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Sedimentary Rocks in the Field

A Practical Guide

FOURTH EDITION

Maurice E. Tucker

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The Geological Field Guide Series

Barnes, J.W. and Lisle, R.J. (2004) *Basic Geological Mapping*, 4th edn. ISBN: 978-0-470-84986-6, 5th edn publishing (2011). ISBN: 978-0-470-68634-8

Fry, N. (1991) *The Field Description of Metamorphic Rocks*. ISBN: 978-0-471-93221-5

McClay, K.R. (1991) *The Mapping of Geological Structures*. ISBN: 978-0-471-93243-7

Milsom, J. and Eriksen, A. (2010) *Field Geophysics*, 4th edn. ISBN: 978-0-470-74984-5

Tucker, M.E. (2011) *Sedimentary Rocks in the Field*, 4th edn. ISBN: 978-0-470-68916-5

Sedimentary Rocks in the Field:

A Practical Guide

FOURTH EDITION

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WILEY-BLACKWELL

A John Wiley & Sons, Ltd., Publication

Wiley-Blackwell is an imprint of John Wiley & Sons, formed by the merger of Wiley's global Scientific, Technical and Medical business with Blackwell Publishing.

Registered office: John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Offices: 9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
111 River Street, Hoboken, NJ 07030-5774, USA

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Library of Congress Cataloguing-in-Publication Data
Tucker, Maurice E.
Sedimentary rocks in the field : a practical guide / Maurice E. Tucker. – 4th ed.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-470-68916-5 (paper)
1. Sedimentary rocks. 2. Petrology–Fieldwork. I. Title.
QE471.T84 2011
552′.5–dc22
2010033307

A catalogue record for this book is available from the British Library.

This book is published in the following electronic formats:
ePDF: 978-0-470-97368-4

Typeset in 9.5/11.5pt Times by Laserwords Private Limited, Chennai, India.

Impression 2011

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PREFACE

The study of sedimentary rocks is often an exciting, challenging, rewarding and enjoyable occupation. However, to get the most out of these rocks, it is necessary to undertake precise and accurate fieldwork. The secret of successful fieldwork is a keen eye for detail and an enquiring mind; knowing what to expect and what to look for are important, although you do need to remain open-minded. Be observant, see everything in the outcrop, then think about the features seen and look again. This book is intended to show how sedimentary rocks are tackled in the field, and has been written for those with a geological background of at least first-year university or equivalent.

At the outset, this book describes how the features of sedimentary rocks can be recorded in the field, particularly through the construction of graphic logs. The latter technique is widely used since it provides a means of recording all details in a handy form; further, from the data, trends through a succession and differences between horizons readily become apparent. In succeeding chapters, the various sedimentary rock-types, textures and structures are discussed as they can be described and measured in the field. A short chapter deals with fossils since these are an important component of sedimentary rocks and much useful information can be derived from them for palaeoenvironmental analysis; they are also important in stratigraphic correlation and palaeontological studies. Having collected the field information, there is the problem of knowing what to do with it. A concluding section deals briefly with facies identification and points the way towards facies interpretations, and the identification of sequences and cycles.

Maurice E. Tucker

ACKNOWLEDGEMENTS

I should like to thank the friends and colleagues who have willingly read drafts of this handbook, suggested changes for this fourth edition, and kindly provided photographs, in particular Jenny Bevan, Telm Bover-Arnal, Jim Gallagher, Annette George, Dougal Jerram, Juan-Carlos Laya, Mike Mawson, Zahra Seyedmehdi and Paul Wright. Zoe took the picture on the front cover. I am indebted to Vivienne for providing support, encouragement, assistance and patience in ways that only a wife can.

Sheet No.

