6 Recording features of sedimentary rocks and constructing graphic logs

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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.

Sedimentary rocks and the fossils they contain should always be considered together because, as 'smart particles' (Section 5.1), fossils provide vital clues on the processes and environment of deposition of the sedimentary deposits. Fossils, for instance, can provide immediate clues on whether the rocks are marine or non-marine, were deposited over a long or short period of time, what conditions were like on the sea or lake floor, as well as, in many instances, providing an immediate relative dating method.

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.* An

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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.)

understanding of where sedimentary rock types are situated in time and space, and how they vary vertically and laterally, enables the main reservoir rocks, seals and source rocks to be mapped out and fully exploited.

- *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, and that the oceans act like a large mixing pot, marine deposits are fundamental to understanding the Earth system in the past. The sedimentary deposits in caves and lakes also form a key part in the understanding of palaeoenvironmental change over about the past 2 Ma. Reconstructing sea-level change relies on examining and correlating both proximal and distal marine successions and looking for both gradual and abrupt changes in the type of sedimentary deposit.

- *Understand and exploit sedimentary building materials and mineral deposits.* Sedimentary rocks form important building materials. Sandstones and limestones are relatively easy to extract and shape because the natural bedding planes can be used to create blocks. Limestones are needed for cement production and agricultural uses, while mudstones are the raw component for bricks.
- *Refine the geological timescale.* The more continuous nature of the sedimentary record compared with that of igneous and metamorphic rocks, together with its fossil content, makes it important for the construction of the geological timescale. The sedimentary record is used for biostratigraphy, constructing magnetic polarity patterns, identification of Milankovitch and other regular cycles, radiometric dating of interbedded volcanic ashes, some direct radiometric dating (e.g. ^{14}C, U series and Re–Os isotope) and chemostratigraphy, all of which contribute a major part of the composite geological timescale.

In addition to the basic geological equipment (Table 2.1, p. 4), it is useful for the study of sedimentary rocks to also have some of the optional equipment listed in Table 2.3 (p. 6). In particular, ensure that you have a comparison chart for identifying grain size, shape, rounding and sorting (see also Appendix A6). A Munsell colour chart is useful if you are recording rocks where there is a significance to the variation in colour, or, where colour is the main distinguishing feature. A 1 lb (*c.* 0.5 kg) geological hammer and a cold chisel are usually sufficient to collect samples.

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 (Appendix A6, Table A6.2); (2) the texture of the rock; (3) the sedimentary structures; and (4) the fossils within them. Composition and texture are taken together as lithology (Section 6.2.1), sedimentary structures are covered in Section 6.2.2 and the recording of fossils was covered in Chapter 5.

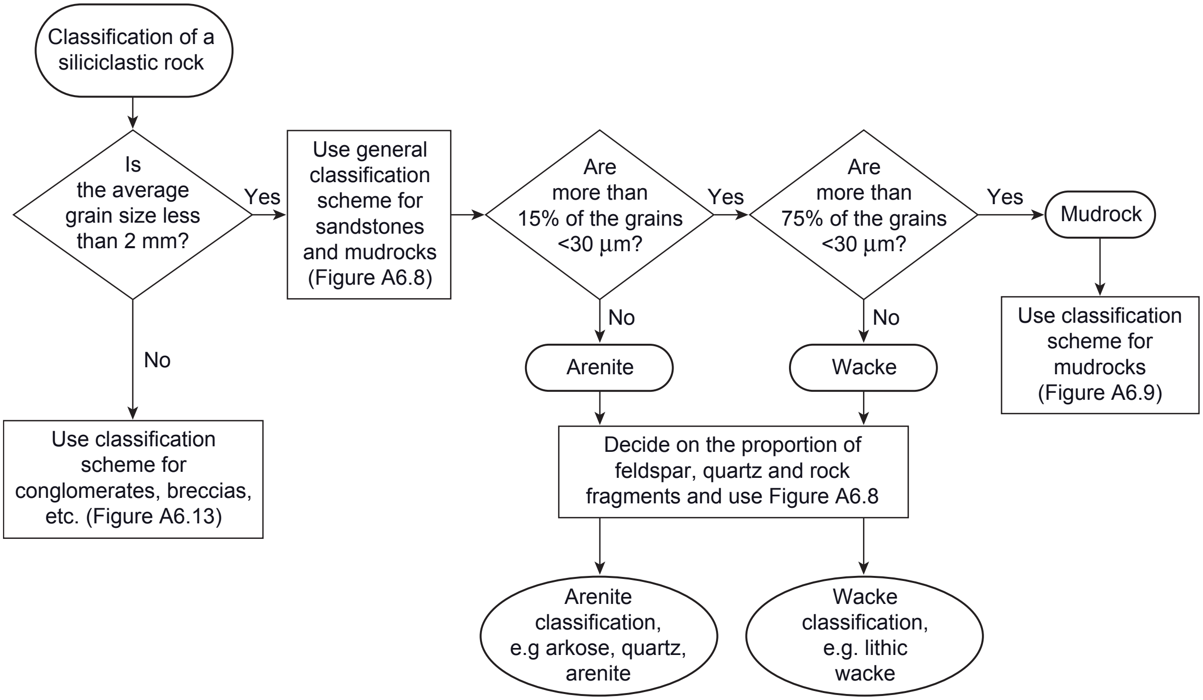
6.2.1 Recording sedimentary lithology

Assuming that the sedimentary section under study is divided into units (Section 3.2.2), the next task is to describe and classify the sedimentary rock type of the unit under consideration. Classifying sedimentary deposits provides an approximate quantification of the rock components and therefore information on the depositional process, sediment source and environmental conditions. Use the following items in Appendix A6 to describe and classify the rocks: checklist (Table A6.1), table of properties of common minerals in sedimentary rocks (Table A6.2), textures (Figures A6.1–A6.4) and rock classification charts (Figures A6.11–A6.13).

To test for small amounts of quartz sand or silt in sedimentary rocks you can grind a small amount of rock between your front teeth. The quartz is gritty and impossible to break whereas siliciclastic clay minerals or carbonate become a fine-grained powder that feels like a smooth paste.

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. The general siliciclastic classification process is illustrated in the following flowchart:



Mudrock (synonomous with mudstone) and coarse-grained siliciclastic rocks can be subdivided further than shown in Figure A6.6 and require slightly different observations than siltstones and sandstones. These features are covered in the following two subsections.

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. Carbonate mudrock with negligible siliciclastic content are covered by the carbonate classification schemes. Figure A6.9 provides a general classification scheme for siliciclastic mudrocks that is applicable to most successions. However, in some instances it may be necessary to devise a classification based on the particular succession that you are examining and the major components within it. To do this, decide what the major components are (e.g. clay minerals, carbonate, phosphate and silica) both visually and, if you are on a return visit, through chemical analysis completed before you return to the field. Then, using these results devise a classification scheme based on the average percentages of each component that it is possible to detect in the field. Listed below are some useful common features of mudrocks to look for in the field. As with all geological observations, use several different lines of evidence to form your interpretation. The features listed below are particularly useful for mudrocks:

Wet rocks, particularly mudrocks, are usually darker (have a lower value; Figure 2.17) than dry rocks. However, the moisture content tends not to alter the hue or chroma. If the colour is critical record either wet or dry rocks and avoid areas that are weathered.

- *Colour:* As for other sedimentary rocks this primarily reflects composition. Most marine mudrocks are various shades of grey. Use a Munsell colour chart and/or carry small rock chips of each of the major colours identified in the succession for comparison. 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 (Figure 2.17d). 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.

Mudrocks rich in marine organic matter that have been buried and moderately heated, such as most Mesozoic strata, have a distinct bituminous smell when they are freshly broken. Those with a very high organic-carbon content are very light in weight due to their lower density.

- *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 (e.g. Figure 2.19b).

(a) (b)

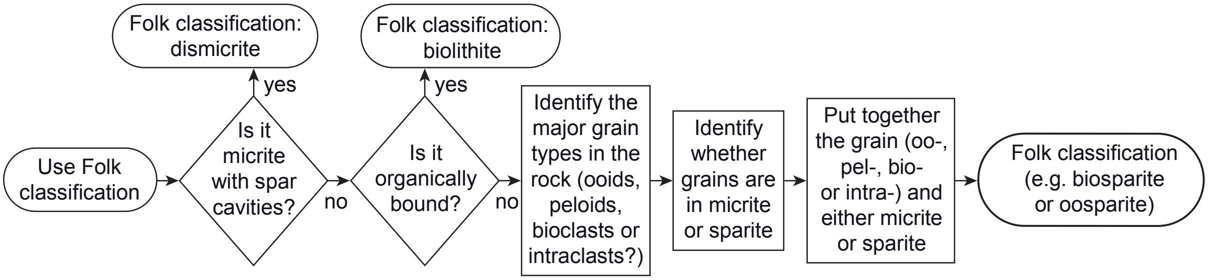
Figure 6.2 (a) Blocky fracture pattern of a siliciclastic mudrock mainly composed of clay minerals. (b) Conchoidal fracture pattern of a mudrock with a significant proportion of carbonate. (a and b: Angela L. Coe, The Open University, UK.)

