THE HASHEMITE UNIVERSITY Faculty of Natural Resources and Environment Department of Earth Sciences and Environment 2nd Semester 2013/2014
Geological Field Techniques 111201391
Course Instructor: Jafar Sadi

Working in the field contributes a crucial element to our knowledge and understanding of Earth processes, whether understanding periods of past climate change recorded in sedimentary deposits, deciphering an episode of structural imprint, or working out where to find mineral resources. The course assumes a basic understanding of the main concepts and theory in geology. It assumes that the student is familiar with: the major rock - forming minerals, how to identify minerals in hand specimen, rock classification, geological processes and common geological terms. The course is designed to tie students with field works through designed field techniques by involving them in to different chapters of how to make data collection from different types of rocks, palaeontological theme and
structural theme. It also deals with the basics of geological mapping construction and implementation.

.Course Outline

Week	Subject	Notes
1-2	**FIELD EQUIPMENT AND SAFETY**	Covers general geological field equipment and its use. It also provides an overview of the health and safety requirements in the field. More specialist field equipment and safety considerations are covered
2-4	**INTRODUCTION TO FIELD OBSERVATIONS AT DIFFERENT SCALES**	Going out into the field and examining rocks at an exposure for the first time, or even subsequently, might well reveal features
5-7	**SAMPLING AND RECORDING FEATURES OF DIFFERENT ROCKS AND CONSTRUCTING GRAPHIC LOGS**	Studying 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 correlation and start to make an interpretation

8-10	**RECORDING STRUCTURAL INFORMATION**	Measuring brittle structures provides information on how and why the upper crust in particular deforms, specifically the orientation of regional and local layer, joints and stresses, and the direction deformation on faults and folds. Such data help us Understanding fracture systems is and mineral resources efficiently. Structural geology plays a crucial role in a wide range of related fields, including groundwater studies, pollution control.
11-14	**MAKING A GEOLOGICAL MAP**	A geological map is one of the most important tools of geologists. It shows how geological features (rock units, faults, etc.) are distributed across a region. It is a two -dimensional representation of part of the Earth's surface, scaled down to a size that is convenient for displaying on a sheet of paper or a computer screen. Information on the third dimension is incorporated by means of strike and dip symbols and other structural labels.

Text Book

Angela l. coe, (2010), Geological Field Techniques, The open university, UK.

References:

1. McClay , K. R. 1991 . *The Mapping of Geological Structures* . John Wiley.
2. Richard J. Lisle, Peter Brabham, John W. Barnes, 2011, Basic Geological Mapping, John Wiley.
3. Internet resources: www.os.is/gogn/unu-gtp-sc/UNU-GTP-SC-11-04.pdf.

Exams and Evaluation:

		Date	Day	Time
Reports, assignments and, attendance	: 25%			
Mid exam	: 25%	3/4/2014	Thursday	11-12:30
Final exam	: 50%			

GEOLOGICAL FIELD TECHNIQUES

Introduction:

Working in the field contributes a crucial element to our knowledge and understanding of Earth processes, whether it is the prediction of volcanic eruptions, understanding periods of past climate change recorded in sedimentary deposits, deciphering an episode of mountain building, or working out where to find mineral resources. Without primary field data and geological samples of the highest quality, further scientific study such as sophisticated isotope measurements or the reconstruction of past life assemblages and habitats is at best without context, and at worst, completely meaningless. Geological fieldwork can be both fun and challenging. It provides the chance to work outdoors under a range of conditions and to explore our natural world. It also provides an often unparalleled opportunity to travel and visit localities as more than a tourist. Indeed it often takes you to un spoilt parts of the world that tourists rarely penetrate. Almost all fieldwork enables us to work as part of a team, often with international partners, and this can be one of the most rewarding experiences of being a geologist because we can learn from each other. Many long - term friendships have been forged through geological fieldwork.

The main aim of field geology is to observe and collect data from rocks and/or unconsolidated deposits, which will further our understanding of the physical, chemical and biological processes that have occurred over geological time. Many of the basic observational principles used in field geology have not changed for hundreds of years, although the interpretation of the data, the scale of resolution and some of the equipment has advanced greatly. Fieldwork involves making careful observations and measurements in the field (Figure 1.1 a) and the collection and precise recording of the position of samples for laboratory analysis (Figure 1.1 b). The very act of collecting field data often raises questions about processes on Earth, which had perhaps not previously been envisaged. Furthermore, during fieldwork it is usual to initiate, or to build on, constructing and testing different hypotheses and interpretations based on the observations; this iterative process will help to determine the essential data and samples to collect.

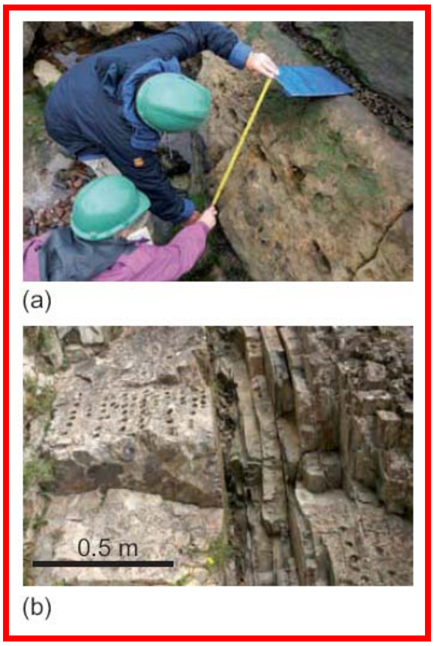


Figure 1.1 (a) Geologists collecting data for a graphic log to record how a sedimentary succession has changed through time and to decipher the overall depositional environment. By working together they can share tasks and discuss their observations.(b) The recessed bed marks the Cretaceous – Paleogene boundary at Woodside Creek, near Kekerengu,New Zealand. Note the holes where samples have been extracted for palaeomagnetism studies. In this case the number of holes is rather excessive and breaks the code of good practice.

Field geology presents four main intellectual challenges. These are:

1. Deciding what data to collect in order to address the scientific question(s).
2. Finding the most suitable exposures from which to collect the data.
3. Making a good record of the data collected; preferably a record that can be understood by others and can be used years after the data were collected.
4. Understanding and interpreting the basic observations that you make.

Field equipment and safety

2.1 Introduction

Before going out into the field it is necessary to: (1) assemble all of the field equipment that you might need; (2) assess any safety issues; and (3) if necessary obtain permission to visit the area. Both the safety and permission aspects may require documentation to be completed. Exactly what equipment you will need depends on the type of fieldwork you will be undertaking. The items required for most fieldwork tasks are listed in Table 2.1, and the equipment usually needed for sampling in Table 2.2. Optional equipment and that needed for more specialist tasks is listed in Table 2.3.

Quantification of geological observations

In almost all cases geological observations should be quantified because of the need to construct accurate and precise records. This is achieved through the use of measuring tapes, a compass - clinometer, rock comparison charts and more sophisticated geophysical equipment. This chapter provides information on how to master the basic geological measurements. More advanced techniques and those applicable to particular rock types are covered in the later chapters and more specialist books.

How accurate the measurement needs to be, or whether an estimate is sufficient, depends on the objective of the exercise and the quality of the exposure. For example, if all you need is a general description of a sandstone body it may be sufficient to describe it as sandstone with beds of variable thickness between about 10 cm and 2 m. However, if you need to sample the sandstone or determine how the thickness of the individual units varies laterally then it will be necessary to measure the thickness of each of the units. Equally in most cases there is a need to record the azimuth (direction relative to north) and the magnitude of the vertical angle or dip to the nearest couple of degrees rather than just the general direction. This is because of the need to convey important information on the direction of different processes (e.g. folding or palaeocurrents) and, importantly, enable an accurate record of the geometry of rock units to be calculated and recorded.