Date:

Formation:

Location:

Samples	
Cycles	
Colour	
Bioturbation index 1 2 3 4 5 6	
Fossils	
Palaeocurrents	
Sedimentary structures	
Carbonates: Mud W P G R F B; Grain size: Mud, Sand (vf f m c vc), G	
Lithology	
Bed number	
Bed/unit thickness	
metres above base	

1

INTRODUCTION

This book aims to provide a guide to the description of sedimentary rocks in the field. It explains how to recognise the common lithologies, textures and sedimentary structures and how to record and measure these features. There is a chapter explaining how fossils can be studied in the field, since they are common in many sedimentary rocks and are very useful for palaeoenvironmental analysis. A concluding chapter gives a brief introduction to the interpretation of sedimentary rock successions: facies, facies associations, cyclic sediments and sequences.

1.1 Tools of the Trade

Apart from a notebook (popular size around 20×10 cm), pens, pencils, appropriate clothing, footwear and a rucksack, the basic equipment of a field geologist comprises a hammer, chisel, hand-lens, compass-clinometer, tape measure, acid bottle, sample bags and marker pen. A Global Positioning System (GPS) receiver is most useful, and not only in remote areas (see Section 1.3). A hard hat for protection when working below cliffs and in quarries, and safety goggles for the protection of the eyes while hammering, should also be taken into the field and used; see Section 1.4 for further safety considerations. A camera is invaluable. Topographic and geological maps should also be carried, as well as any pertinent literature. If a lot of graphic logging is anticipated (see Section 2.4) then pre-prepared sheets can be taken into the field. Non-geological items that are useful and can be carried in a rucksack include a whistle, first-aid equipment, matches, emergency rations, knife, waterproof clothing and a 'space blanket'.

For most sedimentary rocks, a geological hammer of around 0.5–1 kg (1–2 lb) is sufficiently heavy. However, do be sympathetic to the outcrop and remember that many future generations of geologists will want to look at the exposure. In many cases it will not be necessary to hammer

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since it will be possible to collect loose fresh pieces from the ground. A range of chisels can be useful, if a lot of collecting is anticipated.

A *hand-lens* is an essential piece of equipment; $\times 10$ magnification is recommended since then grains and features down to 100 μm across can be observed. When holding the lens close to your eye, the field of view being examined with a $\times 10$ lens is about 10 mm in diameter. To become familiar with the size of grains as seen through a hand-lens, examine the grains against a ruler graduated in millimetres. For limestones, it can be easier to see the grains after licking the freshly broken surface.

A compass-clinometer is important not only for taking routine dip and strike and other structural measurements, but also for measuring palaeocurrent directions. Do not forget to correct the compass for the angle between magnetic north and true north. This angle of declination is normally given on topographic maps of the region. You should also be aware that power lines, pylons, metal objects (such as your hammer) and some rocks (although generally mafic-ultramafic igneous bodies) can affect the compass reading and produce spurious results. A tape or steel rule, preferably several metres in length, is necessary for measuring the thickness of beds and dimensions of sedimentary structures. A metre-long staff with graduations can be useful for graphic logging. A compass usually has a millimetre-centimetre scale, which can be useful for measuring the size of small objects such as pebbles and fossils.

For the identification of calcareous sediments a plastic bottle of hydrochloric acid (around 10%) is useful, and if some Alizarin red S is added, then dolomites can be distinguished from limestones (limestones stain pink, dolomites no stain). Polythene or cloth bags, for samples, and a marker pen (preferably with waterproof, quick-drying ink), for writing numbers on the specimens, are also necessary. Friable specimens and fossils should be carefully wrapped to prevent breakage.

For *modern sediments* and *unconsolidated rocks* you will need a trowel and/or spade. A length (0.5–1.5 m) of clear plastic pipe, 5–10 cm in diameter, is very useful for pushing into modern sediments to obtain a crude core. Epoxy-resin cloth peels can be made in the field of vertical sections through soft sandy sediments. The techniques for taking such peels are given in Bouma (1969). In essence, cut and trim a flat vertical surface through the sediments; spray an epoxy resin onto the cut surface; place a sheet of muslin or cotton against the sediments and then spray the cloth. Leave the resin to set (~10 minutes) and then carefully remove the cloth. A thin layer of sediment should be glued to the cloth and will show the various structures. Lightly brush or shake off excess, unglued sediment. Modern beach, dune, river, tidal flat and desert sediments are ideal for treatment in this way. Fibre-glass foam (a hazardous substance, though) can also be sprayed onto unlithified sediment to take a sample.

