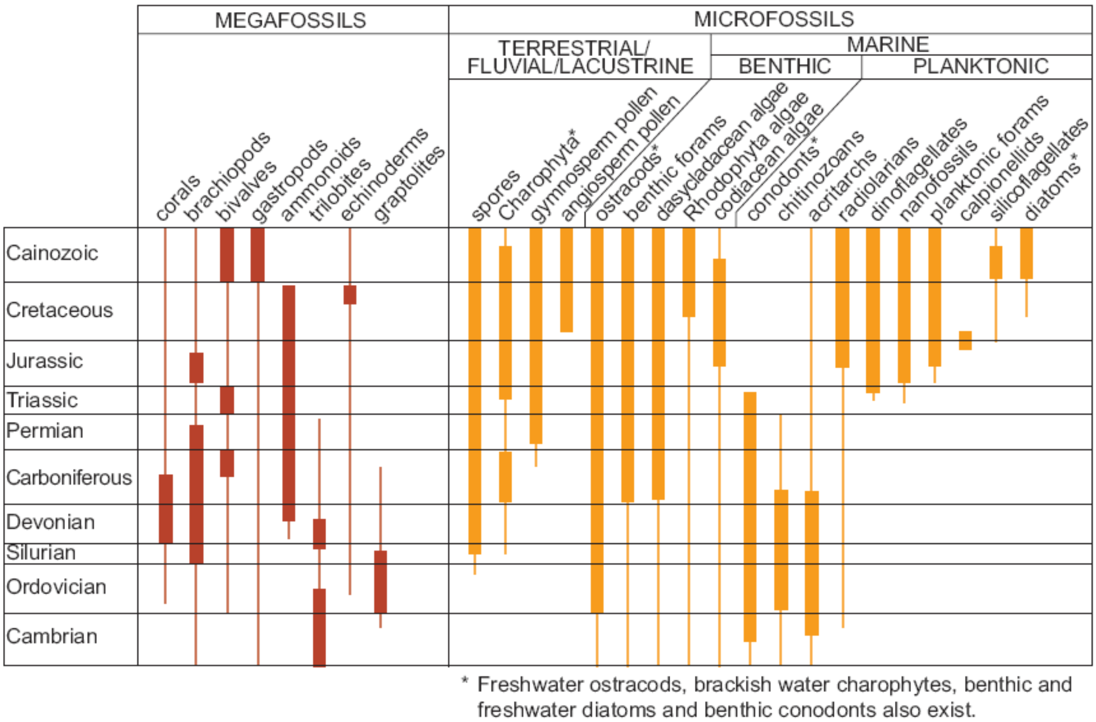


Figure A5.5 Biostratigraphically useful groups of organisms. The thick part of the line indicates the interval where the fossil group is used most extensively. (Modified after Nichols 1999 and Emery and Myers 1996.)

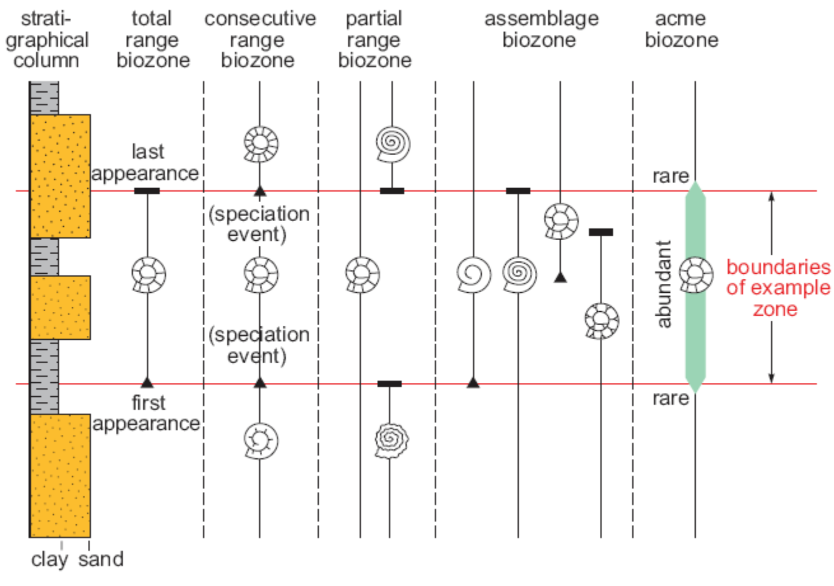


Figure A5.6 The common zonation schemes used in biostratigraphical correlation. (Modified after Nichols 1999.)

Recording features of sedimentary rocks and constructing graphic logs

6.1 Introduction

Sedimentary rocks, particularly coarse - grained siliciclastic rocks, are rewarding to study in the field. This is because you can gain a lot of information about their mode of formation directly from field observations and start to make an interpretation (Figure 6.1) without the need to wait for thin - sections or geochemical analyses, which are required for many igneous and metamorphic rocks. Some carbonate successions and fine - grained mudstones can, however, be tricky to interpret in the field and their study can benefit greatly from follow – up microscope work and/or geochemical analyses.

There are a variety of specific reasons for collecting data from sedimentary deposits aside from the general ones of geological mapping or constructing a geological history for an area. These are to:

• *Understand sedimentary processes and depositional environments.* This leads to a better understanding of natural processes on the Earth's surface.

• *Understand the potential of a sedimentary basin or unit for hydrocarbon recovery or for water resources.*

• *Reconstruct past periods of environmental change, particularly climate and sea - level change.* Fine – grained marine sedimentary deposits contain the most laterally extensive, complete and intact record of the changing chemistry of the Earth's oceans. Because of the interaction between the oceans and atmosphere.

• *Understand and exploit sedimentary building materials and mineral deposits.*

• *Refine the geological timescale.*

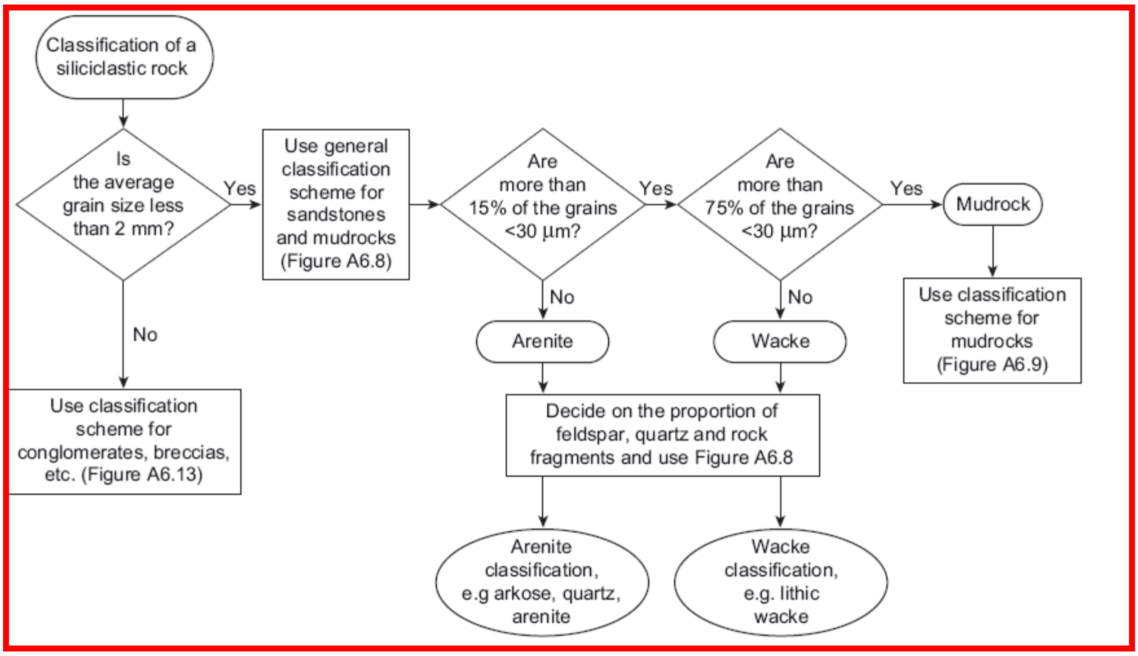
Figure 6.1 An example of a small part of a section of sedimentary strata from which a lot of information about the depositional processes can be gained. The image shows cross-stratification produced by the migration of wave-formed ripples indicating that the sediments were deposited within wave base (less than tens of metres depth) by waves. Some of the ripples near the middle of the image are climbing, indicating high sedimentation rates. The image shows colour variation that is likely to reflect grain and/or compositional changes, which may relate to changing energy or sediment source. There are also several trace fossils indicating animal activity. Carboniferous-age strata exposed near Berwick-upon-Tweed, UK. (Angela L. Coe, The Open University, UK.)