2.2 The hand lens and binoculars

The hand lens is an essential piece of equipment for the detailed observation of all rock types and fossil material. Most have a lens with 10 X magnification and some contain both a 10 X and a 15 X or 20 X lens (Figure 2.1). If your eyesight is poor, a better quality lens will often help, especially a larger lens. It is also possible to obtain lenses with built - in lights, which can enhance the image considerably, e.g. Figure 2.1 ; lenses 2 and 3. To use the hand lens, ensure that you are standing firmly or sitting down. Examine the specimen carefully first with the naked eye to find an area where it is fresh rather than weathered or covered in moss or lichens or algae, and also so that you can see where there are areas of interest such as well defined grains or crystals. If necessary, to ensure that when you look through the lens you have the correct area, place your finger tip or thumb tip as a marker adjacent to the area of interest identified with your naked eye. Place the lens about 0.5 cm away from your eye. Then, gradually move either the rock if it is a hand specimen, or yourself and the lens if it is an exposure, until the majority of the field of view comes into focus (usually about 1 – 4 cm away; Figure 2.2). Not all of the rock ' s surface will be in focus at the same time because of its unevenness. You will need to rotate the hand specimen or move your position to look at different areas. In the case of some metamorphic rocks and carbonate sedimentary deposits it is also useful to examine a weathered surface because the minerals
or grains sometimes weather out and are often easier to see. Binoculars can be very useful during fieldwork. They can be used to assess access, for instance in mountain regions. However, their most common use is to obtain a better view of

Figure 2.1 A variety of different hand lenses. (1) Standard 10× single lens; (2) 10× lens with built-in light – the lens casing matches the focal length; (3) 8× lens with built-in light; (4) 10× and 15× dual lens.

Figure 2.2 Photograph to show correct use of the hand lens. Note that the person is holding the lens close to his eye. The lens is fastened on a lanyard around his neck for ease of access and use.

the details within parts of an exposure that are impossible to reach safely, or are simply better viewed from a distance (e.g. geometry of features such as faults and river channel infills). They are particularly useful for examining the detail of contacts between different units in vertical sea cliffs and quarry faces. A wide range of good quality lightweight binoculars is available on the market.

Table 2.2 Typical sampling equipment.

Sampling equipment
Geological hammer, Sample bags Paper, cling film or bubble wrap to wrap delicate samples Marker pens/tile scribe/correction fluid for labeling, Chisels and other hammers Trowel and/or spade for soft sediments and pyroclastic deposits

Table 2.3 Optional and specialist field equipment. **Optional and specialist equipment**
Mapping pens/fine tipped pens, Relevant literature, Handheld GPS, Camera (Chapter 12), Geophysical tools, Penknife, Weak hydrochloric acid (*c.* 10%), Clipboard or mapping case, Rule and protractor, Mapping pens, coloured pencils, Binoculars, Scratch/streak plate, Pocket stereoscope, Geological Munsell colour chart , Hand brush to clean exposure, Hoe pick for cleaning sections

2.3 The compass – clinometer

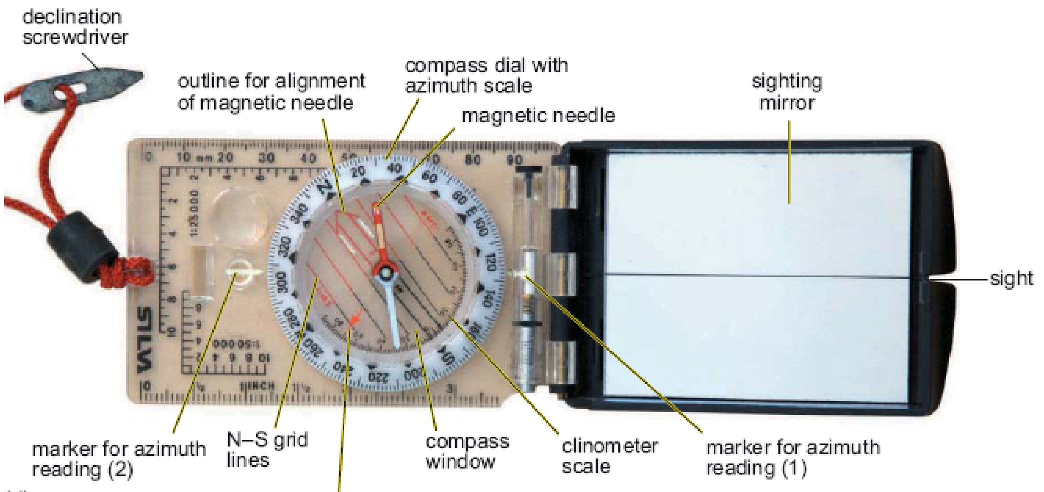
The compass - clinometer is used to measure: (1) the orientation of geological planes and lineations with respect to north; and (2) the angle of dip of geological features with respect to the horizontal. This allows an accurate record of the geometry of the features to be constructed. The compass - clinometer can also be used in conjunction with a topographic map to accurately determine location. There are two main types of compass - clinometer design on the market (Figure 2.3): the first type is made by Brunton, USA, Freiberger, Germany and Breithaupt, Germany; the second type is made by Silva and Suunto, both based in Sweden. The Brunton - type compass-clinometer is a more sensitive device because of the in - built spirit levels and the graduation of the scales in 1 ° rather than 2 ° increments.. The accuracy of the Silva - type compass clinometer is sufficient for most purposes and is much better designed for directly transferring compass directions to a map. Because the design of the two compass - clinometers is different, their operation for some measurements is also different. Instructions for both types of compass - clinometer are provided in this section

The compass - clinometer is both a magnetic compass and a device to measure the magnitude of the angle of dip of a surface from the horizontal. In order to do this it has two needles and two quite different scales (Figure 2.3 b and d). When the compass - clinometer is orientated with the compass window horizontal the magnetic needle will always point towards magnetic north – unless, that is, there is another magnetic body that is affecting it such as your hammer, a metal pen or a large magnetic body of rock. In addition if you are at very high latitudes compasses do not work well. Associated with the magnetic needle is a circular dial on the outside of the compass window that provides a measure of the azimuth in degrees away from north. The azimuth method for determining direction uses a circle with the value increasing clockwise from north at 0 ° .On the Silva - type the dial can be rotated to place the needle at 0 ° . The azimuth reading for the direction in which the sight at the end of the mirror is pointing can be read off using the ‘marker for azimuth reading (1)’ (Figure 2.3d).

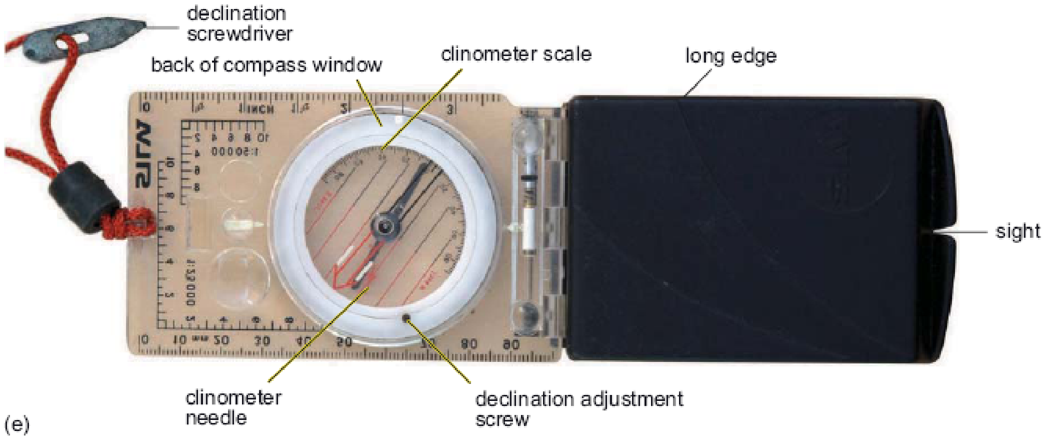
Directions from north can either be reported approximately, e.g. northwest, east, etc., or to the nearest degree.