Conglomerates and breccias

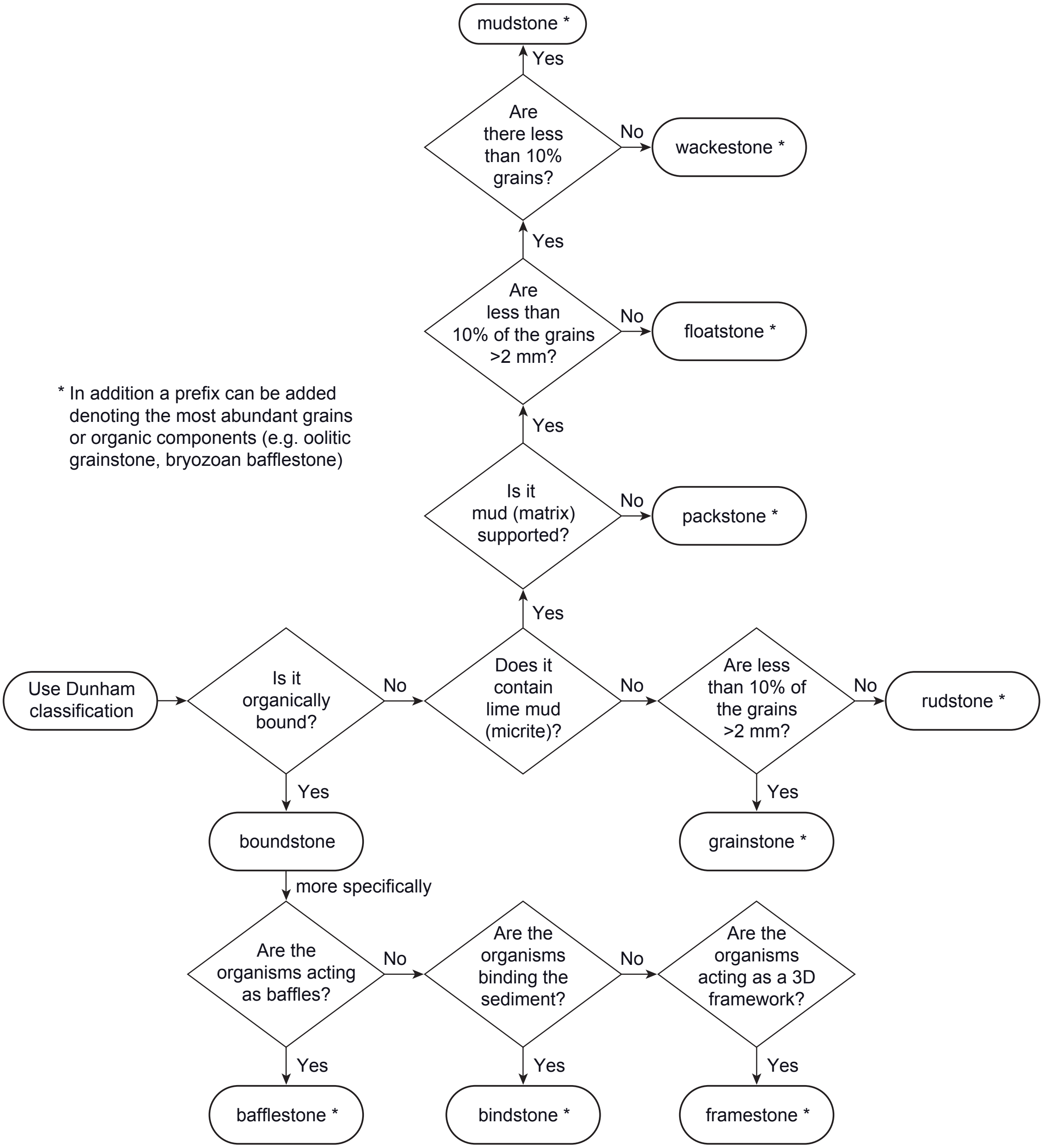
Conglomerates and breccias can be classified according to clast type and matrix properties (Figure A6.13). In complete contrast to mudrocks a 'wide angle' view of these coarse-grained sedimentary deposits is required to obtain representative data because of the potential large-scale variation. The quadrat method is useful for assessing and recording coarse-grained sedimentary deposits (Sections 3.3 and 5.4.2). A quadrat of 0.5 to 1 m square is appropriate for most deposits.

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 (Appendix A6, Figures A6.11 and A6.12). In both cases it is necessary to decide first of all whether the grains are bound together organically (i.e. whether it is a bioherm (reef)) or not). The Folk classification scheme (Figure A6.11) is easier to use; it is based on the nature of the grains and whether these are within matrix or cement. The use of this classification scheme is illustrated by the following flowchart:



In contrast, the Dunham classification scheme (Figure A6.12) 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:



* In addition a prefix can be added denoting the most abundant grains or organic components (e.g. oolitic grainstone, bryozoan bafflestone)

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 and similar to that of royal icing.
- *Siderite:* This is most easily distinguished by its distinctive yellow-red colour (terracotta); it forms both bands and nodules, particularly in mudrock successions.

There is no well-established classification scheme for mixed siliciclastic/carbonate successions and a combination of the various classification schemes is typically used. The type of sediment, together with its depositional environment, governs the synsedimentary and post-sedimentary structures, and influences the preservation of associated features such as fossils. The common features of each sedimentary rock type to look for are summarized in Table 6.1 (pp. 110–111).

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 (Section 6.6). 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.

Sedimentary structures provide very direct clues about the processes responsible for deposition of a sedimentary rock, and the processes that occur after its deposition. In a number of cases they even provide specific information on the depositional setting, e.g. hummocky cross-stratification (HCS) is diagnostic of the offshore transition zone, which lies between fair-weather wave-base and storm wave-base, whereas swaley cross-stratification (SCS) forms close to fair-weather wave-base in the shoreface zone.

In the field you are likely to see structures that you don't understand; this may be because they are unusual, poorly developed, poorly preserved or exposed at a strange angle. So don't worry if you can't identify every sedimentary structure you see – this is not unusual. If you find something you don't understand, search uround for other, possibly better/more revealing examples, preferably in the same unit but also in adjacent units. Then spend more time on the best examples first, returning to the more enigmatic ones later if there is time.

Table 6.1 Sedimentary rock types and the sedimentary structures and features that they are commonly associated with. Section 6.2.2 considers sedimentary structures more fully.

Sedimentary rock type	**Depositional features and sedimentary structures**	**Post-depositional features and sedimentary structures**	**Commonly associated features**
Claystones, mudrocks and marls	*Lamination*: millimetre-scale compositional variation giving fine-scale rock banding *Fissility*: rock breaks easily into thin sheets parallel to bedding (may be related to lamination) *Colour*: change in colour represents compositional variation, particularly iron minerals, organic matter and carbonate content *Fracture pattern*: reflects compositional variation (see above) *Weathering profile*: mudstones with a higher calcium carbonate content tend to stick out as they are often more resistant to weathering. Similarly, those with a high organic-carbon content tend to weather proud. When mudrocks are interbedded with sandstones or carbonates the mudrocks always weather back.	*Nodules*: form below the sediment–water interface under particular geochemical conditions. Early diagenetic carbonate nodules can be used to help calculate the amount of compaction. In some successions they nucleate on fossils *Cone-in-cone calcite*: calcite crystals that grow in cones perpendicular to the pressure during overpressuring of mudrocks *Soft sediment deformation features*: common for high sedimentation rate interbedded mudrocks and sandstones due to density contrast of fresh sediment (mud holds *c.* 80% water whereas sand holds *c.* 50%)	*Fossils*: the low energy of deposition, fine-grained and non-porous nature of mudrocks tends to be excellent for fossil preservation, both mega- and microfossils. Trace fossils are easy to detect if there is a colour change and the fine detail is often well preserved. *Pyrite*: this is often associated with euxinic (free H_2S in the water column) depositional conditions *Organic matter*: marine and terrestrial, which influences colour and can influence lamination. It indicates high productivity and/or suitable preservation conditions (e.g. anoxia)
Siltstones and sandstones	*Sedimentary structures*: there is a wide range (see Section 6.2.2), many of which indicate the processes of deposition	*Nodules*: as above. Late diagenetic nodules are more common *Liesegang rings*: lines of iron concentration that form as later fluids move through the rock. Can appear at first glance to be sedimentary structures	*Fossils*: often present but can be reworked under the high-energy conditions of deposition
Carbonates (non-organically bound)	*Sedimentary structures*: there is a wide range (see Section 6.2.2), many of which indicate the processes of deposition	*Stylolites and other pressure solution features*: carbonates are susceptible to dissolution. Reprecipitation can enhance, mask or destroy primary features *Cementation*: the soluble nature of carbonates makes carbonates particularly susceptible to cementation	*Fossils*: bioclasts are important in many carbonates and provide valuable information on the site and conditions of deposition

Table 6.1 *Continued*

Sedimentary rock type	Depositional features and sedimentary structures	Post-depositional features and sedimentary structures	Commonly associated features
Carbonates (organically bound)	*Sedimentary structures*: often massive with distinct vertical relief. Usually closely associated with horizontally bedded units representing the lagoon and steeply inclined chaotic beds representing the bioherm debris	As carbonate (non-organically bound above)	*Fossils*: by definition these are *in situ* and can provide much information about the environment and palaeoecology
Conglomerates and breccias	*Clast types*: identify the rock types of the clasts, which gives a good indication of the source and sometimes the depositional processes *Sedimentary structures*: cross-stratification, bedding, etc. (see Section 6.2.2)	Compaction of matrix around clasts and cementation	*Fossils*: only the robust large megafossils such as vertebrate remains and large pieces of fossilized wood tend to survive intact
Coal	*Colour and shininess*: indicates type of organic matter and/or clay content (see also Appendix A6, Table A6.3)	Check for an underlying palaeosol that would indicate the coal is *in situ* and not derived. The coal itself may be interbedded with other sedimentary deposits	*Pyrite*: associated with high sulfur content Carbonate nodules in coals can preserve plant remains
Evaporites	Note distribution within sedimentary deposits and crystal shape. Large crystals and fibrous ones are recrystallized	Dissolution and reprecipitation common. Complete dissolution is quite common	Faults and folds due to the ductile nature of evaporites and their high solubility Associated with shallow-water deposits, particularly carbonates
Ironstones, cherts and phosphates	*Colour*: can reflect compositional variation and in the case of phosphates the amount of reworking (pink/buff when a precipitate, grey/brown and black when reworked)	*Banding*: these deposits are susceptible to dissolution and reprecipitation so the banding may be entirely post-depositional	Phosphates are indicative of high productivity areas. The silica for the chert may come from diatoms, radiolaria or sponge spicules. These indicate a wide range of depositional conditions so determining the origin of the silica is important

When recording and describing sedimentary structures try to view and record them in all three orthogonal faces if possible in order to help in their identification.

If you don't find other examples, take a photograph and make some notes so that you can show it to other geologists and/or compare it with other examples in the literature, but don't waste a lot of time on it.