6.2 Description, recognition and recording of sedimentary deposits and sedimentary structures

There are four aspects that need recording in the description of sedimentary rocks: (1) the composition, which is relatively easy compared with igneous and metamorphic rocks as there are not many minerals that are common in sedimentary deposits
(2) the texture of the rock; (3) the sedimentary structures; and (4) the fossils within them.

Siliciclastic rocks

For siliciclastic rocks the classification scheme depends on the grain size and the composition of the major grains, except for conglomerates and breccias where the clast shape is also important (see GFT1, Appendix). The general siliciclastic classification process is illustrated in the following flowchart:



Mudrock

Fine - grained siliciclastic sedimentary rocks make up over 50% of the sedimentary rock record. They are more difficult to work with in the field than coarse - grained siliciclastic rocks because their features are harder to distinguish with the naked eye and the variations are subtle.. The features listed below are particularly useful for mudrocks:

- *Colour:* As for other sedimentary rocks this primarily reflects composition. Most marine mudrocks are various shades of grey. Mudrocks with a higher carbonate or silica content, or less organic matter, tend to be paler. Mudrocks rich in organic matter (i.e. organic - carbon compounds) are a brownish grey. Non - marine mudrocks are often red or green depending on the oxidation state of the iron; they can also be white and various yellows. Bentonites (montmorillonitic clays of volcanic origin) are a distinctive bluish or greenish grey when freshly exposed.
- *Fracture:* The fracture pattern also provides a clue to the composition and subtly changes with the composition. Mudrocks mainly composed of clay minerals have an even, blocky fracture. Increasing amounts of carbonate (e.g. marly clays and marlstones) tend to give the rock a conchoidal fracture pattern (Figure 6.2). Mudrocks with a high silica content are harder.
- *Fissility:* Mudrocks with a fissility (i.e. break into thin (millimetre - sized) layers) are termed shales. They can develop a fissility for two reasons: (1) laminae scale variation in composition; (2) compaction and weathering. Shales with compositional lamination often have a higher overall organic - carbon content and/or some coarser – grained material. Not all compositionally laminated mudrocks are fissile.

(a) (b)

Figure 6.2 (a) Blocky fracture pattern of a siliciclastic mudrock mainly composed of clay minerals. (b) Conchoidal fracture pattern of a mudrock with a significant proportion of carbonate. (a and b: Angela L. Coe, The Open University, UK.)

Conglomerates and breccias

Conglomerates and breccias can be classified according to clast type and matrix properties (Figure A6.13). In complete contrast to mudrocks a ‘ wide angle ’ view of these coarse – grained sedimentary deposits is required to obtain representative data because of the potential large - scale variation. The quadrat method is useful for assessing and recording coarse – grained sedimentary deposits.

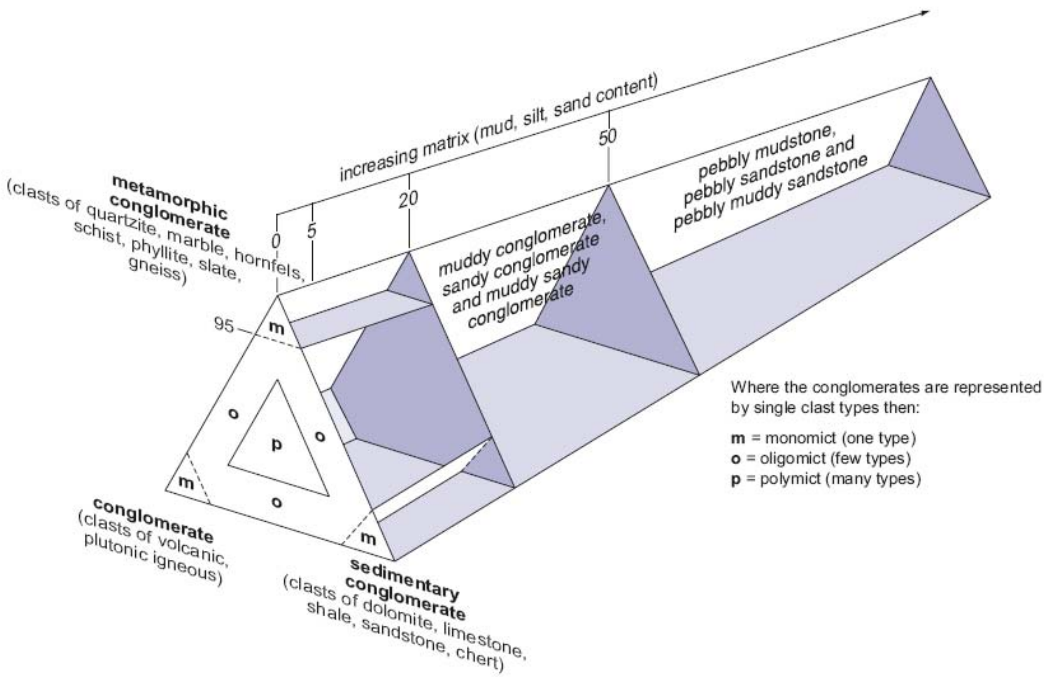
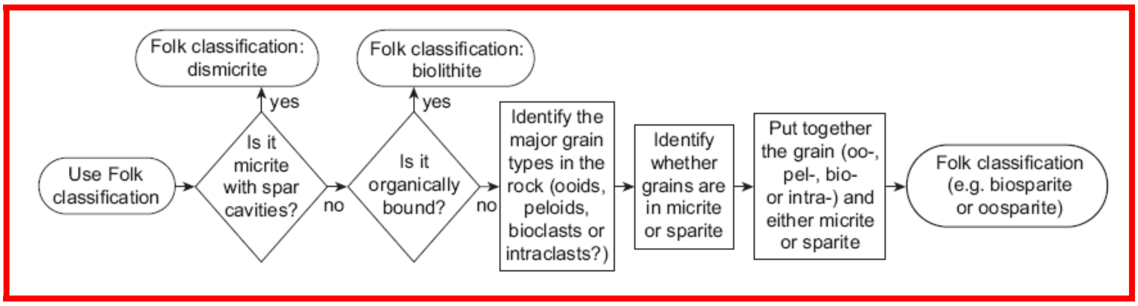
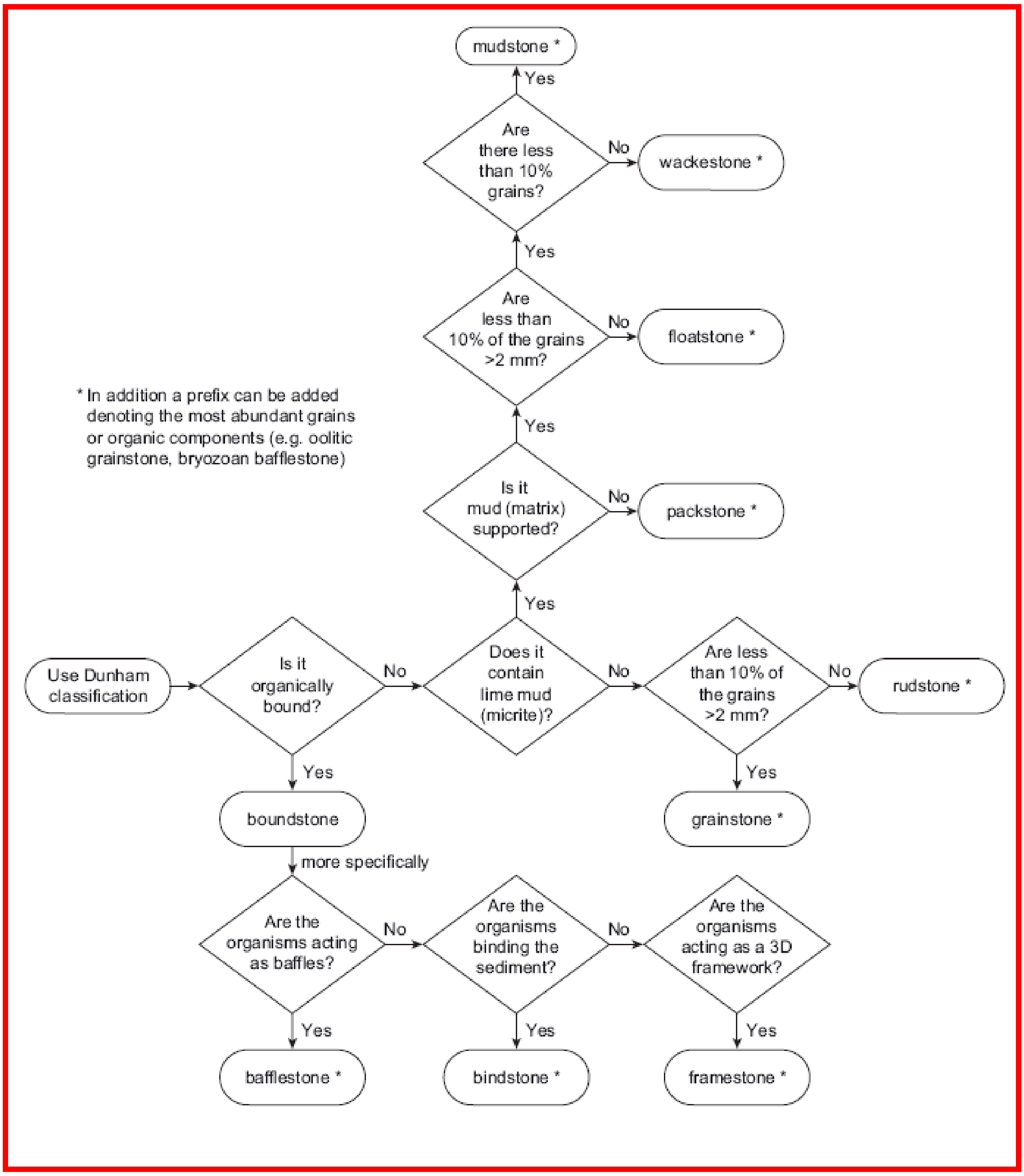