The design and working mechanism of the clinometer part of compass - clinometers varies between the different makes and models. However, the principle of the clinometer is exactly the same. On both types of compass there is a scale on the inner part of the compass window to measure the magnitude of the angle between the needle and the horizontal (clinometer scale; Figure 2.3 d and e). To use the clinometer part, the instrument needs to be held with the compass window vertical and the long edge at the same angle as the dipping surface. the Silva – type has a clinometer needle that floats free and vertically downwards when the device is held on its edge vertically. The clinometer needle will hold its position if the instrument is carefully tilted about 20 ° from the vertical to the horizontal. In order to measure the dip on the Silva - type the compass dial needs to be set so that (i) the ‘ marker for azimuth reading (1) ’ (Figure 2.3d) is at 90 ° or 270 ° and (ii) the long edge of the compass - clinometer is orientated so that the clinometer scale is at the bottom where the clinometer needle is located. It may help to think of the clinometer as a protractor within the compass housing with a plumb line (the needle) indicating the magnitude of the angle relative to the horizontal. To test how your model works try holding the compass - clinometer as if it was on a horizontal plane and then increasing the angle to 45 ° and then to 90 ° . The operation of both types of compass - clinometer for specific applications is explained and illustrated later in this section.

BEWARE! Compasses can be affected by rocks containing magnetic minerals (e.g. serpentinite, gabbro), iron objects (gates, hammers, cars), and wires with electric currents passing along them (e.g. power lines). Always check odd readings!



(d)



(e)

Figure 2.3 *Continued* (d)–(e) Silva-type compass-clinometer: in this case the Silva Expedition 15TDCL. Views: (d) top; (e) bottom. There are small variations from model to model, with more features on some models. Compass-clinometers from other manufacturers have similar features.

Magnetic declination

The Earth ' s rotational pole (true north) is not coincident with magnetic north and varies by as much as 30 ° either side of true north and even greater closer to the poles. Not only that, this declination varies with geographical location *and* over time. On maps the N – S grid lines are orientated as close as possible to true north but again this varies by a very small amount depending on your location. This is because grid systems are rectangular but meridians (lines of longitude) converge towards the Earth ' s pole (Figure 2.4).

Before taking any azimuth readings it is strongly advised that you adjust your compass for magnetic declination for the area you are visiting and the year so that there are no resulting errors in the azimuth measurement. It is a good idea to also make a note of what you have done in your field notebook so that there is no ambiguity later. The less favoured alternative is to make a note at the start of your field notes for that locality that the readings need adjusting for magnetic declination and then to correct them after you return from the field, *except,* that is, if you are using your compass for triangulation to plot your position or if you are plotting measurements directly on the base map – i.e. the topographical map onto which geological data will be added. In this case it must be adjusted at the time of the measurement if your readings are to be accurate.
Adjusting your compass to take the magnetic north variation into account is easy. On the compass dial or side of the compass there is a screw, the declination adjustment screw (turn this screw by the amount of declination relative to grid north for the area and year using either a screwdriver or, for the Silva - type, the tool provided. To find out how much the magnetic declination is for the area there are three possibilities: (a) consult the legend of the topographical map of the area, taking note of changes since the publication date; or (b) use one of the many web pages now available that will calculate the declination for the area where you are completing fieldwork; or (c) determine the declination yourself in the field as follows.

1. Ensure that the magnetic declination on the compass - clinometer is set to 0 °
2. Stand at a known location and take a bearing on a feature identified on a map of the area
3. Compare the compass reading with the azimuth between your location and the feature provided by the map; the difference is magnetic declination.
4. Alternatively use a straight feature on the map such as a wall or forest boundary and compare the reading from sighting along the linear feature with that given on the map.

Once you have determined the declination ensure that you adjust the declination in the correct direction. On the Silva - type compass the numbers increase in a clockwise direction.

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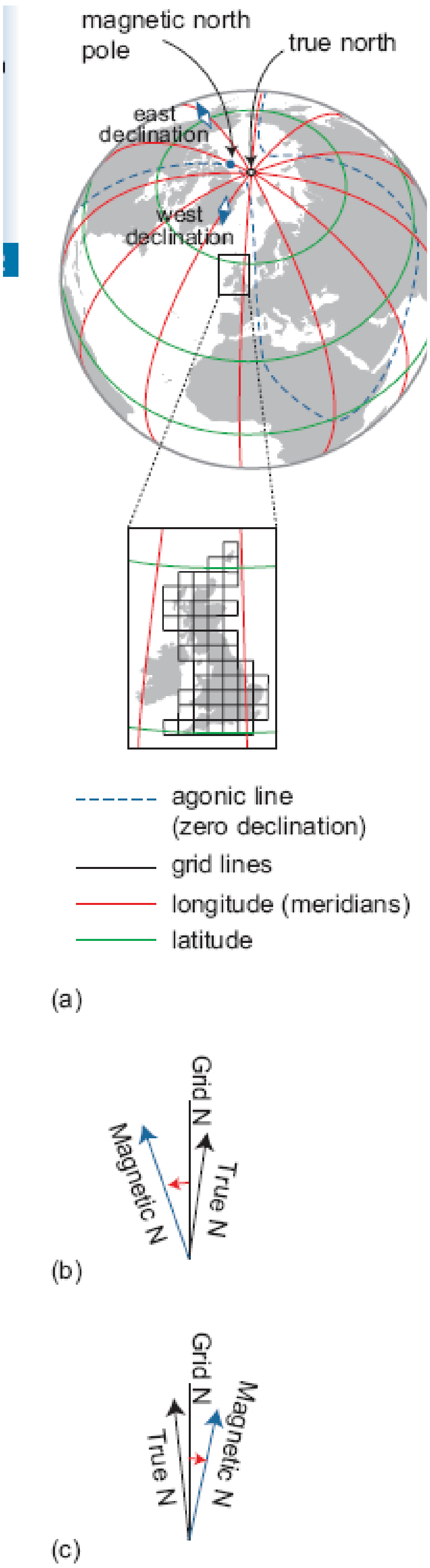

magnetic north pole
true north
east declination
west declination
agonic line (zero declination)
grid lines
longitude (meridians)
latitude
(a)
Grid N
True N
Magnetic N
(b)
Grid N
Magnetic N
True N
(c)

Figure 2.4 (a) Simplified sketch of the Earth to show the relationship between magnetic declination, magnetic north, true north and, via the inset, the longitude, latitude and a grid system (in this case the UK grid squares). (b and c) Typical map information showing magnetic north, true north and grid north. The adjustment of the magnetic declination is shown by the red arrows; (b) is for a westerly declination of magnetic north from true north and (c) is for an easterly declination.