1.2 Other Tools for the Field

More sophisticated instruments are taken into the field on occasion to measure a particular attribute of sedimentary rocks. Normally these are used as part of a more detailed and focused research effort, rather than during a routine sedimentological study. Such tools include the mini-permeameter, magnetic susceptibility recorder (kappameter), gamma-ray spectrometer, and equipment for ground-penetrating radar surveys and laser scanning (LIDAR, Light Detection and Ranging).

The mini-permeameter is a tool for estimating the permeability of a rock, and portable ones are available for use in the field.

The magnetic susceptibility of sedimentary rocks can be measured relatively easily in the field, although in many cases it is very weak. Mudrocks and others with high organic matter contents and iron minerals tend to give higher readings. With measurements taken every few centimetres or so, a mag-sus stratigraphy can be produced; from this, cycles and rhythms can be recognised, especially in basinal facies.

Gamma-ray spectrometry is a technique for measuring the natural gamma radiation emitted from rocks; it can be used to determine the amount of clay in a succession and so is useful for distinguishing different types of mudrock, or the variation in clay content of muddy sandstones and limestones. Measurement of the gamma-ray spectrum in the field with a portable spectrometer has been used to correlate surface outcrops with each other and with the subsurface.

Ground-penetrating radar is a useful technique for looking at the structure and variation of shallow subsurface sediments, as in modern floodplains and coastal plains. Sedimentary units, such as point-bar sands and ox-bow lake fills, can be recognised beneath the surface.

Laser scanning of an outcrop can produce a highly precise digital image that can be used in 3-D imaging software packages. Very accurate measurements can be taken from the data, for detailed study of such features as fracture orientation and bed thickness. The equipment is very expensive, however. Further information on an area can be obtained from multispectral remote sensing and from digital elevation models (DEMs, also called digital terrain models, DTMs), where the relief of an area can be revealed and so examined more closely. Using these techniques 3-D digital images of geological formations can be created.

1.3 Use of GPS (Global Positioning System) in Sedimentary Studies

GPS is becoming a standard instrument to take into the field for determining location, but it can also be used for measuring sedimentary sections. GPS provides a very precise location of where you are, and this reading of latitude and longitude (or grid reference) can be entered in your field notebook and on logging sheets. The receiver also enables you to travel from one place to another or to find a specified location, or to back-track from whence you came. The accuracy of the reading from the receiver depends on several factors (make and model, time at location, design, corrections, etc.) and the method of positioning. With autonomous GPS the precision is 5–30 m; using differential Global Positioning System (DGPS) and applying corrections, accuracy can be less than 3 m. However, a reference station does have to be set up for DGPS.

GPS receivers now have a good memory so that all readings of the day, indeed of the week, can be recalled so you can retrace your steps and visit the localities again with no difficulty. This is immensely useful in landscapes where there are no distinctive features. Data from the receiver can of course be downloaded directly to a PC so that a permanent record is kept of where you went.

Apart from the advantage of knowing where you are, GPS does have the potential to enable you to measure medium to large structures with a better degree of accuracy than by using just a map and tape measure. With channel-fills, reef bodies or conglomeratic lenses, etc., several 100 m across or more, taking several GPS measurements will enable a better estimate of dimension to be obtained. A laser range-finder can be useful for precise measurements of distant objects, such as features on cliff faces, and for knowing more precisely how far you are from somewhere.