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 (see first part of Worked Example 6.3).
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

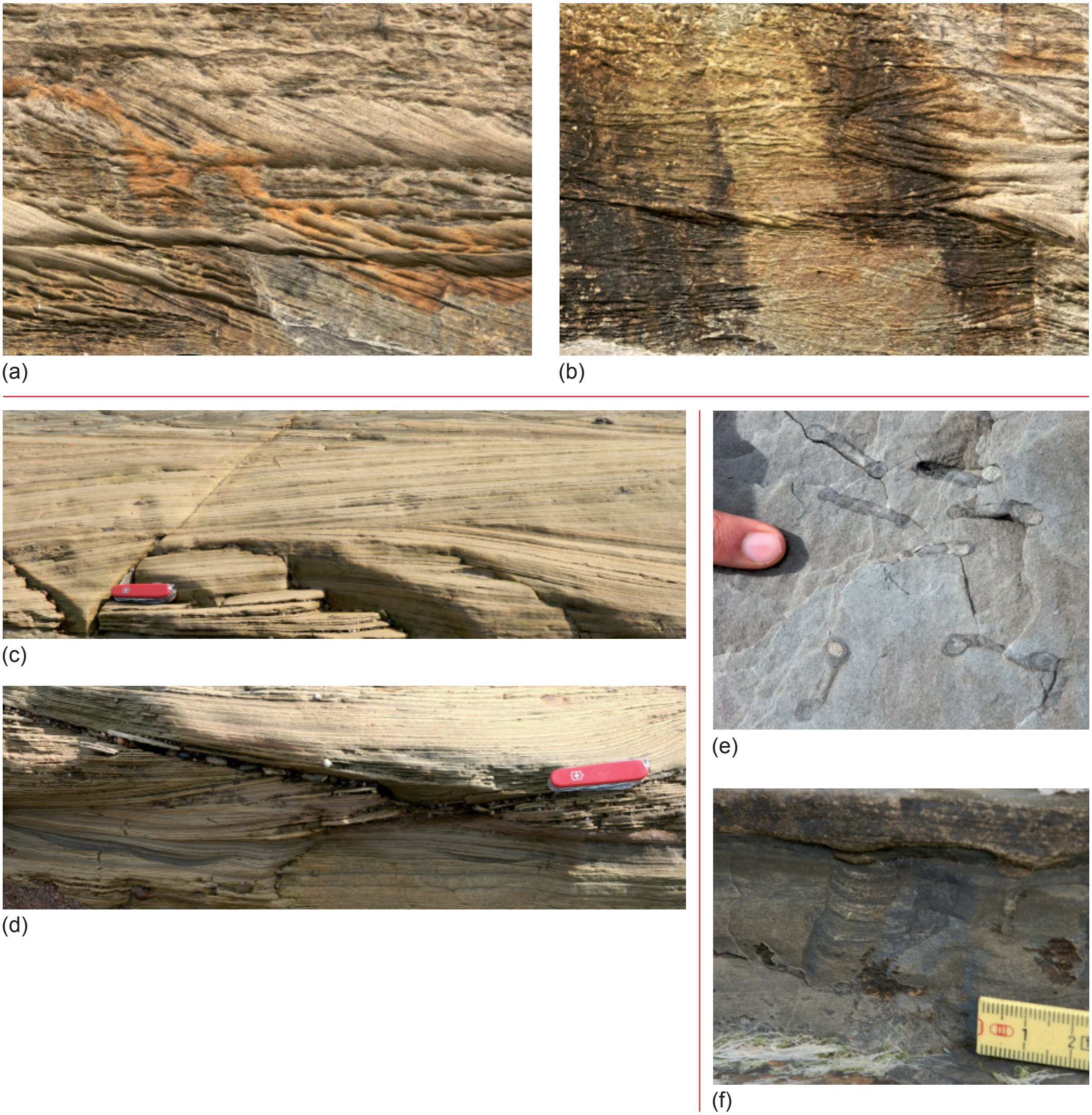


Figure 6.3 Paired photographs of sedimentary structures taken from orthogonal faces. (a) Cross-stratification. Note that from this one view it is impossible to tell whether it is trough or planar stratification. (b) This is from the same bed as (a) and shows distinct troughs indicating that (a) and (b) 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.)

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. Biogenic structures of both plant and animal origin are covered in Chapter 5 and Appendix A5. If the structure is post-depositional, and you are interested only in the depositional sedimentary structures, then you can ignore it. Tables 6.2–6.4 summarize the common depositional, erosional and post-depositional sedimentary structures and bedforms respectively.

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	Figure/Table
Lamination	Less than 1 cm	Continuity, variation, colour	Variation in composition or compaction	2.19b, 12.1, 12.2, 13.2b
Bedding	1 cm to metres	Continuity, repetitions, thickness variation	Varying conditions	3.1, 6.2b, 6.15, 6.16
Grading	Variable	Normal or reverse, gradational or restricted	Waning or waxing currents	A6.17s,t
Wave-formed ripples (bedform)	cm	Three-dimensional. Climbing or not, associated with HCS or SCS or other structures	Waves	6.1, A6.17k,l,m, Table A6.4
Current-formed ripples (bedform)	cm	Three-dimensional. Climbing or not, associated structures, palaeocurrent	Unidirectional currents	A6.17i,j, Table A6.4
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	A6.17
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	2.9, A6.17r

Table 6.2 *Continued*

Sedimentary structure or bedform	Thickness or size	Features to observe	Processes	Figure/Table
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)	A6.17q
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	6.1, A6.17j,l,o
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	6.3a,b, A6.17c,d
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	6.11b, A6.17a,b
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	6.3c,d, A6.17e,f
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	A6.17g,h
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	A6.17p
Desiccation cracks	cm	Look for evaporites, palaeosols and other evidence of subaerial exposure	Subaerial exposure	A6.17u
Pseudomorphs	cm	Geometrical shapes	Replacement of evaporite minerals after their dissolution	A6.17v

Table 6.3 Some of the common erosional 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	Figure
Flute casts	cm	Orientation provides palaeocurrent direction	Turbulent eddy of a turbidity current	A6.17y
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	A6.17x
Scours	m	Possible association with erosion surface	Erosion from currents or waves	A6.17w
Channels	10s m	Evidence for base-level fall; possible change from marine to fluvial or submarine incision	Large-scale erosion from flow	3.1b, 4.5, 6.12
Gutter casts	5–10s cm wide, length 10s m	Orientation provides palaeocurrent direction	Rip currents	6.12f
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	Figure
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	6.2a, A6.17z,aa
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	A6.17gg
Slumps and slides	cm–km			–

Table 6.4 *Continued*

Structure	Size	Features to observe	Processes	Figure
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.	A6.17dd,ff
Load casts	cm	Look for other associated dewatering features		A6.17cc
Ball and pillow	cm	Other evidence of high sedimentation rate		A6.17dd,ff
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	A6.17bb
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	8.5
Leisegang rings	m	Other evidence for diagensis	Late stage pore-fluid movement	A6.17hh
Dendrites	cm			A6.17hh

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, p. 118). 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.

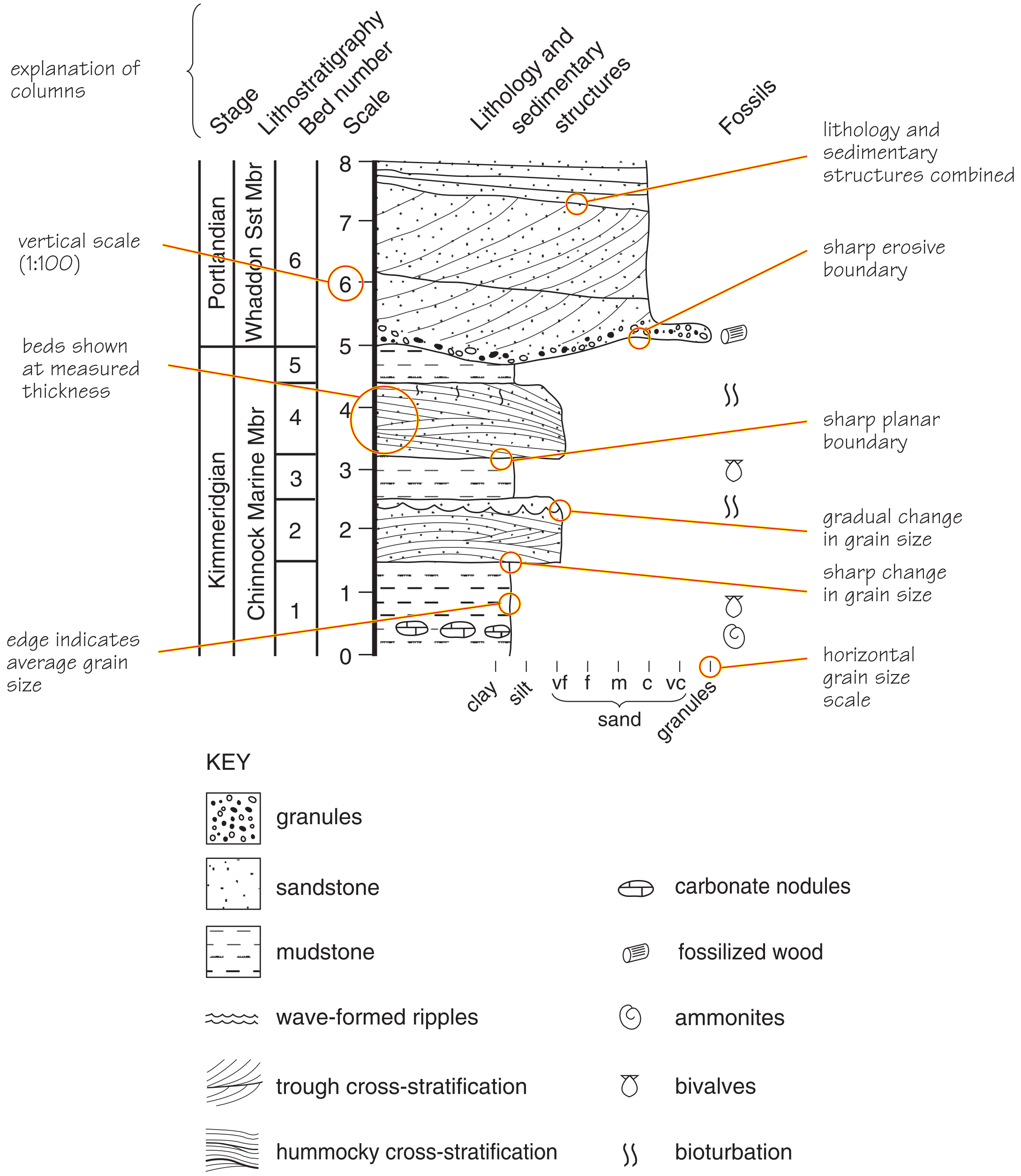


Figure 6.4 A neat version of a typical graphic log with some of the key features labelled. The field version should look very similar except it might not be drawn to scale vertically and there might be other columns with samples, photographs and links to more detailed notes on particular contacts and/or units. For examples of field graphic logs see Figures 4.2b, 5.10, 6.9b, 6.11 and the book cover.

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.

There are many variations on the style in graphic logs, with authors tending to develop a format according to the overall objectives and personal style. There are, however, several set conventions that are generally followed and these are discussed in Section 6.3.1 before some of the common types of graphic log and different conventions are illustrated. Section 6.3.2 explains the stages in constructing a graphic log.

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). Graphic logs can represent successions that range from centimetres to hundreds of metres depending on the scale of observation. The scale factor also varies. It is usual to choose a scale factor that is easy to work with, e.g. 1 m of rock = 1 cm on paper (1 : 100) or 10 m of rock = 2 cm on paper (1 : 500).
- *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 6.5a 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 6.5c).
- *Lithology:* The rock type is represented by particular ornaments, e.g. stipple for sandstone, bricks for limestone.