2.3.1 Orientation of a dipping plane

The most common type of measurement in geology is the orientation of a dipping plane: for instance a bedding plane, a cleavage plane or a fault plane. The following three parameters need to be measured and recorded: (1) maximum angle at which the plane dips (dip magnitude) in degrees relative to the horizontal; (2) the orientation of the plane relative to north (strike, i.e. orientation of the *horizontal* line defined by the plane) in degrees; and (3) the general dip direction (Figure 2.5) because from the strike alone the plane could be dipping in one of two directions at 180 ° to each other. To prevent confusion, strike is always recorded as a three-digit number and dip as a two-digit number. Apart from this convention on the number of digits, there are several equally valid and commonly used notations to combine the dip and strike; these are summarized later in Table 8.1 . For clarity, a consistent style of notation should be chosen.

Determination of the orientation of a dipping plane by the contact method

The orientation of a dipping plane is most commonly measured using the contact method. This is illustrated for the Silva – type compass - clinometer in Figure 2.6 type compass - clinometer in Figure 2.7 (pp. 14 – 15). The exact order that you complete the steps and obtain the strike and dip of the plane is not crucial; this will depend on the instrument used, field conditions and personal preference. What is important is ensuring that you record the three pieces of information (strike, dip magnitude and dip direction). Note that the order of the steps in Figures 2.6 and 2.7 is different to take account of the

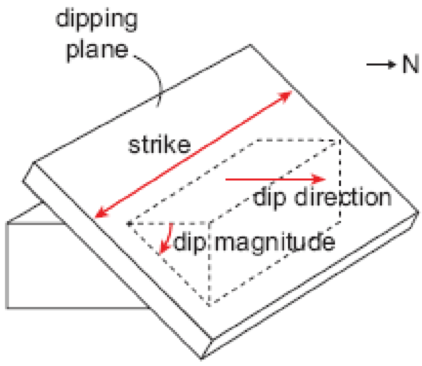


Figure 2.5 Sketch to show strike, dip magnitude and dip direction of a plane. See also Figures 2.6 and 2.7 . Using the north arrow shown this imaginary plane is striking east – west (270 ° or 090 °) and dipping to the north. Any direction down the dipping plane that is not at right angles to the strike will be an apparent dip direction and will have a smaller dip magnitude than the true dip magnitude.

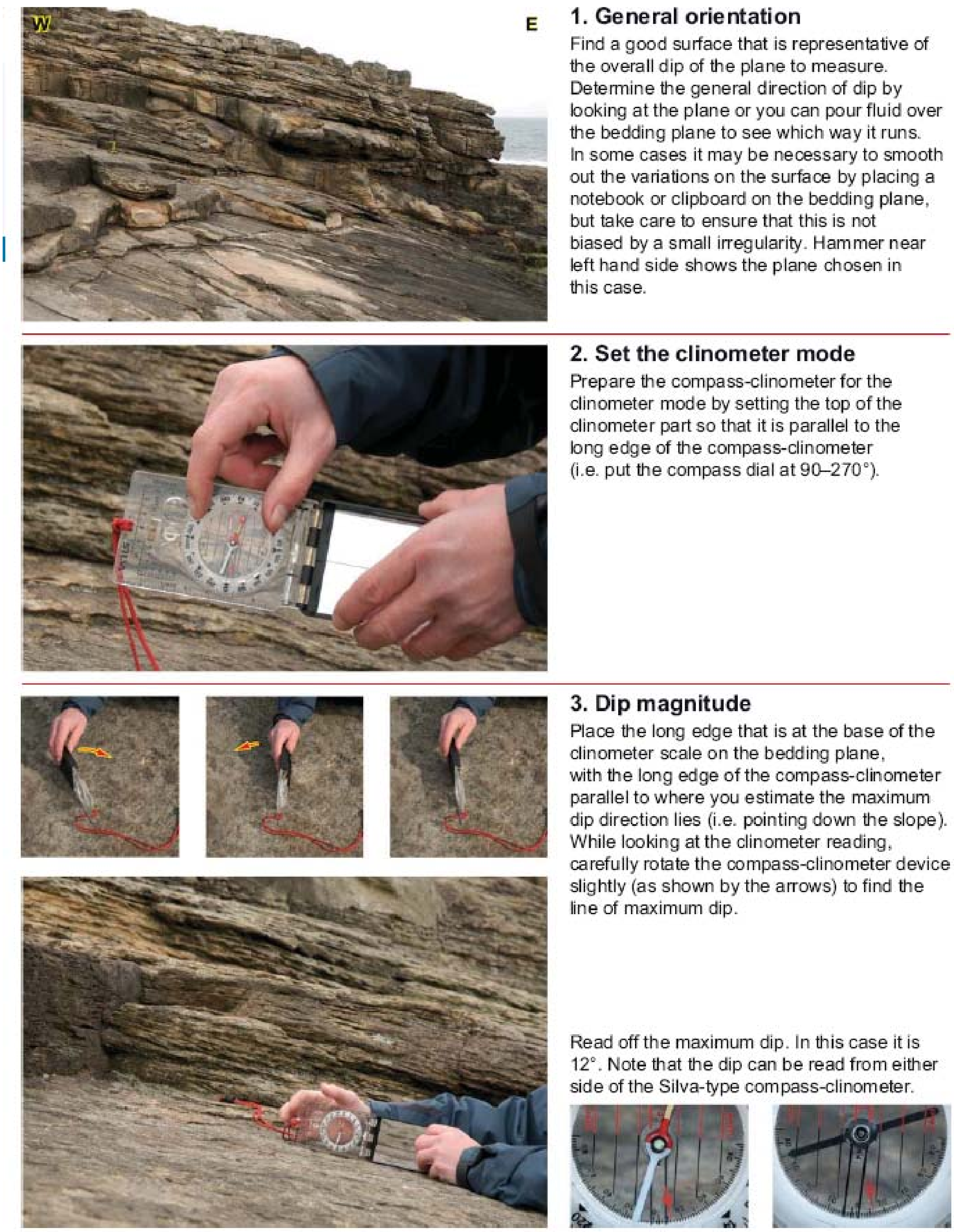


Figure 2.6 How to use the Silva - type compass - clinometer to measure the orientation and dip of a plane using the contact method. The parts of the compass - clinometer are shown in Figure 2.3 d and e.

4. Strike direction

The strike direction is exactly perpendicular to the dip direction, so remembering where the maximum dip lies, lift the compass-clinometer and place the long edge of the compass-clinometer along the line of strike. Pivot the compass-clinometer window (as shown by the red arrow) until it is horizontal.

Rotate the compass dial so that the compass needle lines up with the red outline for the north direction, checking that the compass-clinometer is still horizontal. Take the reading of the strike from the dial. In this case it is 008° or the other end of the line, 188°.

You can double check that the strike direction is correct by placing the compass on its long edge along the strike line and checking that the dip is 0° (don't forget to adjust the compass to the clinometer mode (step 2)).

5. Dip direction

The last measurement is the direction of dip to the nearest cardinal point (e.g. NW or SE, E or W).
In this case it is E.

6. Record

Record the orientation of the plane in your notebook; in this case 008/12E. Note that the strike is always recorded as a 3-digit number to avoid any confusion and that the degree symbols are not normally shown to prevent any confusion with zeros.