1.4 Safety in the Field and General Guidance for Fieldwork

Working in the field should be a safe, enjoyable and very rewarding experience, as long as a few basic and sensible precautions are taken. Geological fieldwork is an activity involving some inherent risks and hazards, for example in coastal exposures, quarries, mines, river sections and mountains. Severe weather conditions may also be encountered in any season, especially in mountainous areas or at the coast. Fieldwork does involve an important element of self-reliance and the ability to cope alone or in a small group. You are responsible for your own safety in the field but, nevertheless, there are some simple precautions you can take to avoid problems and minimise risks.

- Do wear adequate clothing and footwear for the type of weather and terrain likely to be encountered. Try to know the weather forecast for the area before you go out for the day. Keep a constant lookout for changes. Do not hesitate to turn back if the weather deteriorates.
- Walking boots with good soles are normally essential. Sports shoes are unsuitable for mountains, quarries and rough country.
- Plan work carefully, bearing in mind your experience and training, the nature of the terrain and the weather. Be careful not to overestimate what can be achieved.
- Learn the mountain safety and caving codes, and in particular know the effects of exposure. All geologists should take a course in First Aid.
- It is good practice before going into the field to leave a note and preferably a map showing expected location of study and route, and time of return, with the people with whom you are staying/living.
- Know what to do in an emergency (e.g. accident, illness, bad weather, darkness). Know the international distress signal: six whistle blasts, torch flashes or waves of a light-coloured item of clothing, repeated at minute intervals.
- Carry at all times a small first-aid kit, some emergency food (chocolate, biscuits, mint cake, glucose tablets), a survival bag (or large plastic bag), a whistle, torch, map, compass and watch.
- Wear a safety helmet (preferably with a chin strap) when visiting old quarries, cliffs, scree slopes, caves and so on, or wherever there is a risk from falling objects. It is obligatory to do so when visiting working quarries, mines and building sites, along with a high-viz jacket and strong boots.

- Avoid hammering where possible, to be a conservationist.
- Wear safety goggles (or safety glasses with plastic lenses) for protection against flying splinters when hammering rocks or using chisels.
- Do not use one geological hammer as a chisel and hammer it with another; use only a soft steel chisel.
- Avoid hammering near another person or looking towards another person hammering. Do not leave rock debris on the roadway or verges.
- Be conservation-minded and have a sympathetic regard for the countryside and the great outdoors, and the people, animals and plants that live there.
- When you are collecting specimens, do not strip or spoil sites where special fossils and rare minerals occur. Only take what you really need for further work.
- Take special care near the edges of cliffs and quarries, or any other steep or sheer rock faces, particularly in gusting winds.
- Ensure that rocks above are safe before venturing below. Quarries with rock faces loosened by explosives are especially dangerous.
- Avoid working under an unstable overhang.
- Avoid loosening rocks on steep slopes.
- Do not work directly above or below another person.
- Never roll rocks down slopes or over cliffs for amusement.
- Do not run down steep slopes.
- Beware of landslides and mudflows occurring on clay cliffs and in clay-pits, or rockfalls from any cliffs.
- Avoid touching any machinery or equipment in quarries, mines or building sites. Comply with safety rules, blast warning procedures and any instructions given by officials. Keep a sharp lookout for moving vehicles, and so on. Beware of sludge lagoons.
- Do not climb cliffs, rock faces or crags, unless you are an experienced climber and have a partner.
- Take great care when walking or climbing over slippery rocks below high-water mark on rocky shores. More accidents to geologists, including fatalities, occur along rocky shorelines than anywhere else; keep an eye out for rogue waves.
- Beware of traffic when examining road cuttings.
- Railway cuttings and motorways are generally not open to geologists, unless special permission has been obtained from appropriate authorities.