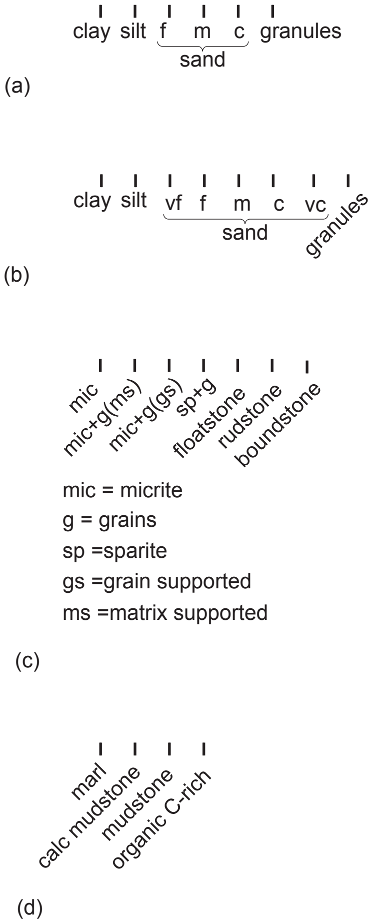


Figure 6.5 Variety of different grain-size scales. (a) Basic scale for siliciclastic rocks. (b) A more technically correct scale with each of the subdivisions representing a doubling in grain-size diameter for the sand subdivision (but this can be harder to distinguish in the field and does not necessarily 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.

For the less common rock types, e.g. ironstones and evaporites, the ornament used may vary slightly. Some of the commonly used symbols for graphic logs are shown in Appendix A6, Figure A6.16.

- *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.

Variations on the conventions for graphic logs

The common variations on the main conventions are:

- using the same or separate columns for the lithology and sedimentary structures – exactly the same information from Figure 6.4 is represented in a split column format in Figure 6.6;
- where the succession is mainly or entirely composed of carbonates, omitting the brick symbol used for carbonates (e.g. Figure 6.10, p. 126);

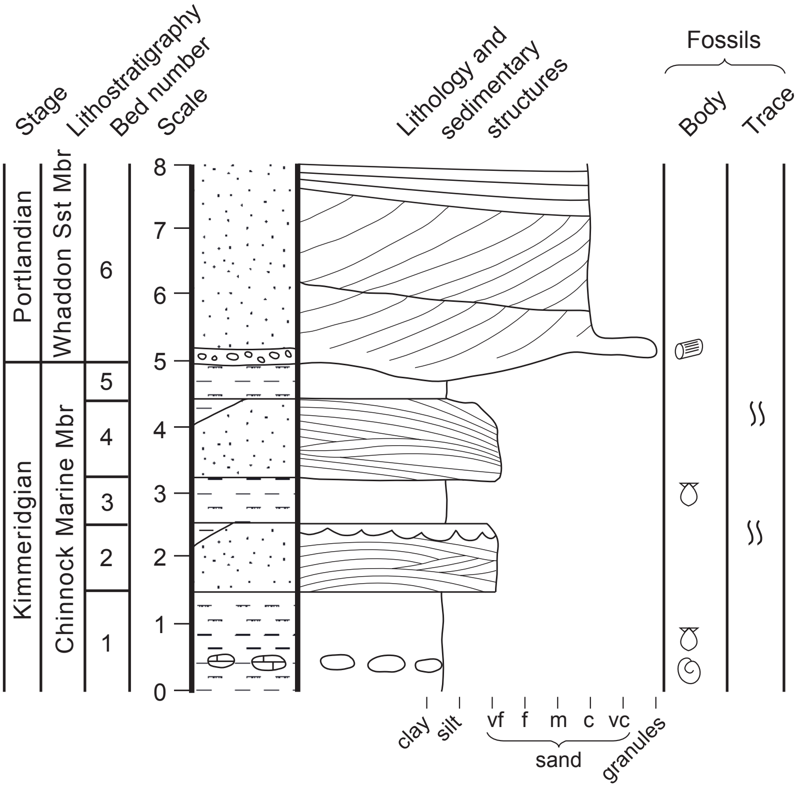


Figure 6.6 Same graphic log as Figure 6.4 but with the sedimentary structures and lithology in two separate columns.

- sedimentary structures are shown as idealized symbols only;
- note that colour is usually used on graphic logs only when it is one of the main defining characteristics (e.g. in a mudrock succession) or for visual purposes for oral presentations.
- completing the graphic log on a pre-formatted graphic logging sheet or directly into a field notebook (Section 6.3.2).

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. There are various options for the format according to personal preference; some examples are shown in Figure 6.7a (p. 122). Some people use preformatted graphic logging sheets (e.g. Figure 6.7b). If logging sheets are put onto standard quality paper the paper and large size of the sheet can be susceptible to damage under poor weather

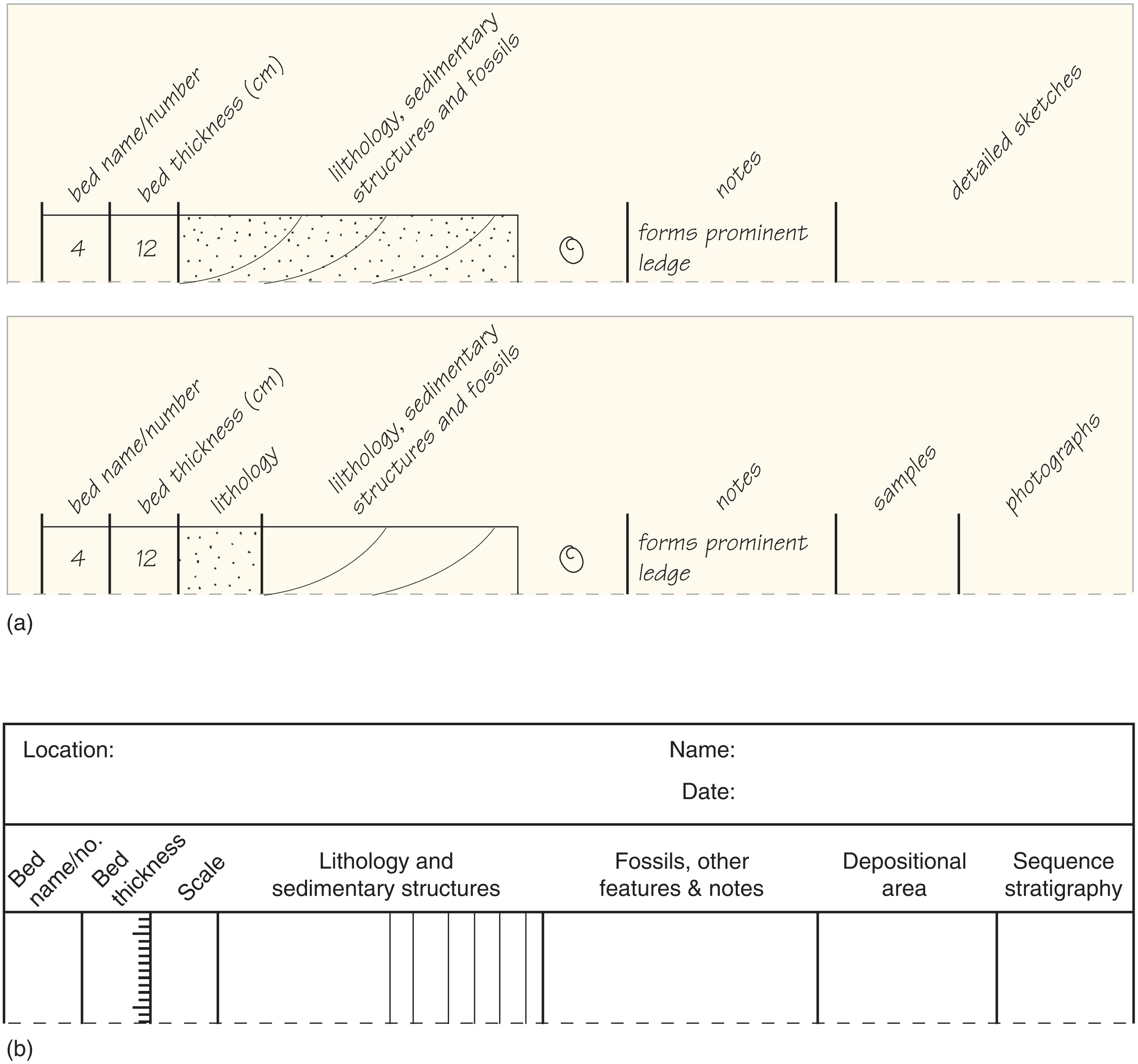


Figure 6.7 (a) Some options for notebook layout for graphic logging. (b) Header of an example graphic logging sheet.

conditions. There is more chance of losing one of a set of loose-leaf sheets than a notebook. Logging sheets are, however, particularly useful and extensively used for logging core (e.g. International Ocean Drilling Program (IODP) legs and petroleum companies), where they are easier to handle and the standard sheet ensures that different authors record the same type of information.

2. 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, 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.

For any units or boundaries that are laterally variable or show a number of different features, use a sketch along with the graphic log to show the lateral variation or particular features (e.g. Figures 6.8 and 4.3c). Worked Example 6.1 shows an example of how the graphical logging technique was used to record a sedimentary succession.

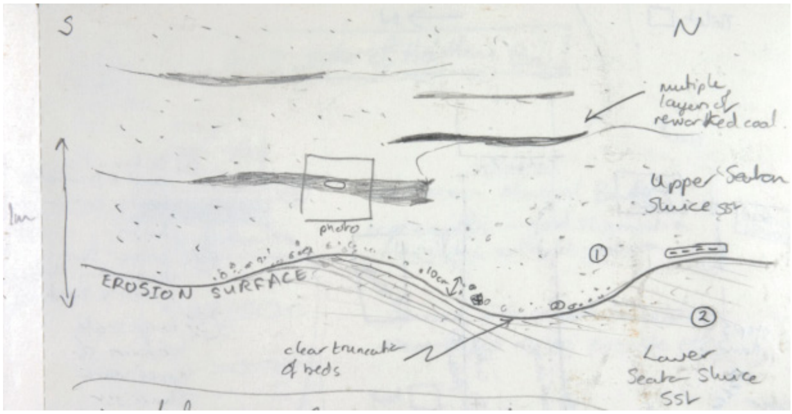


Figure 6.8 Sketch of an erosion surface in the Carboniferous, Northumberland showing the large-scale topography on the surface and details of the laterally variable units above and below. (Notebook of Angela L. Coe, The Open University, UK.)

Worked Example 6.1 Construction of a graphic log of a shallow-water carbonate succession

Figures 6.9 and 6.10 show photographs and the field and published version of a graphic log that was compiled to summarize the features of the Portland Beds at Freshwater Bay, Isle of Portland, Dorset, UK. This work was completed as part of a basin-wide study of the depositional history and sequence stratigraphy of the Portland Beds within the Wessex Basin, southern England. The graphic log in Figure 6.10 is one of a set that was constructed along a proximal to distal basin profile. Thin-sections were cut from the samples taken and these were used to confirm and supplement field observations. A facies model for the main depocentre was also constructed using many sections. Note that the black chert nodules that have formed around *Thalassinoides* burrows are drawn roughly to scale so that the beds can be easily recognized (Figure 6.9). There are notes on the occurrence of ooids; these change through the succession and because of their shallow-water origin they are significant for the sequence stratigraphic interpretation. The thin beds are drawn relatively thickly in the notebook so that there is space for the details.