Figure 2.6 *Continued*

2.3.2 Orientation of a linear feature

The need to measure the orientation of linear features is common in sedimentary rocks and rocks that are deformed. The steps are similar to measuring a plane except that in this case the orientation of the feature with respect to north (the azimuth) is recorded by orientating the long edge of the compass - clinometer parallel to the linear feature (Figure 2.9). As for a dipping plane the azimuth should be recorded as a three – digit number and the plunge as a two - digit number. Alternative notations for the notebook to that shown in Figures 2.9.

measurement: (1) the azimuth is retained by the compass when one moves away from the sighting; (2) the map does not have to be orientated to transfer the measurement (step 3, Figure 2.12); (3) the transparent compass - needle housing makes transfer onto the map easier.

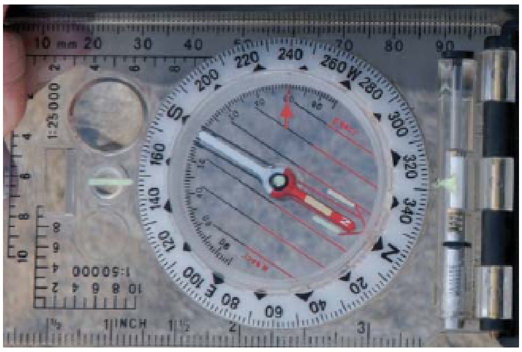
1. General orientation

Assess the linear feature and select a clear part to measure. In this case the feature is current lineation on a sedimentary bedding surface (parallel to the penknife). This feature can be used to obtain a palaeocurrent flow direction.

2. Azimuth

Place the edge of your notebook or clipboard on the linear feature, holding the book/clipboard vertical and parallel to the feature so as to create a vertical plane above it. Hold the long side of the compass-clinometer against the vertical side of the book and measure the azimuth of the lower end of the linear feature relative to north (i.e. the direction of plunge). For the Silva-type compass-clinometer you will need to rotate the dial until the magnetic needle is aligned with the north arrow of the compass. Ensure the compass window is horizontal before recording this measurement (for the Brunton-type compass you can do this by checking the round spirit level). In this case the azimuth is 148°.

Azimuth: Silva-type



Azimuth: Brunton-type

Figure 2.9

3. Plunge

Set the compass dial so that the instrument can be used as a clinometer (see Figures 2.6, 2.7). Place the compass-clinometer along the linear feature and read off the plunge angle from the clinometer. In this case the plunge is 15°.

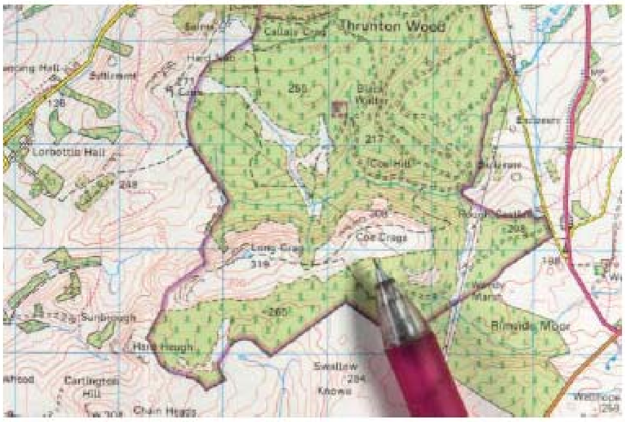
Plunge: Silva-type

Plunge: Brunton-type

4. Record

Record in your notebook the plunge as a 2-digit figure (15°) and the azimuth as a 3-digit figure (148°). For linear features the usual notation is the plunge first, then an arrow indicating 'to' and then the azimuth (15 → 148).

Figure 2.9 *Continued* Steps in the measurement of the azimuth and plunge of a linear feature (lineament) by the contact method – for both types of compass-clinometer. The parts of the compass-clinometers are shown in Figure 2.3.



1. Identify features

Identify two and preferably three distinct features on the map and on the ground from which to take bearings. In this case the purpose was to identify the location along the exposure known as Coe Crags (shown by the end of the pencil). Various landmarks can be picked out on the hills to the north.

2. Measure azimuth

Hold the compass at arm's length and eye level with the mirror tilted towards you so that you can see the compass window in the mirror and the compass window is horizontal (inset). Using the sight (i.e. small slot in middle of the short edge of the compass), align the feature with the sight. Rotate the compass dial so that the compass needle is aligned with the red outline for the north direction on the dial.

3. Transfer azimuth to the map

Lower the compass and place it on the map with the N–S grid lines on the compass dial (ignore the compass needle) aligned with the N–S grid lines on the map. Retaining this orientation place one edge of the compass adjacent to the feature that you have sighted. Draw a feint line on the map using the edge of the compass that passes through the object that you used for sighting. Your position is somewhere along this line.

4. Repeat stages 2 and 3

Repeat for at least one more feature. The point at which the lines intersect marks your position. See further notes on checking your position in Sections 2.3.3 and 10.3.

Figure 2.12 Triangulation using a Silva - type compass. Inset shows line of sight. The terms for the differentparts of the compass - clinometer are given in Figure 2.3 d and e. (Map extract asFigure 2.11 . © Crown Copyright 2010. All rights reserved. Ordnance Survey Licence number 100018362.)

2.4 Global positioning systems and altimeters

Global positioning systems (GPS) use ultra high - frequency radio wave signals from satellites to trigonometrically derive your position to within a few metres laterally. A wide range of GPS systems are available on the market and the reader should refer to specialist reviews and literature for more information. Increasingly, mobile phones contain a GPS unit. Global positioning systems units do not work in deep ravines and on some coastal sections; they are also not particularly accurate for altitude. The GPS can be set up for the particular grid system that you are working with or for a global reference that is based on latitude and longitude. The global reference World Geodetic System 1984 (WGS84) is the most commonly used. Instructions on how to set up your GPS will be in the manufacturer ' s manual. After setting it up or modifying any settings, for instance when you go to a new country, it is a good idea to test it out at a known location. The unit may take some time to locate the satellites if the GPS has been moved hundreds of kilometres. If you use a GPS together with hard copy maps as your main location device in the field you should ensure that you also have a ruler with you so that you can accurately plot your position. A GPS should not be a total substitute for basic navigation skills. You should also know how to locate yourself with a map and a compass so that if the GPS goes wrong, the batteries fail, or you are in an area where the satellites are obstructed, you have an alternative means of location and navigation. Alternatively if you are in an area of the world where the base maps are poor or only available at a small scale, a GPS reading will probably be more precise than compass triangulation and will more easily allow exactly the same locality to be found again. An altimeter is useful for recording elevation more precisely than a GPS when mapping or working in steep terrain, for instance recording a steep stream section. Altimeters use air pressure to measure elevation and this will vary with the weather. You need to calibrate your altimeter by taking a reading when you are at a known elevation at least once a day and throughout the day if the weather is changing significantly.

2.5 Measuring distance and thickness

Thickness and distance are two of the most basic measurements that need to be made for many geological tasks. For most of them a tape measure or folding ruler (Figure 2.13) will suffice but when working on slopes a Jacob staff and compass - clinometer can be useful

2.5.1 Standard thickness and distance measurements

A surveyor ' s 30 m tape is useful for large - scale measurements, for instance during regional mapping. Smaller, shorter and much cheaper, 2 or 5 or 10 m length, retracting metal - tape measures (Figure 2.13 , item 4) are, however, perfectly adequate for small - scale work and for graphic logging. The retracting metal - tape measures also have the advantage that they are stiff and therefore can be used much more easily to obtain an accurate measurement of the thickness of the bed by holding it perpendicular to the bedding. Folding plastic metric rulers that extend to 1 m or 2 m can be obtained in some countries and are very useful as a scale for photographs and for graphic logging (Figure 2.13 , items 2 and 3). These stiff rulers can easily be used to measure the thickness of partially submerged beds, for instance in a rock pool on the foreshore, and can be held at the bottom and pointed up cliffs to measure the thickness of otherwise inaccessible beds. They are also much easier to use when measuring on your own because the thickness of beds that are greater than that of your arm span can be measured. A pole of known length or a long steel rule or wooden rule can also be used for this purpose and for general measurements (Figure 2.13 b). When measuring the dimension of a geological feature it is important to ensure that you have not overestimated the distance by placing the tape oblique to the bedding plane. For instance, in Figure 1.1 a to obtain a true thickness the top of the tape would need to be placed closer to the bed so that it was perpendicular to the bedding plane.