- Do not enter old mine workings or cave systems unless you are experienced and properly equipped.
- Avoid getting trapped by the tide on intertidal banks or below sea-cliffs. Obtain local information about tides and currents. Pay particular attention to tidal range. For sea-cliffs, local advice can be obtained from the local coastguard's office.
- *Permissions*: Always try to obtain permission to enter private property. There are also many areas, such as national parks and nature reserves in many countries, and sites of special scientific interest (SSSIs) or protected sites, where official permission is required to collect samples, in some cases even just to carry out field observations and scientific study.
- *Risk assessment*: In many cases these days, it is necessary to conduct a risk assessment before commencing fieldwork. This may be a requirement for insurance purposes, as well as for research project proposals and permissions. Although perhaps seemingly unnecessarily bureaucratic, making a risk evaluation can be a useful exercise in thinking about the problems and issues you might encounter and so make you better prepared.

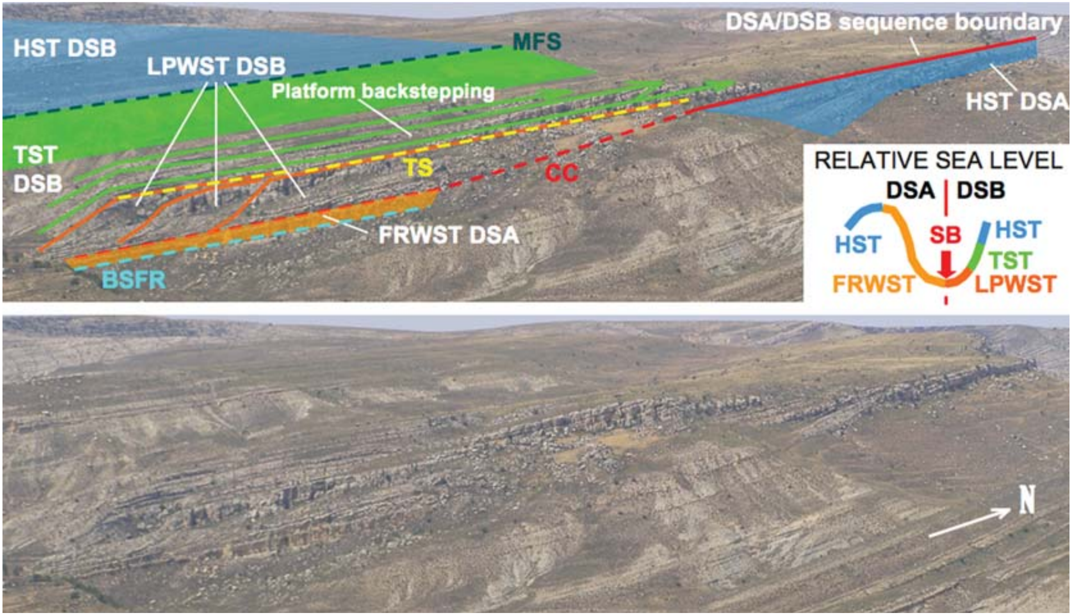

Figure 1.1 *Sequence stratigraphic interpretation of two middle Cretaceous sequences (DSA and DSB) from the Maestrat Basin, eastern Spain. Abbreviations: ST systems tract; LPW lowstand prograding wedge; T transgressive; H highstand; FRW forced regressive wedge; BSFR basal surface of forced regression; CC correlative conformity; TS transgressive surface. See Bover-Arnal et al. (2009) for further information.*

2

FIELD TECHNIQUES

2.1 What to Look For

There are six aspects of sedimentary rocks to consider in the field, and these should be recorded in as much detail as possible. These are:

1. the **lithology**, that is the composition and/or mineralogy of the sediment;
2. the **texture**, referring to the features and arrangements of the grains in the sediment, of which the most important aspect to examine in the field is the grain-size and its variation;
3. the **sedimentary structures**, present on bedding surfaces and undersurfaces, and within beds, some of which record the palaeocurrents that deposited the rock;
4. the **colour** of the sediments;
5. the **geometry** and **relationships** of the beds or rock units to each other, and their lateral and vertical changes in thickness and composition; and
6. the nature, distribution and preservation of **fossils** contained within the sedimentary rocks.