All of the ammonite biostratigraphic information was compiled from the literature. Particular note was taken of stratigraphic gaps evident from both the sedimentology and the biostratigraphy. The facies and the stratigraphic gaps were used to construct a sequence stratigraphic interpretation (Section 6.5.1). The surface marked P2 (Figure 6.10) is a sequence boundary that corresponds to an incised fluvial valley cut into marine deposits on the basin margins and is therefore interpreted as a forced regression. Surface P3 is also a sequence boundary associated with more minor marine incision.

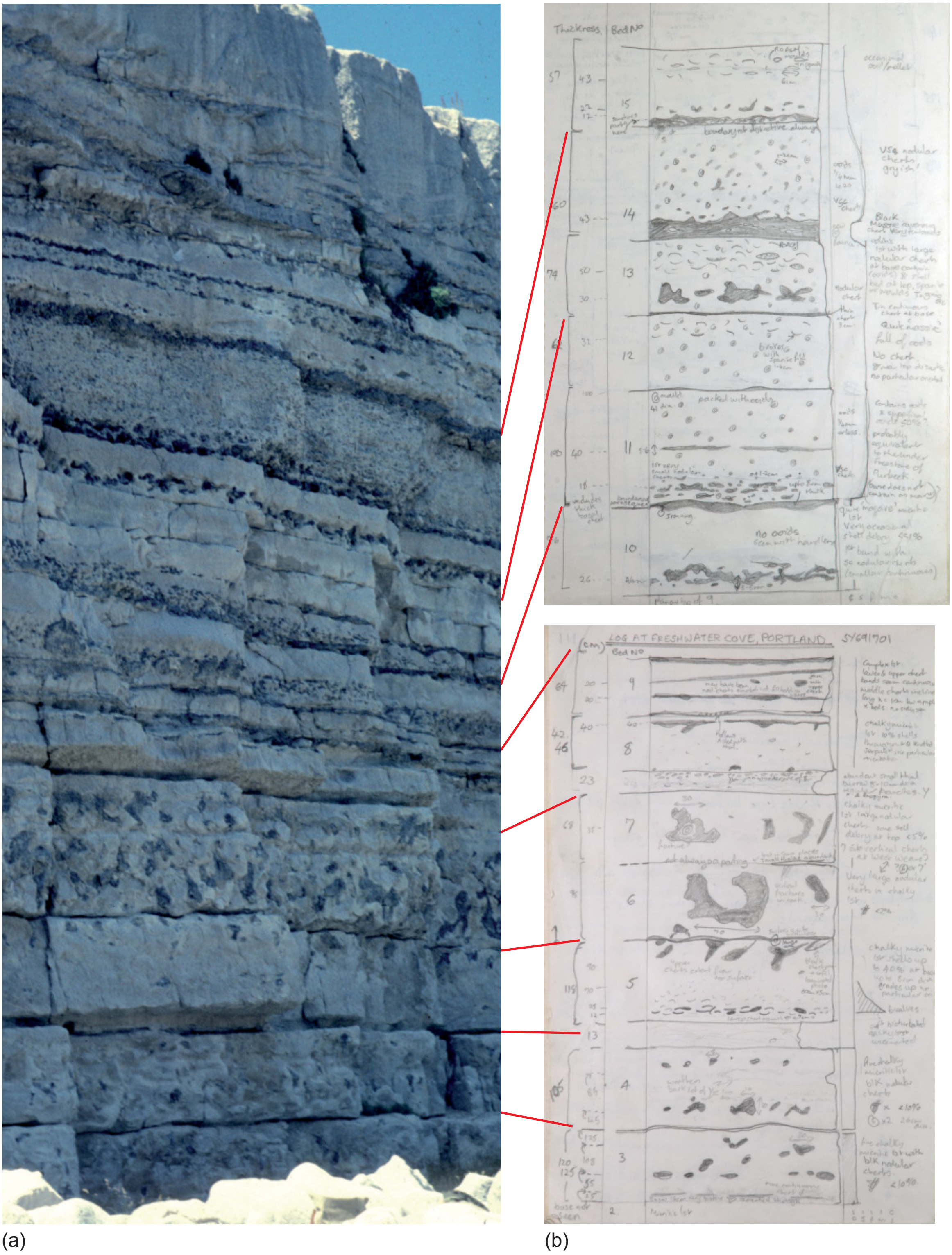


Figure 6.9 Field data. (a) Photographs of part of the exposure at Freshwater Bay, Isle of Portland, UK. (b) Two pages of a field notebook showing part of the graphic log constructed in the field. Note that the field log is drawn only to an approximate scale. (a and b: Angela L. Coe, The Open University,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

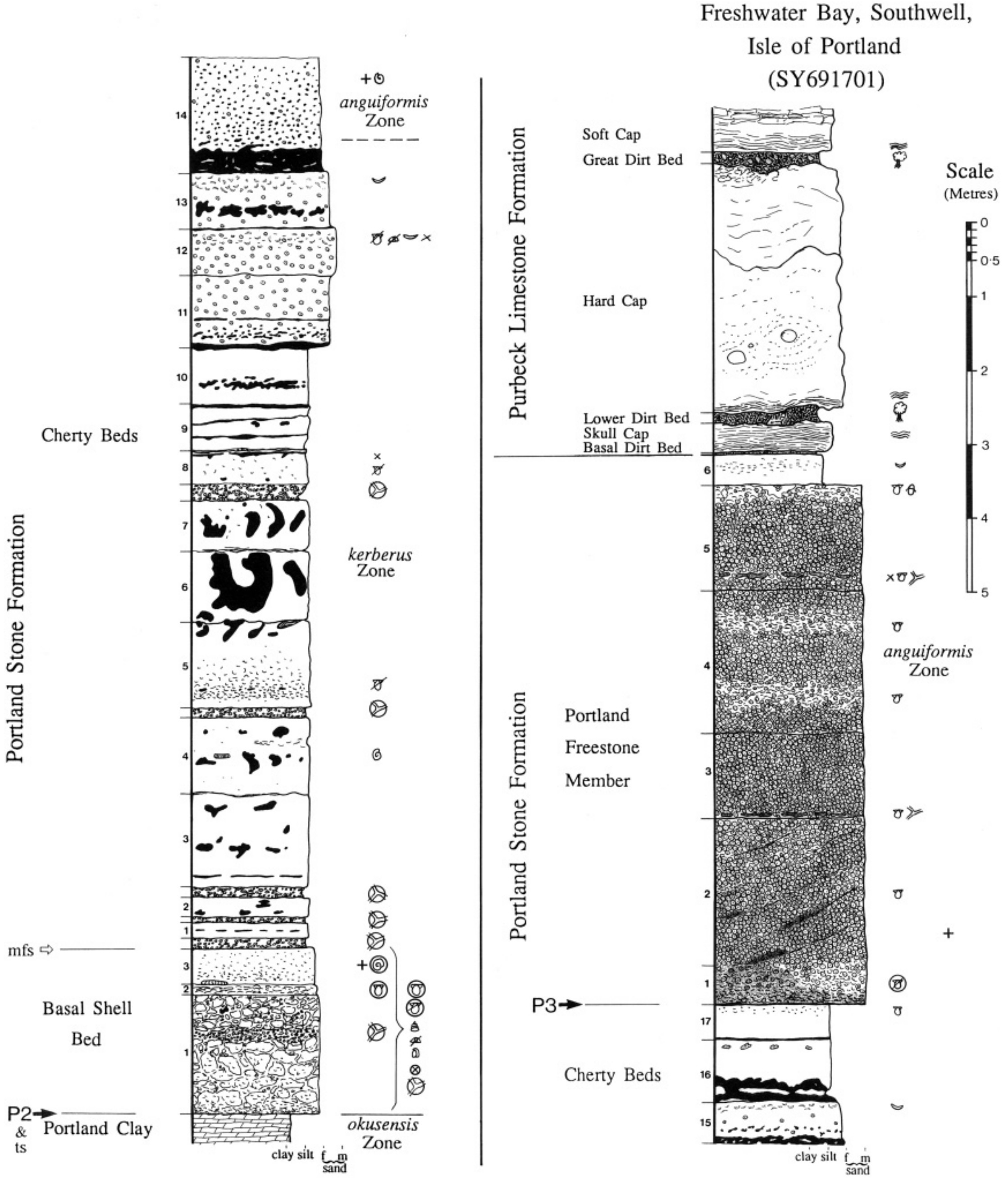


Figure 6.10 The published version of the graphic log from Freshwater Bay, Dorset including the data shown in Figure 6.9. (From Coe 1996.)

6.4 Rocks in space: Reconstructing sedimentary environments and their diagnostic features

A set of graphic logs in proximal and distal locations, together with sketches and other information, can be used to record and interpret the depositional environment(s) of the strata. The graphic logs should provide a summary of features to allow division of the succession into sedimentary facies (i.e. rock bodies with similar composition, texture, fossils and sedimentary structures that represent a particular set of processes and depositional conditions). Using Walther's Law, and knowledge of the different parts of depositional environments and the processes within them, the facies can be grouped together into architectural elements or facies associations. The construction of facies associations is particularly appropriate for depositional environments where there are large lateral changes, such as within a fluvial system. The elements of completing such a study are illustrated in Worked Example 6.2 (pp. 130–133).

For pilot projects, broad-scale regional studies or simply if time is short, generalized graphic logs recording the main sedimentary features to an approximate scale can be useful (e.g. Figure 6.11, p. 128). The advantage of this is that it is fast, allowing time to visit more locations and gain a better overview.

The benefit of carrying out facies analysis is that the facies patterns are then predictable and can be used to assess reservoir and source rock potential. In addition facies models underpin the interpretation of changes in relative sea-level, the establishment of stratigraphic gaps and can add to interpretation of long timescale changes in the climate, palaeolatitude and altitude.

Fine-grained hemipelagic and pelagic carbonate and siliciclastic successions tend not to vary for hundreds of metres or kilometres. Usually with this type of succession, because the variation in facies is so small, there is no need to define facies associations. The visual differences between facies in the field are often very subtle, but may well reflect large changes in parameters such as run-off, temperature and productivity.

In summary, facies analysis needs to consider the following.

- Is the area chosen for the graphic log and facies analysis representative?
- Are sections along a proximal to distal profile available (basin centre and basin margin)?
- Do the facies obey Walther's Law or not?