Figure A6.13 Classification of coarse-grained sedimentary rocks (conglomerates, breccias, etc.). Modified after Boggs 1992, Nichols 1999 and Stow 2005. In addition the following terms can be applied: intraformational conglomerate and breccia, composed of clasts of the same material as the matrix; extraformational conglomerate, composed of a mixture of rock types; clast-supported (or orthoconglomerate); matrix-supported (or paraconglomerate or diamictite).

Carbonates
It is useful to look at both a weathered and a fresh surface of carbonate rocks. The carbonate grains tend to weather out making them easier to identify on weathered surfaces. There are two commonly used classification schemes for carbonates see the appendix in GFT1 lecture.



In contrast, the Dunham classification scheme conveys information about the matrix or cement and the texture of the rock. The grain type(s) can be indicated by adding an adjective denoting the grain type (e.g. oolitic grainstone). The observations necessary to decide on an appropriate Dunham classification are illustrated by the flowchart below:


mudstone *
Yes
Are there less than 10% grains?
No
wackestone *
Yes
Are less than 10% of the grains >2 mm?
No
floatstone *
Yes
* In addition a prefix can be added denoting the most abundant grains or organic components (e.g. oolitic grainstone, bryozoan bafflestone)
Is it mud (matrix) supported?
No
packstone *
Yes
Use Dunham classification
Is it organically bound?
No
Does it contain lime mud (micrite)?
No
Are less than 10% of the grains >2 mm?
No
rudstone *
Yes
boundstone
Yes
grainstone *
more specifically
Are the organisms acting as baffles?
No
Are the organisms binding the sediment?
No
Are the organisms acting as a 3D framework?
Yes
bafflestone *
Yes
bindstone *
Yes
framestone *

The other common types of carbonate are:

- *Dolomite:* Dolomite has three field characteristics that distinguish it from other carbonates: (1) it tends to be a pale yellowy - brown colour; (2) it reacts only slowly with dilute hydrochloric acid; and (3) if ground between the teeth its texture is softer than that of limestone.
- *Siderite:* This is most easily distinguished by its distinctive yellow - red colour (terracotta); it forms both bands and nodules, particularly in mudrock successions.

6.2.2 Recording sedimentary structures

Sedimentary structures are varied and complex. They are dealt with in detail in many geological textbooks and in specialist sedimentological textbooks. A full coverage is beyond the scope of this book, so instead this section concentrates on how to: (1) record and describe them; (2) distinguish between structures that look similar; and (3) decipher cross - cutting relationships.

Here are some suggestions for observing, describing and identifying sedimentary structures.

1. Examine the structure if possible in plan view and in cross - section, preferably in faces that cut through the structure parallel and perpendicular to the current direction. This is because different structures look similar or even exactly the same if only one view is taken. The three - dimensional morphology of sedimentary structures is often complex, because sedimentary structures are the result of the migration of three - dimensional bedforms, or of animals and plants disrupting the sediment. Figure 6.3 shows some common examples of how sedimentary structures look different depending on the orientation of the rock face.

2. Decide whether the structure is common in the succession or unusual. If the latter, is it important or an oddity that is not worth spending much time on?

3. Record the size (in all three dimensions where possible) and any systematic variation or repetition, both laterally and vertically.

4. If it is a large - scale structure that disrupts other beds and changes its nature along strike, record these details using photographs and/or sketches.

5. Record where the sedimentary structure is located within the bed. Is it at the base or top of the unit or in the middle?

6. If you cannot identify the structure, sketch and/or take photographs of it. Label the sketch with notes on the geometries and ensure that you have notes on whether this is a cross - section or plan view, and that you can relate different views of the structure.

7. Look for associations of sedimentary structures both laterally and vertically. For instance flute casts and tool marks are both formed through mass flow processes, and

are likely to be found in the same succession. In addition, if you find flute marks look for other evidence of mass flow deposits, such as the pattern of sedimentary structures typical of a Bouma Sequence. In some cases sedimentary structures can subtly change through the succession from one form to another. For instance in coastal successions, HCS is likely to change to SCS as the succession records conditions that represent water depths closer to fair - weather wave - base rather than storm wave - base.

8. Determine, by examining the nature of the contacts, which of the conventional four categories the sedimentary structure falls into: depositional, erosional, biogenic (e.g. trace fossils) or post - depositional.