A general scheme for the study of sedimentary rocks in the field is given in Table 2.1, starting from the larger-scale to the smaller-scale features.

The various attributes of a sedimentary rock combine to define a *facies*, which is the product of a particular depositional environment or depositional process in that environment. Facies identification and facies analysis are the next steps after the field data have been collected. These topics are briefly discussed in Chapter 8; there are numerous books on facies and facies models. Nowadays, there is much interest

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Table 2.1 *Broad scheme for the study of sedimentary rocks in the field, together with reference to appropriate chapters in this book.*

Take a look at the locality from a distance and see the general arrangement of rock types and units. Make a quick assessment of any structural features, faults and folds, and any prominent sedimentological structures – channels, reefal limestones, clinoforms, synsedimentary folds, before having a closer look at the exposure
Record details of the locality and succession by means of notes and sketches in the field notebook, and photos; if appropriate, make a graphic log; if rocks are folded check way-up of strata; see Table 2.2
Identify lithology by establishing mineralogy/composition of the rock; see Chapter 3
Examine texture of the rock: grain-size, shape and roundness, sorting, fabric and colour; see Chapter 4
Look for sedimentary structures on bedding planes and bed undersurfaces, and within beds; see Chapter 5
Record the geometry of the sedimentary beds and units; determine the relationships between them and any packaging of beds/units or broad vertical grain-size/lithological/bed thickness changes; is the succession cyclic? See Sections 5.7 and 8.4
Search for fossils and note types present, modes of occurrence and preservation; see Chapter 6
Measure all structures giving palaeocurrent directions; see Chapter 7
Consider, perhaps at a later date, the lithofacies, cycles, sequences, depositional processes, environmental interpretations and palaeogeography; see Chapter 8
Undertake laboratory work to confirm and extend field observations on rock composition/mineralogy, texture, structures, fossils, etc.; pursue other lines of enquiry such as the biostratigraphy, diagenesis and geochemistry of the sediments and read the relevant literature, for example sedimentology/sedimentary petrology textbooks and appropriate journals, or use the internet. See Recommended Reading and chapter references

in the broader-scale aspects of sedimentary successions: the geometric arrangements of rock units; the lateral and vertical variation in such features as lithology and grain-size; the packaging and stacking patterns of units; and the presence of depositional cycles in the succession. These aspects are treated in Sections 5.7 and 8.4. These features reflect the longer-term, larger-scale controls on deposition, primarily relative sea-level change, *accommodation* (the space available for sediment to be deposited), tectonics, sediment supply/sediment production and climate.

2.2 The Approach

The question of how many exposures to examine per square kilometre depends on the aims of the study, the time available, the lateral and vertical facies variation, and the structural complexity of the area. If it is a reconnaissance survey of a particular formation or group then well-spaced localities will be necessary. If a specific member or bed is being studied then all available outcrops will need to be looked at; individual beds may have to be followed laterally.

The best approach at outcrops is initially to survey the rocks from a distance, noting the general relationships and any folds or faults that are present. Some larger-scale structures, such as channels and erosion surfaces, the geometry of sedimentary rock units, bed thickness variations and the presence of cycles, are best observed from a short distance. Notice the way the rocks are weathering out and the vegetation. These may be reflecting the lithologies (e.g. mudrocks less well exposed or covered in vegetation) and may show the presence of cycles. Then take a closer look and see what lithologies and lithofacies are exposed there. In folded or vertical rocks, check the way-up of the strata using sedimentary structures such as cross-bedding, graded bedding, scours, sole structures, geopetals in limestone or cleavage-bedding relationships, so you know the younging direction (see Section 2.9).