When dipping rocks are exposed on a horizontal surface only (e.g. on a quarry floor, in a stream section or in the foreshore) it is very difficult or impossible to measure directly a true bed thickness. By measuring the horizontal distance perpendicular to strike (d) and the angle of dip of the beds (θ) this can be solved (Figure 2.14). The true thickness is given by the equation:

True thickness = $d \sin \theta$

This technique can be used to obtain a very good estimate of the thickness of beds, to estimate the distance over which beds are not exposed (for instance on the foreshore between resistant beds when the non - resistant bed is covered by beach deposits) or to check the cumulative thickness of a series of dipping beds. If the thickness of a bed is critical to the objective of the fieldwork it is always a good idea, if possible, to measure the thickness in more than one way, for instance by measuring each bed individually and then by measuring the thickness of a group of beds.

(a)

(b)

Figure 2.13 (a) A variety of useful tape measures for fi eld use: 1, surveyor ' s tape; 2, folding rule; 3, 1 m folding rule; 4, retracting metal - tape measure. (b) Home - made wooden pole with decimeter graduations to give a general idea of scale.

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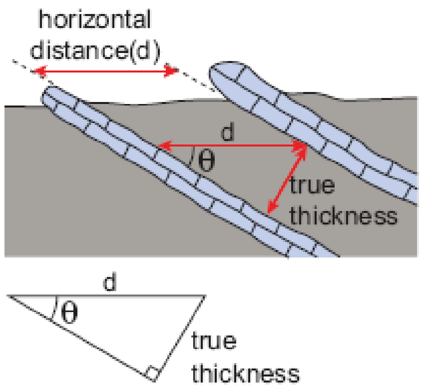


Figure 2.14 Sketch to show the basic trigonometry for obtaining a true thickness by measuring the horizontal distance between dipping beds.

2.6 Classification and colour charts

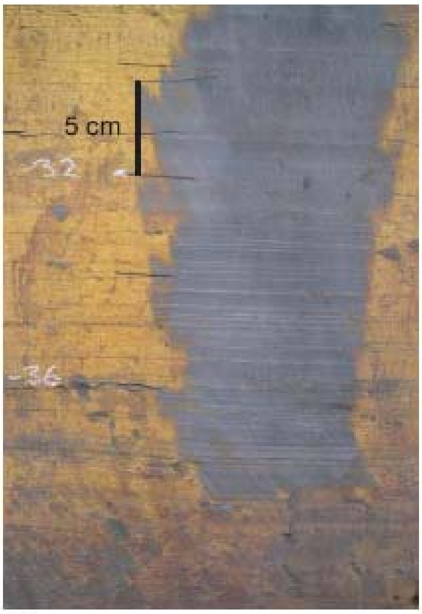
Various well - established comparison charts can be used to provide a semi - quantitative description of the rock and any changes in it. These include grain - size charts and rock classification diagrams. The figures commonly used are included in the appendices at the end of this book but charts such as those for grain size and texture can also be purchased for use in the field. The grain size chart should be used by placing the edge of the card on top of a clean fresh surface of rock and comparing the grain size on the chart to that of the rock until a match is found for the average grain size and if appropriate the maximum and minimum size (appendix). If the grain size is small it might also be necessary to use a hand lens on the card and rock. If the rock is poorly consolidated, scatter a few representative grains across the grain - size images to determine the average size. Weak hydrochloric acid can be used to test for carbonate. A fresh surface of the rock free from any coating minerals and weathered coating must be obtained before dropping acid on the rock. The acid will fizz strongly with fresh calcium carbonate but much less strongly for dolomite (calcium - magnesium carbonate). Freshly powdered dolomite will fizz more readily. Health and safety precautions for the handling of acid should be followed. In sedimentary rocks an easier and less destructive method of determining whether there is carbonate is to test the hardness of the rock. The most common colourless minerals in sedimentary rocks are quartz and calcite (with feldspar less frequently). Quartz will scratch steel.

2.7 Hammer, chisels and other hardware

A geological hammer is necessary for most geological fieldwork, both for the collection of samples and, where necessary, to create fresh surfaces so that the rock and the minerals within it can be described (Figure 2.18). Having said this it is perfectly possible to do a lot of geological fieldwork without a hammer provided samples are not required. Rocks that are exposed in sea - cliffs and along foreshores, in new trenches or in road cuts often do not need hammering and indeed the slightly weathered or wave washed surface is often as good as, if not better than, a hammered surface. For sedimentary rocks a 1 lb (*c.* 0.5 kg) hammer is often sufficient. For igneous, metamorphic and hard or well - cemented sedimentary rocks a 2 lb (*c.* 1 kg) or even a sledge - hammer may be necessary if good quality and/or large samples are required. However, a good chisel or pick hammer can be used to exploit planes of weakness (joints, bedding planes, foliation, vein margins) and extract samples from tougher rock types. Matters of conservation should always be considered. For safety reasons it is important to use a geological hammer rather than one designed for other materials such as wood or metal. This is because to hammer rocks you need a head that is robustly mounted on to the hammer shaft, made of a suitable grade of steel that will not splinter and is of an appropriate ergonomic design. Brick and stone hammers can be used if a specific geological hammer is not available. Other features to consider when purchasing a hammer are the type of head that is most suitable for your use and whether it feels comfortable when you use it. All geological hammers have one flat face: the other end is either a chisel or pick (Figure 2.18). The chisel end is useful for splitting rocks apart although it is not as effective or accurate as using a hammer with a separate chisel; the pick is useful for hammering into crevices to lever samples out and for generally weakening a rock surface before extracting a sample. Some geological hammers have the head and shaft all cast from one piece of metal and this makes them exceedingly robust; however, they pass more of the impact from hammering through the shaft and into your hand and arm. The other option is a steel head mounted on a wooden or fibreglass shaft. The shaft on these absorbs most of the impact; however, the head on this type of hammer can work its way off. This is, however, very uncommon with the new fibreglass models. Note that the rust on the hammer or chisel that is an inevitable consequence of use in wet conditions (e.g. Figure 2.18 items 2, 4, and 5) is a potential contaminant for samples being used for geochemical analysis. The hammer can be cleaned with a wire brush and wire wool (e.g. Figure 2.18 , item 1). If the rocks have no good partings or fractures and/or precisely placed samples are required, it is best to use a chisel. Many of the larger cold chisels are now supplied with hand guards (Figure 2.18, item 3). For delicate specimens such as fossils or minerals a small pencil chisel is useful (Figure 2.18, item 6). If you need to do lots of chiselling, a lump or crack hammer may be useful (Figure 2.18, item 8). For unconsolidated and poorly consolidated sedimentary deposits a spade or hoe pick and/or a masonry trowel is invaluable for removing the weathered or slipped material on the surface and then cleaning the surface so that the sedimentary structures can be seen (Figure 2.19 a). If the surface of the rock is hard and coated with a thin layer of lichen, moss or iron minerals and there is not an alternative exposure surface, a hard nylon brush or a wire brush can be used to clean the surface (Figure 2.19 b).