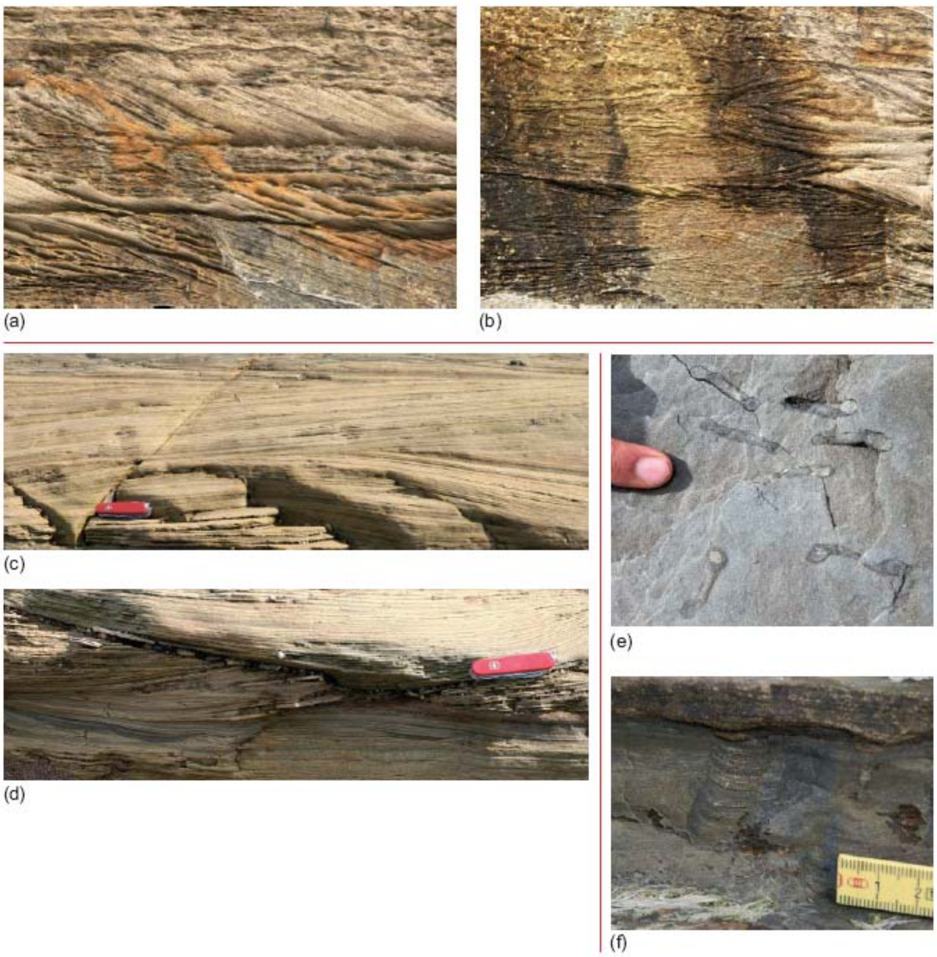


Figure 6.3 Paired photographs of sedimentary structures taken from orthogonal faces. (a) Cross-stratification. Note that from this one view it is impossible to tell whether it is trough or planar stratification. (b) This is from the same bed as (a) and shows distinct troughs indicating that (a) and (b) are part of a trough cross-stratified deposit. (c and d) Hummocky cross-stratification (HCS) showing that the structure is similar no matter which section is viewed. (e) *Diplocraterion* burrow showing the plan view of this vertical burrow. The circles are the top of the tubes and the lines joining them are the disrupted sediment in between. (f) Cross-section view showing the vertical U-tube and spreiten. This view is more typical of that illustrated in the literature. Figure 5.4 (p. 86) shows an idealized cross-sectional view of *Diplocraterion*. (a–f: Angela L. Coe, The Open University, UK.)

Table 6.2 Some of the common depositional sedimentary structures, bedforms (marked) and their process of formation. Note: cross-stratification refers to both cross-bedding and cross-lamination with no scale implication. Figure numbers prefixed with an A can be found in Appendix A6.

Sedimentary structure or bedform	Thickness or size	Features to observe	Processes
Lamination	Less than 1 cm	Continuity, variation, colour	Variation in composition or compaction
Bedding	1 cm to metres	Continuity, repetitions, thickness variation	Varying conditions
Grading	Variable	Normal or reverse, gradational or restricted	Waning or waxing currents
Wave-formed ripples (bedform)	cm	Three-dimensional. Climbing or not, associated with HCS or SCS or other structures	Waves
Current-formed ripples (bedform)	cm	Three-dimensional. Climbing or not, associated structures, palaeocurrent	Unidirectional currents
Impact ripples (bedform)	cm	Size, orientation	Aeolian
Lenticular bedding	cm	Wave- or current-formed ripples? Vertical changes and whether it is part of a fining- or coarsening-upward trend	Fluctuation between deposition from traction currents and settling from suspension
Flaser bedding	cm		
Dunes (bedform)	1–10s m	Shape of bedform	Wind and water
Current lineation	cm	Provides a direct measure of palaeocurrent. Check orientation with respect to other structures	Upper flow regime

Table 6.2 *Continued*

Sedimentary structure or bedform	Thickness or size	Features to observe	Processes
Planar lamination	mm to 1 cm	Continuity, nature (compositional or grain size), presence of current lineation	Traction currents from currents or waves (upper or lower flow regime)
Cross-lamination	Less than 1 cm	Sedimentary structure resulting from current- or wave-formed ripples. Examine continuity and observe whether ripples are climbing	Migration of wave- or current-formed ripples
Trough cross-stratification	cm to several metres	Observe in three dimensions to confirm identification; provides palaeocurrent direction	Migration of curved bedforms at particular speed and depth
Planar cross-stratification	cm to several metres	Observe in three dimensions to confirm identification; provides palaeocurrent direction	Migration of straight bedforms at particular speed and depth
Hummocky cross-stratification (HCS)	m (but smaller than SCS)	Structure should look the same in all cross-sections; plan view and cross-section show a 1 : 1 ratio of antiforms and synforms	Storm waves
Swaley cross-stratification (SCS)	m	Structure should look the same in all cross-sections; plan view and cross-section show mainly synforms	Fair-weather waves
Tidal bundles	cm	Note the orientation; look for associated tidal features (bi-directional cross-stratification, clay drapes) and consider possible tidal regime (diurnal or semi-diurnal)	Cross-stratification usually picked out by finer grained deposits with the cross-stratification surfaces in distinct groups of 7 that change from closely to widely spaced, representing neap and spring tide deposition respectively. Diagnostic of tidal currents
Desiccation cracks	cm	Look for evaporites, palaeosols and other evidence of subaerial exposure	Subaerial exposure
Pseudomorphs	cm	Geometrical shapes	Replacement of evaporite minerals after their dissolution

Table 6.3 Some of the common erosional sedimentary structures and their processes of formation. F numbers prefixed with an A can be found in Appendix A6.

Structure	Size	Features to observe	Processes
Flute casts	cm	Orientation provides palaeocurrent direction	Turbulent eddy of a turbidity current
Tool marks including groove casts	cm	Orientation of some provides palaeocurrent direction	Features produced by the erosion and entrainment of larger clasts by currents. The clasts are dragged, bounced or dropped on the surface. There are a wide range of structures from prod marks to grooves
Scours	m	Possible association with erosion surface	Erosion from currents or waves
Channels	10s m	Evidence for base-level fall; possible change from marine to fluvial or submarine incision	Large-scale erosion from flow
Gutter casts	5–10scm wide, length 10s m	Orientation provides palaeocurrent direction	Rip currents
Glacial striations	cm to m	Orientation shows direction of ice movement	Ice-sheet movement

Table 6.4 Some of the common early and late post-depositional sedimentary structures and their processes of formation. Figure numbers prefixed with an A can be found in Appendix A6.