Having established approximately what the outcrop has to offer, decide whether the section is worth describing in detail. If it is, it is best to record the succession in the form of a graphic log (see Section 2.4). If the exposure is not good enough for a log, then notes and sketches in the field notebook will have to suffice. In any event, not all the field information can go on the log.

2.3 Field Notes

Your notebook should be kept as neat and well-organised as possible. The location of the section being examined should be given precisely, preferably with a grid reference and possibly a sketch map too, so you can find it again in years to come. If you have GPS, this can give you a very precise location (see Section 1.3). You may wish to number your localities sequentially and put the numbers on a topographic map. You could use the pin-hole method (not favoured by everybody!); make a hole in the map with a pin and write the locality number on the back. Relevant stratigraphic information should also be entered in the notebook if you know it: formation name, age and so on. It is easy to forget such things with the passage of time. Incidental facts could be jotted down, such as the weather or a bird seen, to make the notebook more interesting and jolt the memory about the locality when looking back through the book in years to come.

Notes written in the field book should be factual, accurately describing what you can see. Describe and measure where possible the size, shape and orientation of the features as discussed and explained in later chapters of this book. Also record the structural data if the rocks are dipping or there are folds and cleavage present. Note major joints and fractures and their orientation, and any mineralisation. Make neat and accurate labelled sketches of features, with a scale, and orientation, such as direction of north.

Record the location and subject of *photographs* in the notebook. When taking photographs do not forget to put in a scale. Photomosaics of cliffs and quarries can be very useful for extensive exposures, and they can always be annotated directly or with an overlay.

One attribute of sediments that cannot be recorded adequately on a graphic log is the geometry of the bed or the rock unit as a whole (see Section 5.7). Sketches, photographs and descriptions should be made of the shape and lateral changes in thickness of beds as seen in quarry and cliff faces. Binoculars can be very useful for observing inaccessible cliffs and as a preliminary to closer examination. Local detailed mapping and logging of many small sections may be required in areas of poor exposure to deduce lateral changes. GPS can be useful here to get accurate locations of outcrops and even to get the dimensions of features. Where there are excellent outcrops and you have a focused research project, laser scanning a cliff or quarry face could help enormously.

Table 2.2 The main points to be covered in a field notebook entry.

Locality details: location, locality number, grid/GPS reference; date and time; weather
Stratigraphic horizon and age of rock unit, structural observations (dip, strike, cleavage, etc.)
The large-scale features of the exposure (e.g. faults, folds, channels, strong erosion surfaces, any geometric arrangements of units – thinning out, onlapping)
Lithology/mineralogy and texture: identify and describe/measure
Sedimentary structures: describe/measure and make sketches/take photographs
Palaeocurrent measurements: collect readings and plot rose diagram
Fossils: identify and make observations on assemblages, orientation, preservation, and so on
Construct graphic log if appropriate and sketches of lateral relationships
Note location of samples and fossils collected
Identify facies present, note facies associations and repetitions
Determine/measure rock units and any cycles in the succession
Make appropriate interpretations and notes for future work (e.g. in the lab)

Table 2.2 gives a checklist of the main points to be covered in the description of a locality in a field notebook.

2.4 Graphic Logs

The standard method for collecting field data of sediments and sedimentary rocks is to construct a graphic log of the succession (Figure 2.1). Logs immediately give a visual impression of the section, and are a convenient way of making correlations and comparisons between equivalent sections from different areas. Repetitions of facies, sedimentary cycles and general trends may become apparent, such as a systematic upward change in bed or cycle thickness or in grain-size, increasing or decreasing upward. In addition, the visual display of a graphic log helps with the interpretation of the succession. However, a log does emphasise the vertical changes in the succession, at the expense of lateral variations.