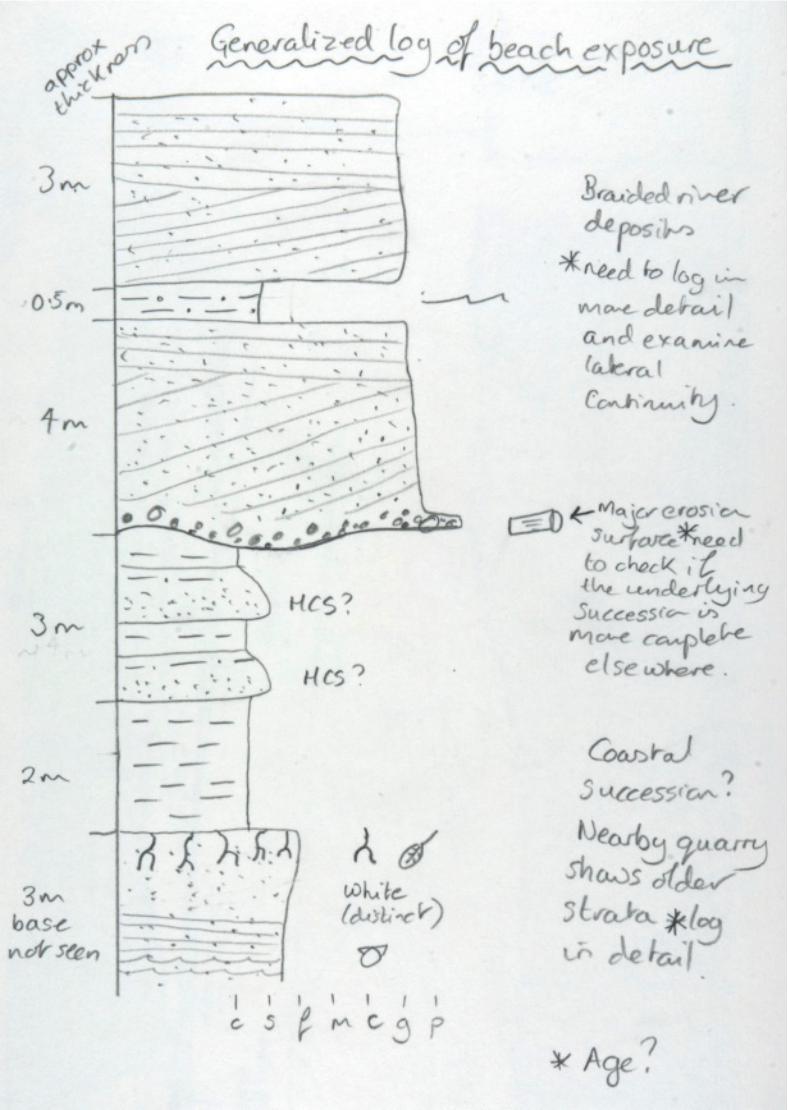


Figure 6.11 Example of a generalized graphic log from a field notebook incorporating, in part, the beds shown in Figures 6.4 and 6.6. (Angela L. Coe, The Open University, UK.)

- Are there key sedimentary structures and fossils that indicate relative water depth and/or processes of deposition (e.g. hummocky cross-stratification, non-marine fauna)?
- Are there any repetitions?
- Are there any large-scale features (e.g. river channels, intrabasinal highs, depocentres next to synsedimentary faults)?
- Is there lateral continuity of the facies and is the method of correlation robust?

A description of the typical facies in the range of possible sedimentary environments is beyond the scope of this book. A good summary is provided by Stow (2005) and most textbooks on sedimentology (e.g. Section 6.6). Table 6.5 provides a list of some of the clues to look for when trying to decipher the depositional environment. The most robust interpretation comes from a wide range of evidence and no one set of observations should be taken in isolation. In addition, for coastal environments Appendix A6, Figure A6.14 shows the dominance of different processes and resulting variation in morphology.

Table 6.5 Summary of some of the processes/features and the sedimentary environments that they might represent. In all cases it is the combination of different lines of evidence that will help to determine the depositional environment.

Processes/ features	Possible environments
Water currents (current-formed ripples, cross-stratification, etc.)	Fluvial, lacustrine or marine
Waves (ripples, HCS, SCS, etc.)	Large standing body of water, i.e. large lake or the sea. Consider: lacustrine or marine environments (high water mark to wave base)
Large-scale cross-stratification	Aeolian, alluvial or movement of sand on the continental shelf or within an inlet by tides
Tidal features (e.g. mud-draped ripples, tidal bundles)	Marine environments near the coastline
Low diversity/brackish fauna	Restricted lagoon or estuary or coastal embayment
High diversity marine fauna	Shallow marine (or possible deep-marine condensed succession). Consider strandplain or delta or barrier island
Mainly or totally pelagic fauna	Deep marine (unless there is another factor to exclude benthic organisms such as evidence for anoxic conditions)
Abundance of fossilized plant remains	Delta or fluvial or possibly lacustrine
Numerous coals	Delta or aggrading fluvial system
Extensive evaporite deposits	Carbonate platform or lacustrine or aeolian
Fine-grained, laterally continuous beds over 100s km	Deep marine; pelagic/hemipelagic or large-scale lacustrine
Mass gravity features	Alluvial fan or submarine fan but also consider synsedimentary faulting and/or steep slopes such as at the edge of a carbonate platform
Wind features (frosted grains, large-scale high-angle cross-stratification, impact ripples)	Aeolian (but if the evidence is not laterally extensive consider backshore)
Cyclic successions	Any environment, but less likely to be regular in fluvial and aeolian
Turbidites	Anywhere in water where there is a slope of more than a few degrees. If they are extensive and associated with other deep-marine features and mass flow deposits, possible submarine fan. Carbonate turbidites will form off the edge of the carbonate platform due to the vertical build-up of reefs, etc.

Table 6.5 *Continued*

Processes/ features	Possible environments
Ooids, peloids, abundant bioclasts or bioherm/biostrome	Part of a carbonate platform. Consider position and distribution of different facies to determine the type of carbonate platform (ramp, rimmed shelf, isolated, etc.)
Sedimentary deposits of highly variable composition	Consider submarine and alluvial fans, glacial environments
Ice features (e.g. dropstones, glacial striations, hummocks, eskers)	Glacial environments
Large-scale lensoid sand bodies encased in fine-grained deposits	Meandering fluvial system or part of a submarine fan complex

Worked Example 6.2 Meandering river depositional environment: Burniston, Yorkshire, UK

Figure 6.12 shows the interbedded mudstones and sandstones exposed near Burniston, Yorkshire, UK. These sedimentary rocks form part of the Long Nab Member and are Middle Jurassic in age. The sea-cliffs and foreshore together provide an opportunity to record the three-dimensional nature of these laterally variable sedimentary deposits. Many publications have been written on these deposits and the material presented here shows only some of the findings. The research that was conducted on these deposits was of particular interest not only for understanding the architecture of a meandering river system, but also because it provided an analogue for petroleum reservoir rocks in the North Sea, offshore UK.

The deposits at this exposure require a combination of different techniques because of their variable nature. These include the construction of sets of graphic logs with the positions of the logs carefully chosen so that they recorded the overall variability, mapping of the geometry of the sandstone bodies using aerial photographs of the foreshore at low tide (Figure 6.13) and sketching the geometry of the sand bodies. From these observations a facies model could be constructed (Figure 6.14).

Figure 6.12a illustrates a typical view of these (and other) meandering river deposits with a lensoid sandstone body (the river channel fill) encased in floodplain mudstones. The sand to clay ratio will vary with the energy of the river, sediment source and its proximity to the centre of the channel. Figure 6.12b shows a tabular cross-stratified quartz arenite that is interpreted to have been deposited as a subaqueous sand bar near the centre of the fluvial channel. Figures 6.12c and 6.12d show the lensoid point bar that is laterally equivalent to this channel sand bar. The succession also contains thin, fairly laterally continuous, sandstones with rootlets (Figures 6.12e). This distinctly different sandstone facies represents crevasse-splay deposits. Some of these sandstones have gutter casts at the base (Figure 6.12f) from which palaeocurrent measurements could be taken to ascertain the orientation of the channel. Figure 6.12g shows an abandoned channel filled with plant-rich mudstones. It probably represents the sediment fill of a small ox-bow lake.

In addition to the sedimentological interest the low-energy overbank environment provided ideal conditions for the preservation of plant fossils. Plant fossils from these deposites have been used to reconstruct the Jurassic vegetation at that time and to gain an understanding of the climatic regime (Figure 5.14, p. 98).