Structure	Size	Features to observe	Processes
Early post-depositional structures			
Nodules (early diagenetic)	cm–m	Size, composition. Early diagenetic nodules are flattened ovoids and the laminae or bedding become gradually wider apart near the middle of the nodule. Check if multigenerational due to reworking	Changes in the pore-water chemistry a few decimetres to metres below the sediment–water interface
Deformed/convolute bedding	cm–m	Extent, any sense of movement direction, possible erosion	Unstable sediments due to angle of deposition, high sedimentation rate, change in pore-water pressure or earthquakes or other structural disturbance
Slumps and slides	cm–km		

Table 6.4 *Continued*

Structure	Size	Features to observe	Processes
Sandstone sills, dykes and mud volcanoes	m–km	Direction of extension, associated features, whether the infill sedimentary deposits are part of the 'normal' succession	Synsedimentary movement. Often found close to faults
Dish and pillar structures	cm	Small concave-up shapes. Look for other associated dewatering features	Water escape structures form where sedimentation rate is high and the underlying sediments have not had chance to compact before more sediment is laid down on top.
Load casts	cm	Look for other associated dewatering features	
Ball and pillow	cm	Other evidence of high sedimentation rate	
Late post-depositional structures			
Nodules (late diagenetic)	cm–m	Size, composition. Late diagenetic nodules have a high sphericity. They often preserve other sedimentary features	Change in pore-water chemistry 10s to 100s m below the sediment–water interface
Pressure solution structures (e.g. stylolites, cone-in-cone calcite)	cm–m	Extent laterally and vertically	Sediment compaction and movement of fluids. Presence depends on the chemistry of the sedimentary deposits and pore waters as well as the amount of pressure
Leisegang rings	m	Other evidence for diagensis	Late stage pore-fluid movement
Dendrites	cm		

6.3 Graphic logs

The preceding section should have provided you with the tools to start recording the features of individual units that make up sedimentary rock successions in the form of written notes and also sketches of both large - and small – scale features. However, the standard way to record and summarize data on sedimentary rock successions is by using a graphic log (e.g. Figure 6.4). This is an idealized and pictorial summary of each of the sedimentary rock units as they were laid down stratigraphically on top of each other and preserved.

Graphic logs have many advantages because they:

- are a succinct method of summarizing a lot of data;

- immediately give an impression of the vertical succession and can therefore aid in the identification of repetitions and major changes in the sedimentary facies;

- are a convenient way of testing and making correlations between sections of similar age from different places.

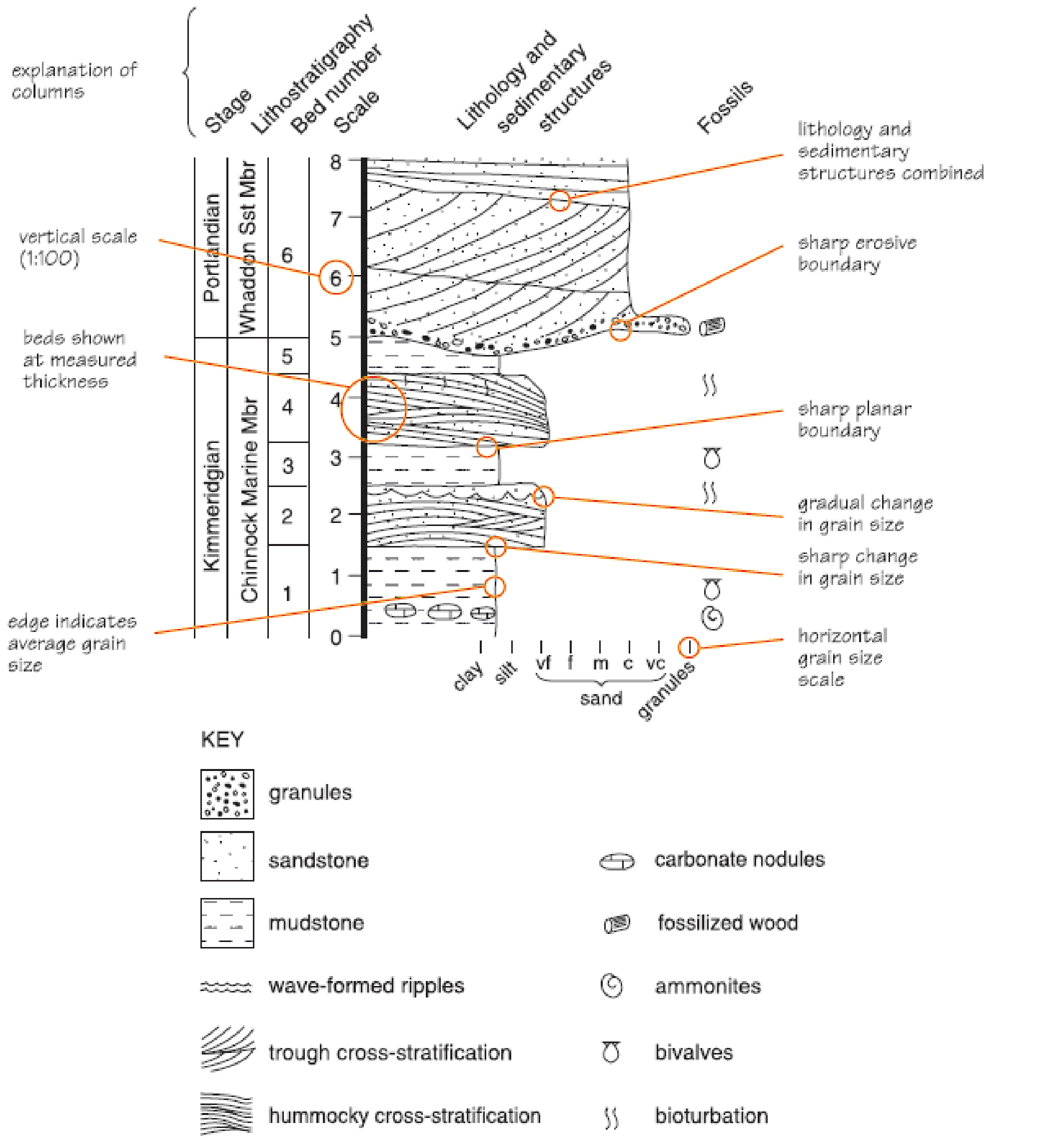


Figure 6.4 A neat version of a typical graphic log with some of the key features labelled. The field version should look very similar except it might not be drawn to scale vertically and there might be other columns with samples, photographs and links to more detailed notes on particular contacts and/or units. For examples of field

6.3.1 Conventions for graphic logs

The set conventions for recording graphic logs can be summarized as follows:

• *The vertical scale:* This represents cumulative thickness, above a particular datum on the exposure (distance above datum increases upwards) or in the case of a borehole core the depth down from the top (distance below datum increasing downwards).

• *The horizontal scale:* For siliciclastic deposits this always represents the average size of the grains, and by implication deposition from high - or low - velocity currents or suspension (Figure 6.5 a and b). Usually the grain size is shown increasing to the right. In the case of carbonate deposits the grain size is more complex because the size of the clasts is often a function of factors other than the energy (e.g. size of the biota producing the bioclasts or whether ooids or peloids or pisoliths are forming). Nevertheless the horizontal scale is based on decreasing amounts of carbonate mud towards the right (Figure 6.5 c).