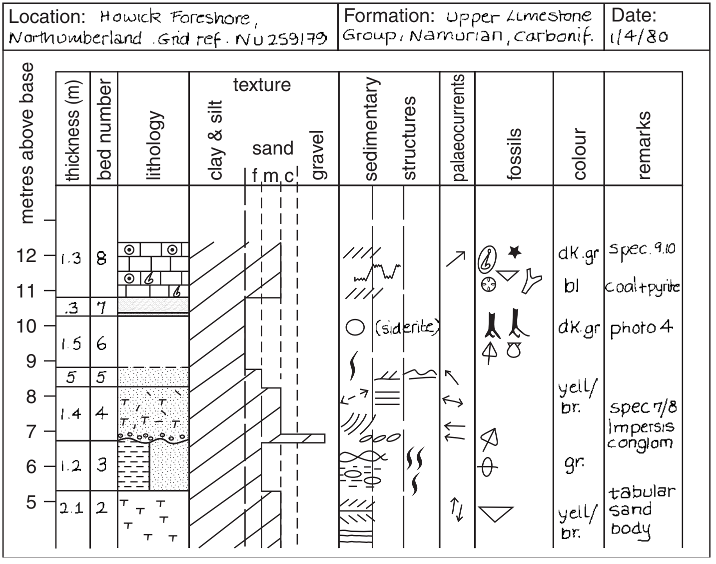

Figure 2.1 *An example of a graphic log; symbols are given in Figure 2.2.*

The vertical scale to use depends on the detail required, sediment variability and time available. For precise work on short sections, 1:10 or 1:5 is used, but for many purposes 1:50 (that is 1 cm on the log equals 0.5 m) or 1:100 (1 cm equals 1 m) is adequate. In some situations, it may not be necessary to log the whole succession, or the whole succession at the same scale. A representative log may be sufficient.

There is no set format for a graphic log; indeed, the features that can be recorded do vary from succession to succession. Features that it is necessary to record and that therefore require a column on the log are: bed or rock-unit thickness; lithology; texture, especially grain-size; sedimentary structures; palaeocurrents; colour and fossils. The nature of bed contacts can also be marked on the log. A further column for special or additional features ('remarks') can also be useful. Several types of graphic log form are illustrated by Graham in Tucker (1988), and the columns for a logging sheet are shown on the inside cover of this book and are available for downloading from www.wiley.com/go/sedimentaryrocks4e. If you are going to spend some time in the field then it is worth preparing the log sheets before you go. An alternative is to construct a log in your field notebook, but this is usually less satisfactory since the page size of most notebooks is too small.

Where exposure is continuous or nearly so, then there is no problem concerning the line of the log; simply take the easiest path. If the outcrop is good but not continuous everywhere it may be necessary to move laterally along the section to find outcrops of the succeeding beds. Some small excavations may be required where rocks in the succession, commonly mudrocks, are not exposed; otherwise enter 'no exposure' on the log. It is best to log from the base of the succession upwards. In this way you are recording how deposition changed as time progressed, rather than back through time, and it is generally easier to identify bed boundaries and facies changes by moving up the section.

2.4.1 Bed and rock-unit thicknesses

These are measured with a tape measure; care must be exercised where rocks dip at a high angle and the exposure surface is oblique to the bedding. Attention needs to be given to where boundaries are drawn between units in the succession; if there are obvious bedding planes or changes in lithology then there is no problem. Thin beds, all appearing identical, can be grouped together into a single lithological unit on the log, if a large scale is being used. Where there is a rapid alternation of thin beds of different lithology, for example interbedded sandstones and shales (heterolithics), they can be treated as one unit and notes made of the thicknesses and character of individual beds, noting any increases or decreases in bed thickness up through the unit.

Thus, when first approaching a section for logging, stand back a little and see where the natural breaks come in the succession to define the various beds or rock units.

It is often useful to give each bed or rock unit a number so as to facilitate later reference; begin at the stratigraphically lowest bed.

2.4.2 Lithology

On the graphic log, lithology is recorded in a column by using an appropriate ornamentation (Figure 2.2). If it is possible to subdivide the lithologies further, then more symbols can be added, or coloured pencils used. If two