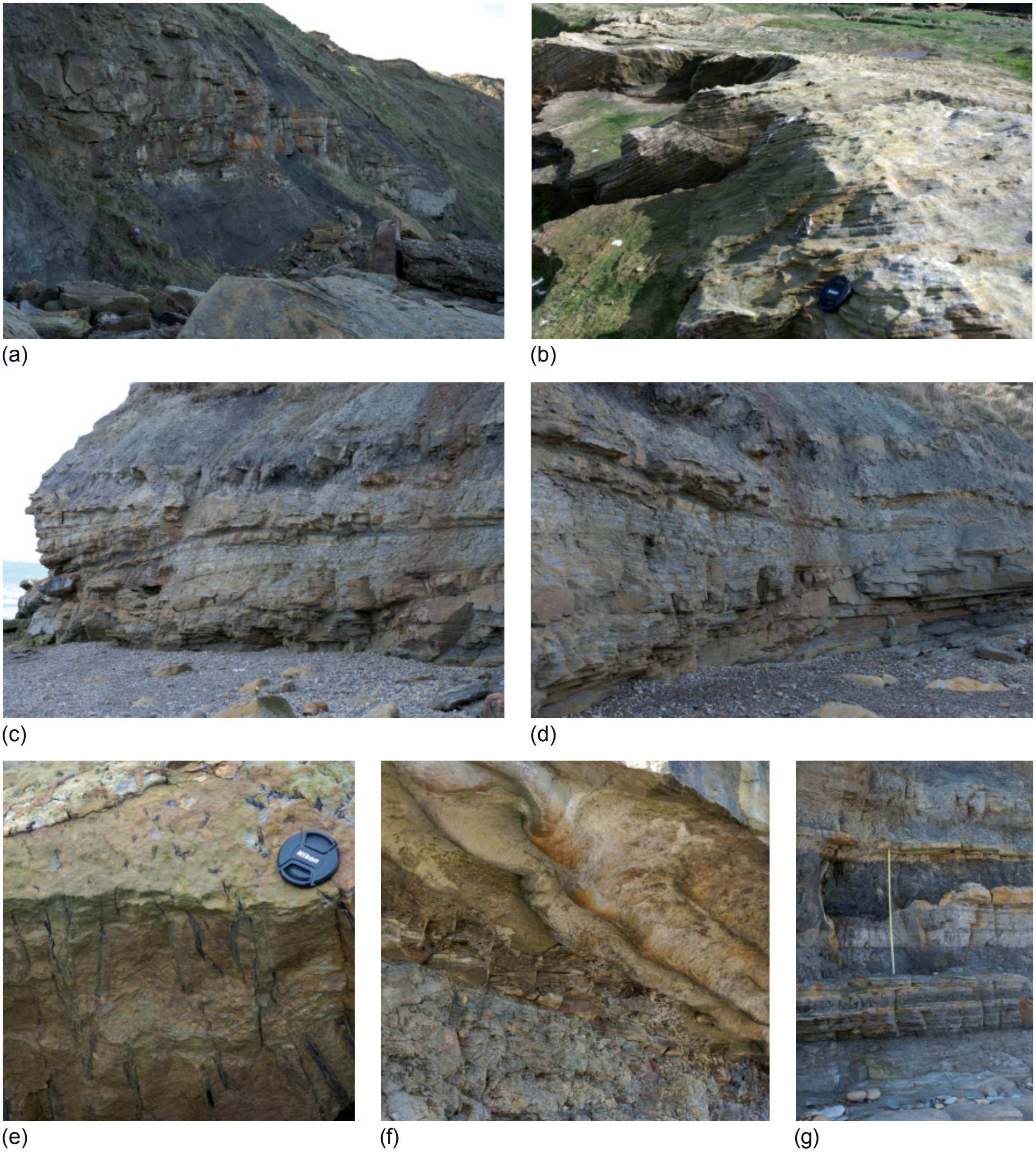


Figure 6.12 Photographs of the exposure near Burniston, Yorkshire, UK, showing the highly variable nature of the deposits. (a) General overview showing a channel sand body encased in floodplain mudstones. (b) Trough cross-stratified clean sandstones of the river channel. (c and d) Cross-cutting nature of a point bar. (e) Roots in a crevasse-splay sandstone facies. (f) Gutter casts at the base of the crevasse-splay sandstone. (g) Interbedded mudstones and sandstones interpreted as overbank deposits and crevasse splays. The dark-grey bed is a plant-rich mudstone interpreted as an ox-bow lake sediment plug. (a–g: Angela L. Coe, The Open University, UK.)

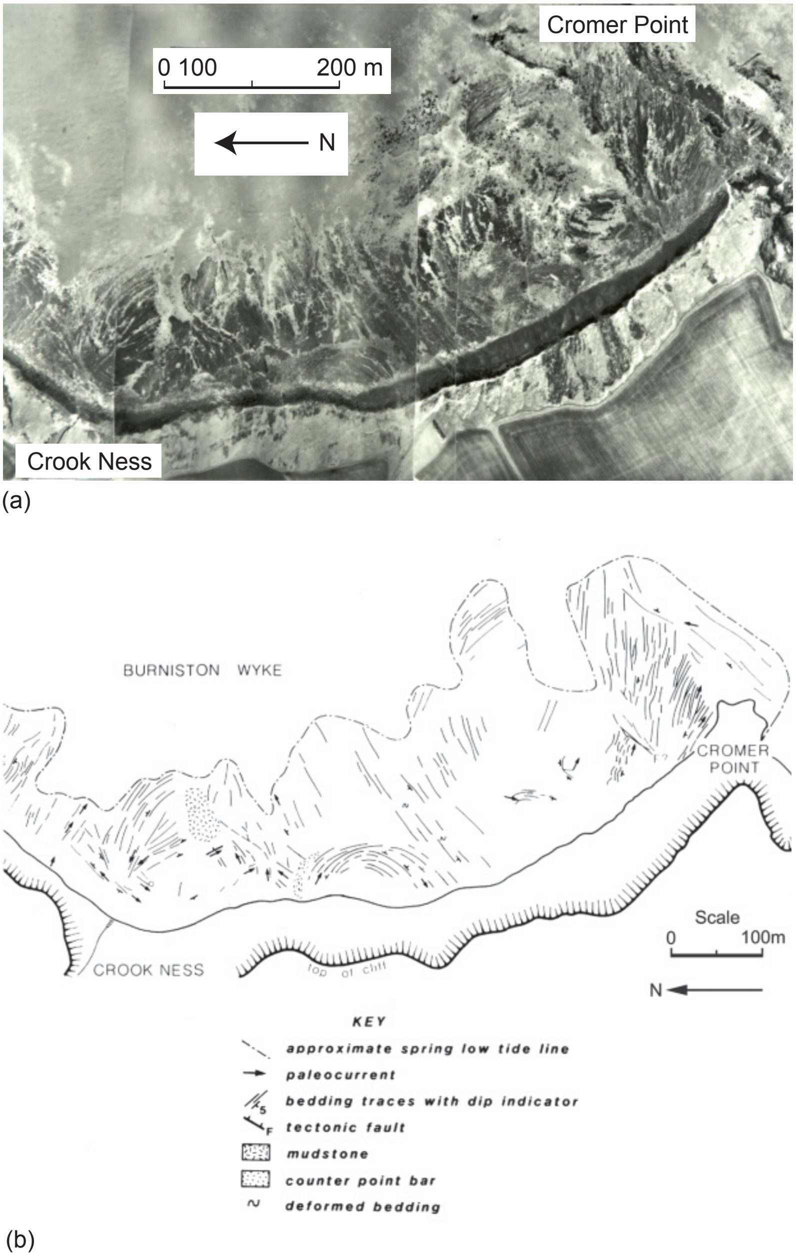


Figure 6.13 (a) Extract of part of an aerial photograph of the foreshore at Burniston, Yorkshire, UK and (b) part of a line drawing showing the foreshore in (a) with the distinct curved features interpreted as point bars and counter point bars. (From Alexander 1992.)

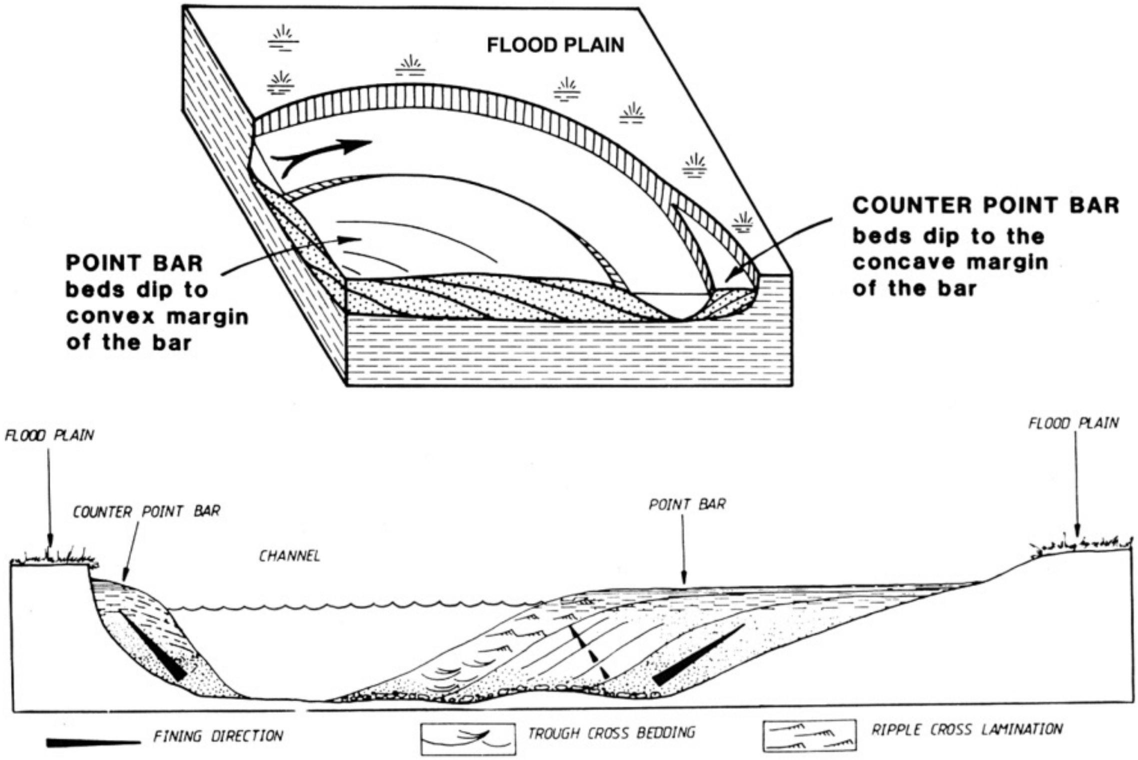


Figure 6.14 Three-dimensional block model and idealized cross-section to illustrate the depositional environment interpreted for the Long Nab Member, Yorkshire, UK. The right-hand part of the cross-section relates directly to the deposits at Cromer Point shown in Figure 6.11c and d. (From Alexander 1992.)

6.5 Using sedimentary rocks to interpret climate change and sea-level change

Marine and lacustrine sedimentary records are unique because below storm wave-base in the oceans and in lakes sedimentation can be fairly continuous over hundreds of thousands and even millions of years. This continuous record can be correlated with the usually less complete nearshore and terrestrial records. Together these sedimentary records enable us to collect information on how the Earth's surface environment has progressively changed over time. The processes that occur on the land surface and near-shore environments affect those in the ocean. The position of sea-level influences both land and ocean processes because changes in topography or sea-level will cause the system to change its equilibrium profile. By piecing together evidence from terrestrial, shallow-marine and deep-marine successions deposited at the same time we can gain a more complete understanding of Earth processes.

6.5.1 Climate change

Long-term climatic indicators include the presence or absence of the following: coals, evaporites, palaeosols, plant megafossils (Chapter 5), palynomorphs, foraminifers, diatoms, corals and particular animal taxa that are latitudinally dependent. Three main types of sedimentary rock are used to study and construct short-term changes in climate through time : (1) fine-grained marine sedimentary rocks deposited on the continental shelf below storm wave-base or in the deep ocean; (2) fine-grained lake deposits; and (3) other non-marine deposits such as fine-grained wind-blown sediment (loess) and cave deposits. These deposits are used because in general sedimentation is continuous and fairly constant so they contain a fairly unbroken record of past changes. Sedimentary deposits of the same age can be used to determine, for example, the temperature gradient over latitude or altitude. Because the climate affects the chemistry and biota of the rocks laid down, a range of geochemical proxies (e.g. C-, O-, Sr- and Os-isotopes, Mg/Ca ratios and $CaCO_3$ content) has been developed to obtain an indication of the changes in the climatic variables. Sections 6.2.1 and 13.1.3 provide information on obtaining a record from this type of succession for these purposes.

6.5.2 Sequence stratigraphy and relative sea-level change

The facies patterns, unconformity surfaces, geometry and preservation of many shallow-marine and non-marine sedimentary rock successions can be used to interpret changes in relative sea-level. This works particularly well when it is possible to correlate, with certainty, between shallow-marine and deep-marine facies and even into non-marine successions across sedimentary basins or wide regions. Sequence stratigraphy provides a conceptual model for the detection of past changes in relative sea-level change by predicting the geometry and composition of sediment packages and surfaces that form during a single cycle of relative sea-level change. Sequence stratigraphic analysis is used widely to predict facies distributions, to examine the sea-level history over a period of time, to understand the genesis of the rock succession and predict where gaps and condensed sections may be present. For the theory of sequence stratigraphy and examples of its application see suggested further reading in Section 6.6. Listed below is the typical data set and general methodology for a sequence stratigraphic interpretation.