Figure 2.18 Some of the different geological hammers and cold chisels available on the market. (1) Estwing pick end hammer, (2) Estwing chisel end hammer, (3) cold chisel with hand guard, (4 and 5) 2.5 lb and 1 lb geological hammers with fibreglass shafts, (6) pencil chisel, (7) tile scribe and (8) 3 lb lump hammer.

(a)



(b)

Figure 2.19 (a) Poorly consolidated sandstone showing current – formed climbing ripples. This structure has been revealed by carefully scraping the surface of the sandstone with the edge of a trowel. An unprepared surface lies to the right and at the level of the trowel. Shellingford cross – roads quarry, Oxfordshire, UK. (Angela L. Coe, The Open University, UK.) (b) Lower Jurassic mudstones shown with the surface iron coating (yellow) and after a clean surface was obtained through vigorous wire brushing. Note how the scraped surface shows laminations that were not previously apparent. Deep scratch marks are 5 cm apart. Such slight surface abrasions quickly weather and do not pose significant conservation issues. (Anthony S. Cohen, The Open University, UK.)

2.8 The hard copy field notebook

Except for safety equipment, provisions and suitable clothing (Table 2.1), the hardcopy or electronic field notebook is probably the most essential piece of field kit. There is a wide range of hardcopy notebooks suitable for fieldwork available on the market and the choice is a matter of identifying something suitable for the particular task that is to be undertaken and personal preference. The advantages and disadvantages of different features are listed below.

• *Hardback or softback*: Given that the notebook will need to be used outdoors hardback notebooks are more robust and are therefore recommended. Some notebooks have a soft inner cover and an outer plastic cover and these are also relatively robust.

• *Size*: The size of the notebook is a matter of personal preference. Points to consider are the normal size of your handwriting, how you will be carrying it, how much sketching you need to do and whether you will be working in awkward places, for instance in a confined space where a small notebook can be easier to hold. Many professional geologists use notebooks that, when closed, are about 15 * 20 cm, although some prefer a larger size of about 30 * 20 cm.

• *Sewn, glued or spiral binding*: Sewn and ring bindings are robust in the field. Glued bindings can fall apart unless they are very well secured and are therefore not recommended. Spiral bindings enable the notebook to be bent back on itself, which is useful if the notebook is large; however, in these notebooks it is less easy to use facing pages as is sometimes required. In addition, the pages can accidentally tear out and become lost.

• *Plain, lined or graph paper*: Again this is very much a matter of personal choice. Plain paper allows the most flexibility and is particularly good for sketches, but lines or a grid can help to order the notes, and they are also useful for scale and guidelines in fi gures and tables.

• *Standard paper, water resistant and fully waterproof paper*: Poor quality paper soon disintegrates under extensive field use or in adverse conditions. It is therefore well worth purchasing a notebook with good quality paper. Some surveyor ' s notebooks have water - resistant paper that lasts well during extensive field use. Most art sketchbooks have good quality paper. It is also possible to purchase notebooks with totally waterproof paper; these are excellent in areas where the weather is particularly wet or that involve working close to water, for instance on a foreshore or in river sections where the chances of the notebook getting wet are high.

• *Position of the hinge*: Some notebooks hinge along the top edge whereas others hinge along the right - hand edge. This is worth considering in conjunction with whether you are right or left handed.

2.10 Writing equipment, maps and relevant literature

2.10.1 Writing equipment

• *Pencils*: Several pencils for recording notes and sketches are essential. Mechanical pencils (also known as propelling pencils) work well for notes and labels on sketches. Conventional pencils tend to work better for the line work of different thicknesses and shading in sketches. Leads for either mechanical or conventional pencils of HB to 2H hardness are appropriate for most purposes. Leads of H or greater hardness have the advantage of being fairly permanent and not smudging as the notebook becomes used. Softer leads of B and 2B are useful for writing on damp paper without tearing it, for shading and for very cold conditions. Under hot conditions pencils of 2H or greater will not tend to smudge as much.

• *Pens*: Most geologists never use pens in the field whereas a few prefer them. Pens have the disadvantage that the work cannot be erased and they are not always reliable under outdoor conditions. Care needs to be taken to ensure that the ink is waterproof and also that it does not blot under hot conditions. Ball point pens will not write on damp paper.

• *Pencil sharpener or penknife*: Conventional pencils will need to be sharpened. A good quality sharp pencil can make all the difference between neat and untidy notes. If the pencil is being used for shading it often works better if it is slightly blunt.

• *Coloured pencils*: A few coloured pencils are useful in the field for recording specific items, e.g. samples

.• *Eraser*: Essential for correcting mistakes and/or improving parts of the sketches.

2.10.2 Maps and relevant literature

Geological and topographical maps, field maps *, photographs, published papers, etc., can form an essential part of your field tools. A topographic map for locating your position is fairly essential; aerial photographs are also useful for this. If the area and exposures are well studied and part of the objective of your fieldwork is to assess and/or correlate your work with published material then you will need to take key publications and/or relevant sections from these into the field. This will enable you to check up on the details of these previous studies and to correlate your new data with those of others. It is much easier and more useful to do this in the field where you can test different possibilities and identify key features that have been described in the literature than it is to try and do it when you return.

* Topographical base maps on to which geological information is added in the field are also referred to as field slips.

2.11 Comfort, field safety and field safety equipment

2.11.1 Clothes, backpack/rucksack and personal provisions

Fieldwork usually involves physical exertion and can involve being outside in extreme weather conditions and/or working in inhospitable or remote areas. For these reasons it is important to select comfortable clothing and to be prepared for a range of conditions. Find out the expected weather conditions in the area at the time you will visit. Most mountain walking and outdoor clothing is suitable. An outer layer with pockets to store field equipment such as pens, pencils and compass -clinometer so that they are readily accessible is useful. Alternatively, a small shoulder or belt - mounted bag is useful for this field equipment together with your notebook. If you are working in an area where you may get wet it is important to wear clothes that dry relatively quickly for comfort and to prevent exposure. If you are working where conditions are hot, loose clothing made from natural fabrics is often the most comfortable and it is advisable to cover most of your exposed skin to protect against sunburn. On most geological fieldwork it is essential to wear a hard hat; head protection (either a sun hat or large piece of material) should also be used when you will be under the sun for prolonged periods. A hat is also important in cold conditions to help prevent heat loss. A backpack/rucksack is usually essential to carry all your field equipment, food, drinking water, first aid and spare clothing. Further advice on clothing and personal field kit can be found in mountain walking guides.

2.11.2 Field safety

It is essential that you plan for emergencies and for hazards particular to the area that you are visiting. There are, however, three aspects that are important for safety in the field anywhere: For robustness under field conditions it can be useful to laminate maps or diagrams such as fossil identification charts or stratigraphic logs that are used regularly.

(1) Be prepared

Ensure that you or one of the members of the field group have the correct equipment and that it is all in good working order, but also the means to locate yourself and to return via a safe route to civilization (i.e. a map and compass and/or a GPS), enough food and drink for the time you will be spending in the field along with some emergency rations, sufficient clothing for the expected range of weather conditions, a first aid kit and the means of raising the emergency services (i.e. mobile phone, radio or satellite phone; Table 2.1). At least one member of the party should be trained in first aid. If required by your field organizer, university or employer you should complete a risk assessment form (example risk assessments are provided on the website that accompanies this book – www.wiley.com/go/coe/geology). The party members should also decide whether they are physically fit enough to traverse the terrain that they will encounter.