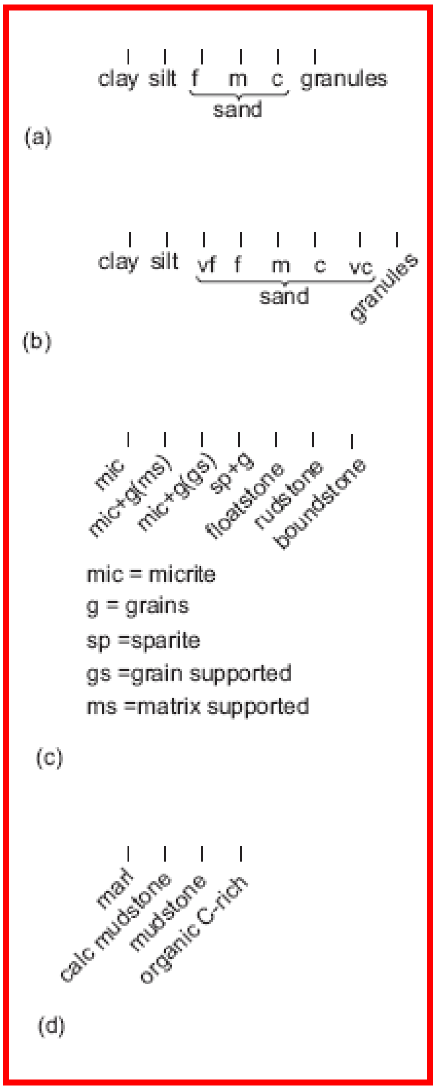


Figure 6.5 Variety of different grain-size scales. (a) Basic scale for siliciclastic rocks. (b) A more technically correct scale with each of the subdivisions representing a doubling in grain-size diameter for the sand subdivision (but this can be harder to distinguish in the field and does nc necessarily add that much more information). (c) Grain-size scale for carbonate rocks. (d) Potential subdivisions based on composition for mudstone successions. For mixed siliciclastic carbonate rocks both grain-size scales are often added to the graphic log.

• *Lithology:* The rock type is represented by particular ornaments, e.g. stipple for sandstone, bricks for limestone.

• *Sedimentary structures.* The sedimentary structures are represented either by very idealized symbols or by a sketch (to scale) of the structures as seen. The latter has the advantage of not having to identify the structure immediately and/or showing the particular geometry of the sedimentary structure in that succession. For instance, the typical thickness of the cross - stratification sets or the variation in angle can be shown.

• *Other information:* Other information includes the lithostratigraphic nomenclature, fossils, biostratigraphic zones, sample and photograph information, bed numbers, palaeocurrent data and sequence stratigraphy. These are usually put into columns adjacent to the main log with the information aligned horizontally with the particular level that it pertains to. These columns are usually ranked in a logical order, e.g. for lithostratigraphy: group name, formation name, member name and bed number. If the data you have collected need to be compared with those of previous studies this is often also shown in a summary format. It is a good idea to work out the correlation in the field where a variety of features are more obvious and different correlations can be tested. This is essential if you are relying on previous data sets for biostratigraphic or geochemical information.

• *Stratigraphic order:* The rock units should, if possible, be examined and recorded in the notebook in stratigraphic order, i.e. with the notes on the overlying unit above the unit it supersedes. This enables the contacts between the units to be depicted graphically. Sometimes in the field, because of particular conditions, it becomes necessary to log the youngest units first and work down through the stratigraphy. In this case the units should still be recorded in the correct stratigraphic order in the notebook; this is easily achieved by working down from the top of the notebook pages.

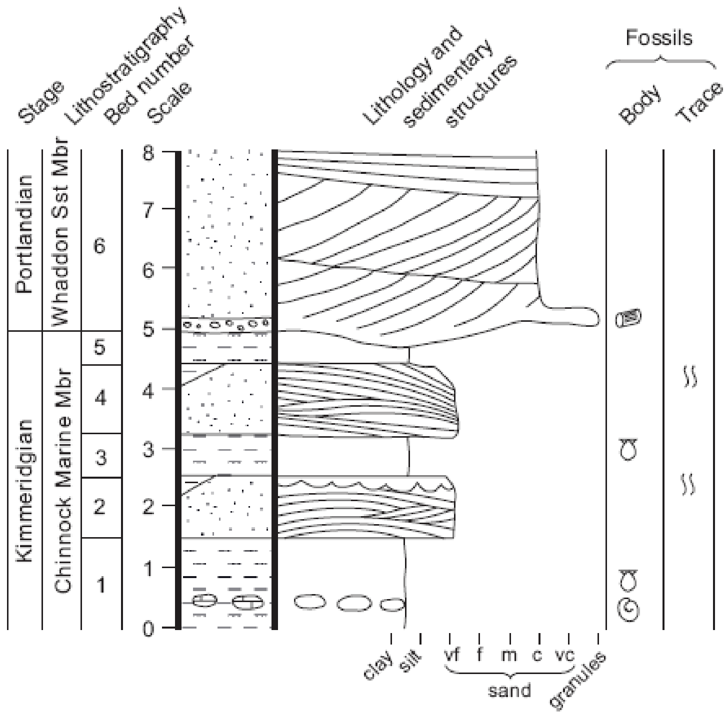


Figure 6.6 Same graphic log as Figure 6.4 but with the sedimentary structures and lithology in two separate columns.

6.3.2 Constructing a graphic log

1. Prepare your notebook or graphic logging sheet(s). Divide up the notebook page with vertical ruled lines, both to order the data systematically and to serve as a reminder for what data need to be collected. If necessary use two facing pages for all the different columns pertaining to one unit