1. Record the vertical and lateral changes in the sedimentary succession along a proximal to distal profile of the depocentre. This is usually done through the graphic logs of exposures and/or seismic sections and borehole information. The sedimentological and palaeontological data all need to be integrated.
2. Incorporate any other published information (e.g. evidence for subaerial exposure, biostratigraphy, fossil assemblages).
3. Interpret the facies in terms of facies models so that it is obvious where facies that are juxtaposed obey Walther's Law and where they do not.
4. Construct, or integrate into the data set from the literature, a robust 100 thousand year to million year resolution relative timescale for each of the sections to enable correlation.
5. Identify patterns and repetitions within the succession with a view to interpreting the parasequences, their stacking patterns and the systems tracts. The transgressive systems tract is unique in containing retrogradational parasequences so this is sometimes the easiest systems tract to identify.
6. Identify major unconformity surfaces (one or more sequence boundaries) and trace them laterally in a distal direction to find the correlative conformity. Identify condensed sections that might represent the maximum flooding surfaces and the transgressive surfaces.
7. Integrate the data on the sediment packages and key surfaces in order to construct a sequence stratigraphic interpretation identifying all of the systems tracts and key surfaces.

Examples of sequence stratigraphic interpretations are beyond the scope of this book but Worked Example 6.3 (pp. 136–137) illustrates data collection along a sequence boundary and Worked Example 6.1 (pp. 124–126) also shows some sequence stratigraphic interpretation. More extensive examples in a range of depositional settings can be found in Coe (2003), Emery and Myers (1996) and Catuneanu (2006).

Worked Example 6.3 Set of photographs and sketches to illustrate a key sedimentary contact

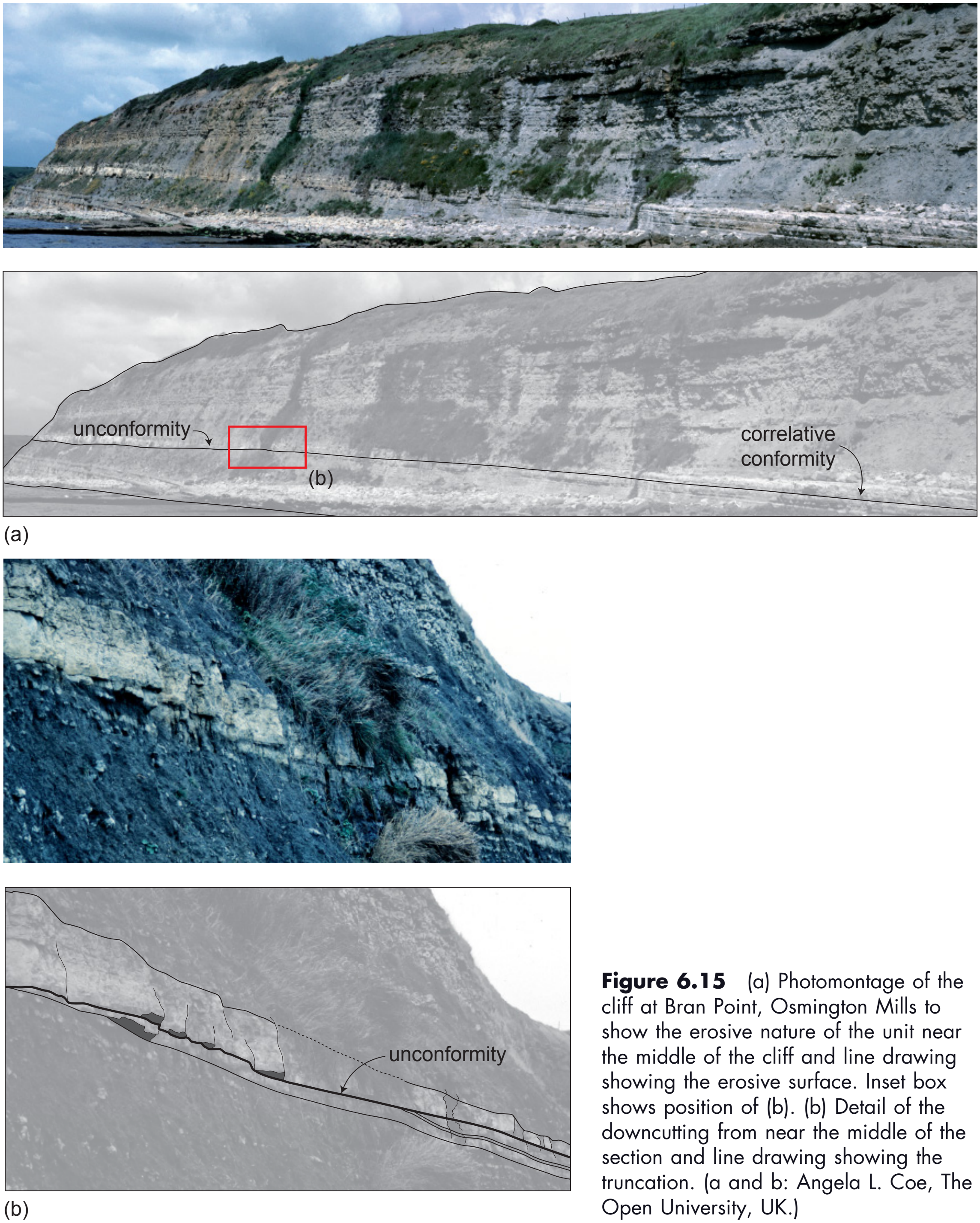


Figure 6.15 (a) Photomontage of the cliff at Bran Point, Osmington Mills to show the erosive nature of the unit near the middle of the cliff and line drawing showing the erosive surface. Inset box shows position of (b). (b) Detail of the downcutting from near the middle of the section and line drawing showing the truncation. (a and b: Angela L. Coe, The Open University, UK.)

The sea-cliffs at Osmington Mills, near Weymouth, Dorset, UK show a marked facies change from micritic limestones (biomicrite) to oolitic grainstones (oosparite). The base of the oolitic grainstone facies is erosional and down-cuts towards the west. The objective of this field exercise was to gather evidence for the erosive nature of the contact and to interpret its possible origin. The photographs show both an overview (Figure 6.15a) and a close up view along the section (Figure 6.15b). Accompanying sketches or line drawings (Figure 6.15) can be used to show the large-scale geometry of this important surface. A graphic log was constructed (Figure 6.16) where this section was interpreted to be at its most stratigraphically complete. This erosive contact has been interpreted as a sequence boundary on the basis of the erosion at this location, and others across the basin, together with evidence from sections in the Cleveland Basin to the north, where there is also a sharp facies change.

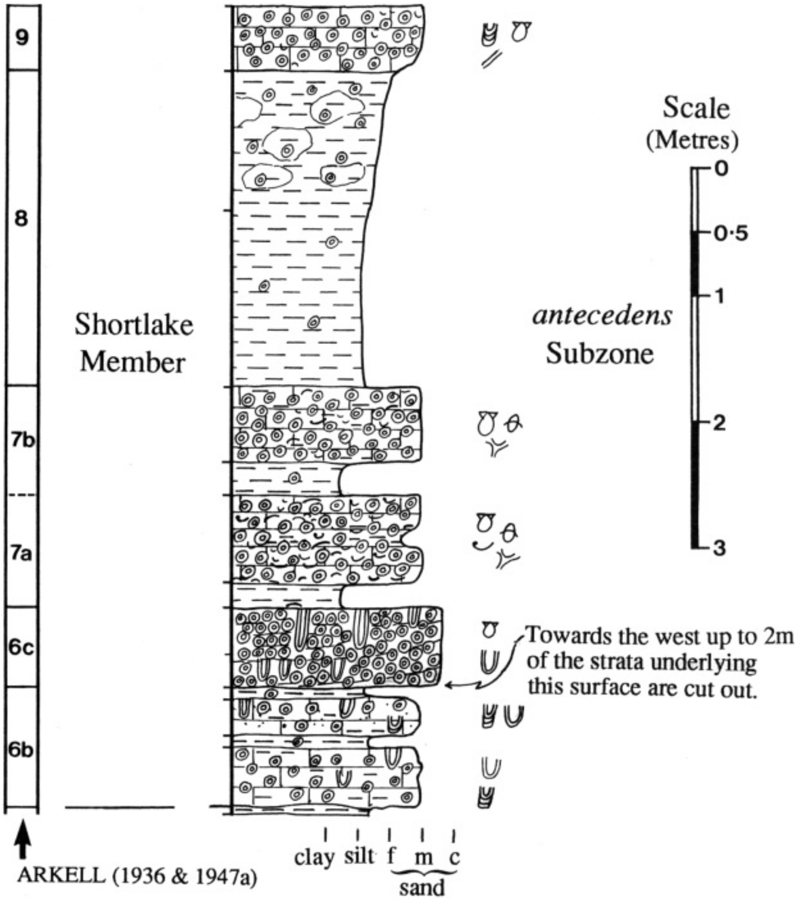


Figure 6.16 Extract from a published graphic log of the most complete part of the succession across the sedimentary contact shown in Figure 6.15. (From Coe 1995.)

6.6 Further reading

Alexander, J. 1992. Nature and origin of a laterally extensive alluvial sandstone body in the Middle Jurassic Scalby Formation, *Journal of the Geological Society, London*, **149**, 431–441. [Summary paper of the Middle Jurassic succession described in Worked Example 6.1]

Catuneanu, O. 2006. *Principals of Sequence Stratigraphy*, Elsevier, 375 pp. [In-depth coverage of a wide range of sequence stratigraphy models.]

Coe, A. L. 2003. *The Sedimentary Record of Sea-level Change*, Cambridge University Press and The Open University, 287 pp. [Textbook on sequence stratigraphy.]

Collinson, J., Mountney, N. & Thompson, D. 2006. *Sedimentary Structures*, Terra Publishing, 292 pp.

Emery, D. and Myers, K. 1996. *Sequence Stratigraphy*, Blackwell Science, 304 pp. [The first comprehensive textbook on sequence stratigraphy. Wide coverage of subsurface data.]

Miall, A. D. 2010. *The Geology of Stratigraphic Sequences*, Springer, 480 pp. [In-depth textbook on sequence stratigraphy and various controversies.]

Nichols, G. 2009. *Sedimentology and Stratigraphy*, Blackwell Science, 432 pp. [Good book covering the basics of sedimentology and stratigraphy.]

Parish, J. T. 2001. *Interpreting Pre-Quaternary Climate from the Geologic Record*, Columbia University Press, 348 pp. [Excellent reference text on interpreting climate change from the geological record.]

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