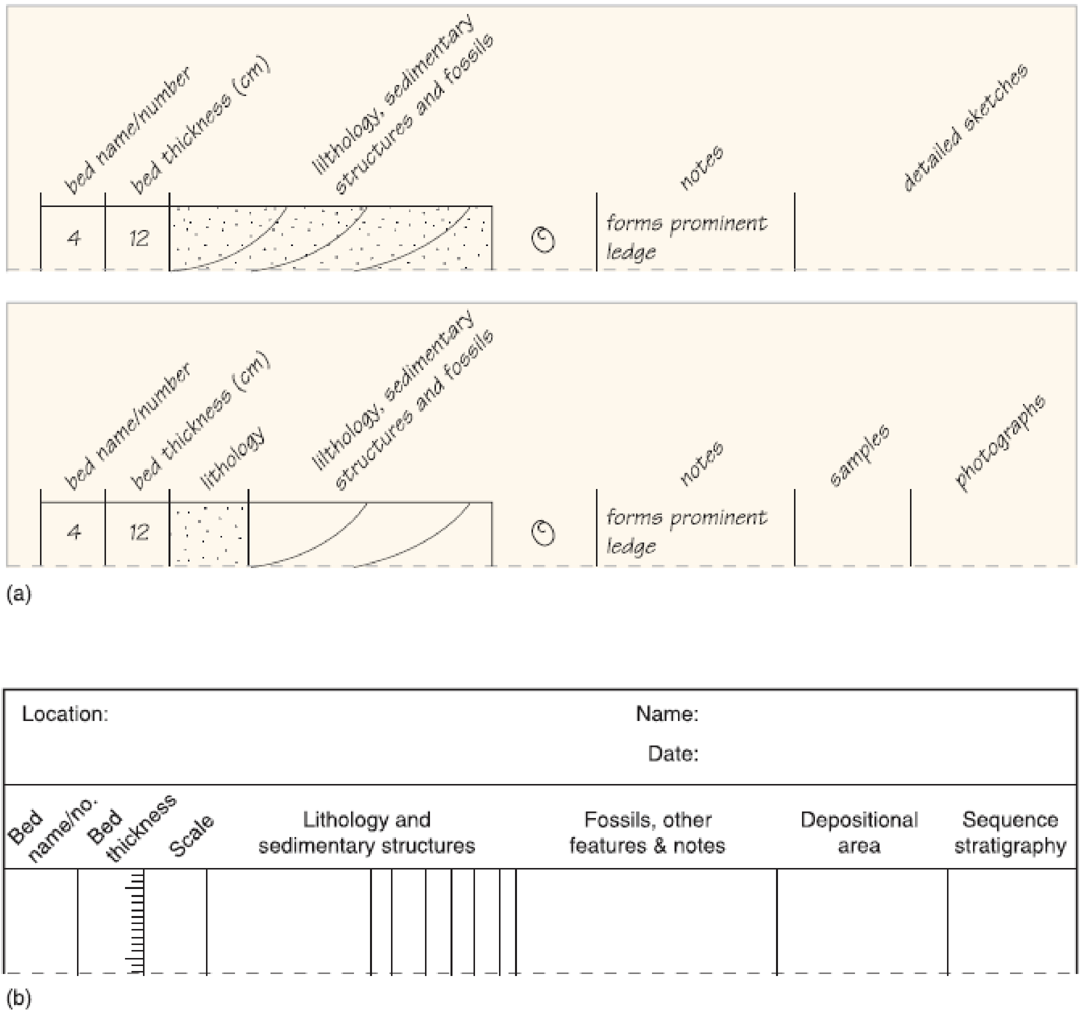


Figure 6.7 (a) Some options for notebook layout for graphic logging. (b) Header of an example graphic logging sheet.

2. <u>Decide on an appropriate vertical scale, taking into account the average and minimum thickness of the units to be logged, the total thickness of strata to be recorded</u>, the time available and the aim of the logging. Alternatively you could draw the log to a very rough scale in the field and then draw it to scale in the neat version. The advantages of not completing the log to scale in the field are that it allows you to put the details into very thin beds and to not take up too much space with thick beds that show few features; it is also much quicker. The disadvantage is that you do not have as good a visual record of the beds in the field.

3. Decide where exactly along the exposure you are going to make your measurements and observations. You need to ensure that you complete the logging somewhere that is representative, where you can access the stratigraphy safely and where beds are not covered by scree or vegetation. Many exposures are of dipping beds so it may be necessary to move along in order to examine all of the beds. As you construct your log you should note any major changes that occur laterally, for instance if one of the contacts is erosional and cuts out the underlying beds.

4. Record the nature of the boundary at the base of the section to be logged. Note whether it is gradational or sharp. If it is gradational record over what distance this occurs. You should also note whether the contact is planar or undulose. For undulose contacts the nature of the contact should be noted preferably in graphical form.

5. Decide where the upper boundary of the unit lies. The ‘ unit ’ is either a bed or set of beds depending on the nature of the succession and the scale of resolution required for the graphic log.

6. Measure the total thickness of the unit, ensuring that you measure perpendicular to the bedding surface.

7. Record the nature of the contact with the overlying unit.

8. Record the composition and sediment texture information (lithology) for the unit. Note any changes within the unit if that scale of resolution is required.

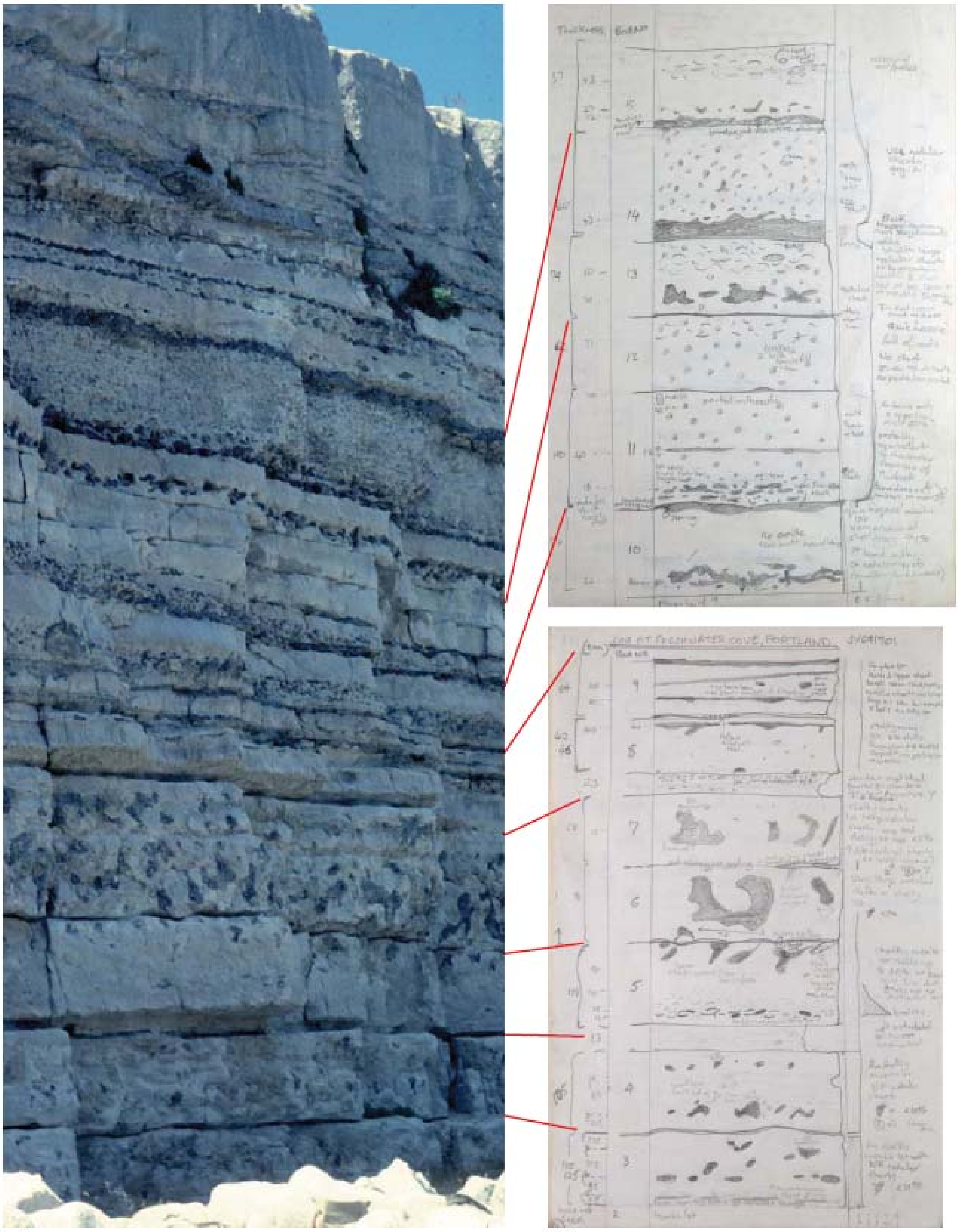
9. Record the sedimentary structures and fossils in that unit.

10. Record any samples or photographs taken.

11. Record any unusual features and/or topographic features that may help you relocate the unit.

12. Complete any correlation and comparison to previous work as necessary.

13. Repeat steps 5 to 13 for the next stratigraphically younger unit and so on, continuing on further pages of the notebook as necessary.



(a) (b)

Figure 6.9 Field data. (a) Photographs of part of the exposure at Freshwater Bay, Isle of Portland, UK. (b) Two pages of a field notebook showing part of the graphic log constructed in the field. Note that the field log is drawn only to an approximate scale. (a and b: Angela L. Coe, The Open University, UK.)

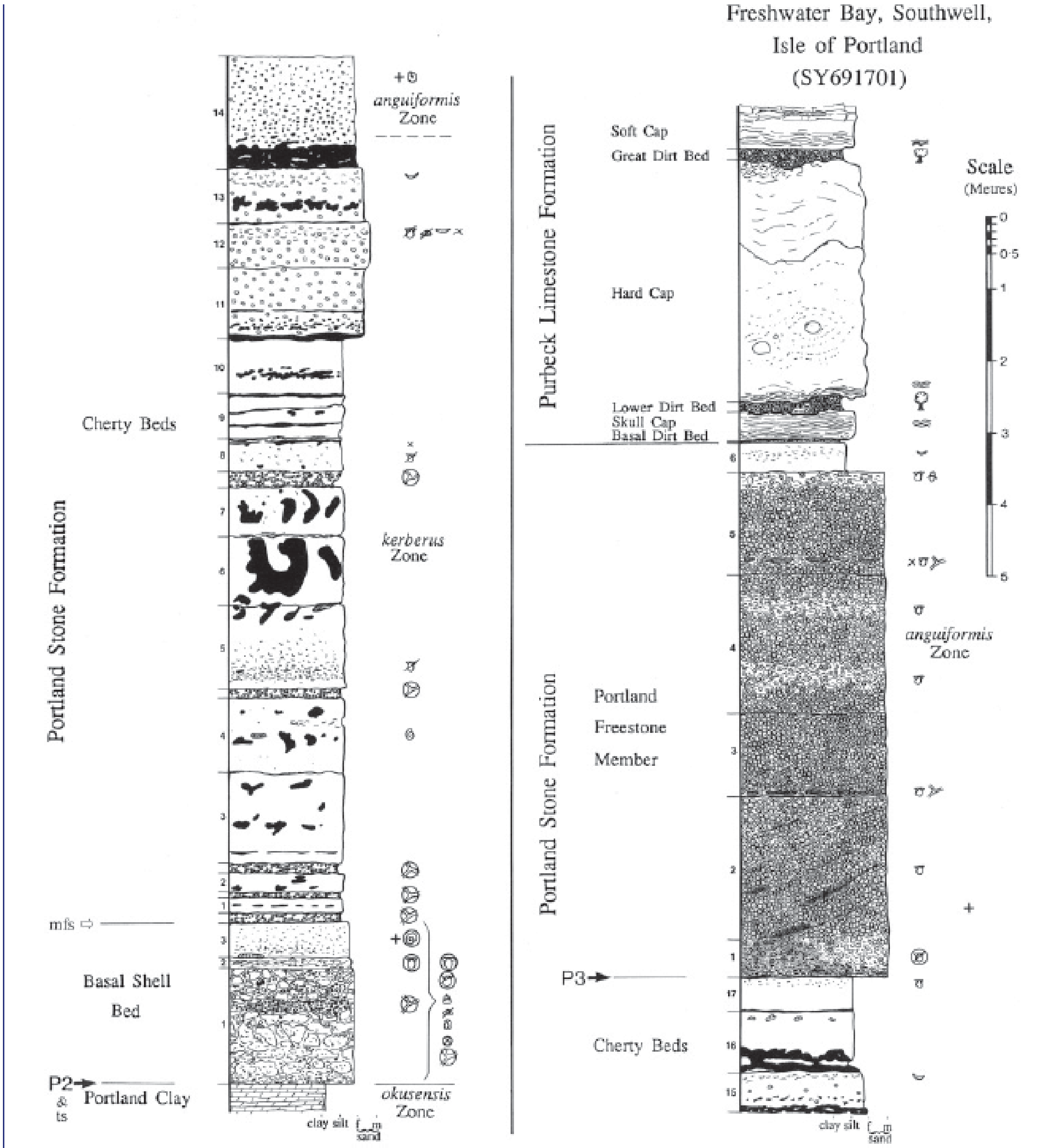


Figure 6.10 The published version of the graphic log from Freshwater Bay, Dorset including the data shown in Figure 6.9. (From Coe 1996.)

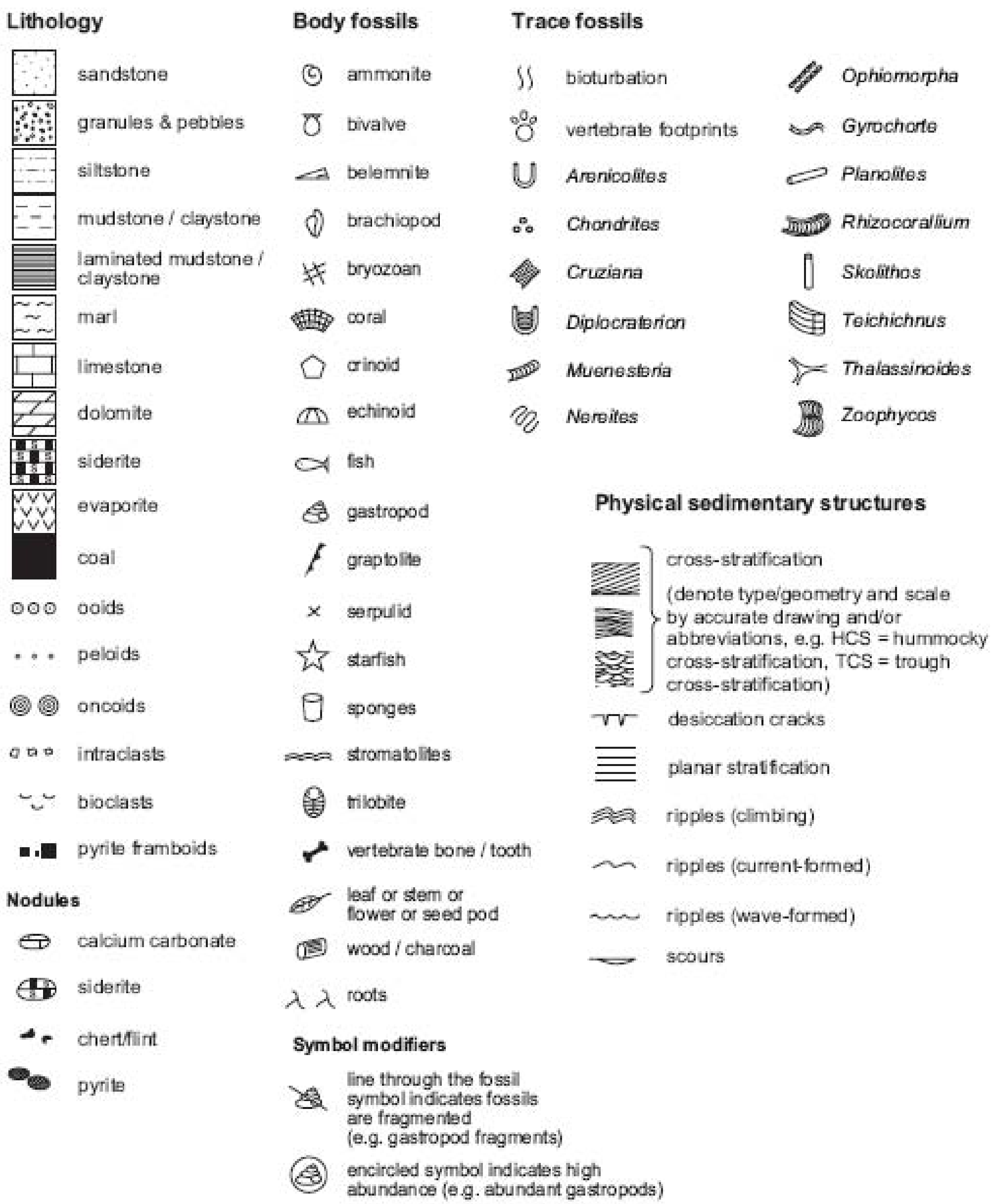


Figure A6.16 Some of the commonly used symbols for graphic logs and some ideas for other more specific features.

Key lithological log for study area