(2) Assess and monitor the potential hazards

If possible, assess the hazards before going into the fi eld area either by talking to someone who has been before or with the use of maps, guidebooks to the area, satellite images (such as Google Earth TM), aerial photographs and field photographs. Even if you are able to assess the hazards prior to your visit, or it is a locality you have visited before, it is still necessary to
constantly monitor any potential dangers whilst you are in the field. If it is really dangerous and there is a high probability of injury or worse you should be prepared to

discontinue fieldwork at this locality. Common hazards and the preventative action that can be taken to avoid them are as follows.

• *Falling rocks*: Avoid areas of recent rock fall and/or areas with large overhangs or unstable faces. Wear a hard hat that meets safety standards at all times. Take care not to dislodge rocks onto other people. Many cliffs and slopes become unstable as the weather conditions change, e.g. after heavy rain or as they dry out and heat up in the sun. If the rocks are often unstable observe under what conditions they are least likely to fall and complete fieldwork at these times if possible.

• *Snow avalanches*: These are only a hazard in high mountain areas where there has been snow fall. They are most common after new snow fall, on convex slopes of 30 – 45° and as temperature changes. You should ensure you know where avalanches occur, take note of any avalanche warnings, and pick routes that use uneven/wooded slopes or follow a ridge.

• *Mudslides and unconsolidated rocks*: Freshly formed mudslides and other water-saturated sediments are dangerous to walk on because of the possibility of getting stuck. Mudslides tend to occur during heavy rainfall and care should be taken to avoid areas where they are active.

• *Rising tides*: If you are working in a tidal coastal area ensure that you know the time and position of high tide, where any potential tidal cut - offs are along your access route, and be aware of any onshore winds or high surf conditions that will drive the tide in more quickly and potentially higher than average.

• *Slippery rocks*: Algae - covered rocks on the foreshore or stream beds can be exceedingly slippery. Avoid these areas wherever possible, for instance by walking above the high water mark on the beach or well below it where the algae has been scoured away by waves. The area will also tend to be less slippery when the algae - coated surfaces are dry.

• *Uneven surfaces and surfaces covered with boulders*: Ensure that you are wearing strong footwear that will protect your ankles, toes and feet, take your time to pick out a good route and ensure that you do not become fatigued and slip.

• *Unpredictable weather*: This can easily result in hypothermia, sunstroke or dehydration. Be prepared for the range of possible weather conditions. In hot conditions ensure you have something to cover your head with, sunglasses, sun block and plenty of fluids. In winter ensure you wear warm clothing and have good quality waterproofs, which will also protect you from the wind. A warm hat is essential since a significant proportion of the heat that your body generates is lost through your head.

• *Lightning*: If you are caught out in the open in a thunderstorm that is less than about 5 miles away, avoid sheltering under a tree or anything tall where lightning is likely to ground. If there is time, retreat from high ground. Crouch down in an open space touching as little of the ground as possible. If you are in a vehicle you will be fairly safe, but avoid touching any of the metal body of the car. If you are close to water (e.g. a lake or the sea) move away from the water ' s edge where lightning is likely to strike.

• *Dangerous beasties and plants*: Be aware of any local dangerous or poisonous biota, e.g. bees, wasps, snakes, leeches, scorpions, spiders, bears, poison oak (USA) and ticks, water - borne infections and how to deal with any other hazards that are particular to your field area.

• *Working machinery, toxic substances*: In quarries and mines, working machinery is a major hazard. The position of the driver in large diggers and excavators often means Equipment 39that they have a considerable blind area so special care must be taken. For hazardous substances follow the specific health and safety guidelines provided.

• *Fatigue*: Tiredness is dangerous because reactions are slowed. It is quite easy on fieldwork to work long hours especially when there are many hours of daylight. Maintain your normal working hours if possible and ensure that you eat and drink at regular intervals. In a party the leader or fist aider should look out for any members of the party who show fatigue, headaches or nausea and take appropriate action (e.g. for altitude sickness, immediate descent).

(3) Know what to do in an emergency

Members of the party should know who is trained in first aid. In larger field parties it is also advisable to set up a chain of command in case an incident occurs. Ensure that you know how to contact the emergency services, what the emergency telephone number is for the country that you are visiting, what the local mobile phone signal coverage is and where you have to go to obtain a signal. On many beaches with sea - cliffs and in mountainous areas the coverage is poor or patchy. In some parts of the world it may be necessary to carry a satellite phone or radio.

Working a lone

Sometimes, it may be necessary to do fieldwork alone. In this case regular (i.e. daily) contact should be maintained with someone who can organize help in the event that you go missing. In case help does need to be raised, it is also good practice to leave information indicating the route that you will take and where you will be working that day.

2.11.3 Field safety equipment

It is not only necessary and sensible to wear protective clothing when working in hazardous areas, it is also now law in much of the world, along with the completion of some type of risk assessment form. All safety equipment should be checked regularly.

• *Hard hat* : In areas where there are cliffs and therefore risk of rock falls a hard hat is essential. The hard hat will prevent concussion or skull fracture from rocks up to fist - sized; it will not, of course, protect you from much larger pieces of falling rock. The plastic builder - type hard hats with an internal plastic cage that is adjustable for the size of your head and leaves a space between the top of your head and the hat are adequate for most purposes. These are available from most builders merchants/hardware stores. In addition, more specialist hard hats can be used, e.g. rock climbing and caving helmets. The advantage of these is that they have a chin strap, which holds the hat in place; a disadvantage is that they often lack a brim at the front and therefore do not protect your face as well. Sunlight degrades plastics and they eventually become brittle so check that your hard hat has not exceeded its use - by - date. Hard hats with a small rear gutter are also useful in rainy conditions as it prevents the water running down the back of your neck.

• *Reflective clothing* : When working in quarries and at the side of a road it is often necessary and practical to wear specialist fluorescent clothing so that you can easily be seen.

• *Goggles* : When hammering rocks it is good practice to protect your eyes with goggles or wrap - around protective glasses to prevent eye injury from rock splinters. Rock splinter wounds are a reasonably common cause of injury among geologists. Depending on the type of rock being hammered it is also sensible to cover other bare flesh. There have been incidents with rock or hammer splinters from hammering not only entering a person ’ s eyes, but also neck, legs and arms. Different types of rock splinter in different ways. Igneous rocks, particularly peridotites, are very splintery, as are cherts. All items of field equipment should be checked regularly, for instance whether the head of your geological hammer is secure on its shaft and whether your hammer and chisels show any metal fatigue, spalling and cracks. Many cold chisels are now supplied with hand guards; these are very effective in preventing you from inadvertently hitting your hand with the hammer.

2.12 Conservation, respect and obtaining permission

For all geological sites on private land, or those that involve crossing private land to get to them, a member of the field party should first seek permission for the party to enter the land and if necessary to sample. This can be quite a complex process as it is commonly not obvious who owns the land unless it is something like a working quarry. Geological surveys, other geologists who have visited the area, local councils, national park authorities and people who live in the neighborhood may all be able to provide information. With all sites you should respect the land and follow the code for the area. Do not forget that other geologists may wish to visit the site too. In addition there may be local cultural, religious or national heritage codes of conduct that should be respected. These may in some cases not permit any access to certain sites and certainly not allow the removal of samples without special permission. Codes of conduct vary from country to country and area to area but most of it is common sense. Many countries have conservation or protected sites of either biological and/or geological interest. These sites are protected from building development but also special rules may apply to sampling *in situ* material and sometimes even to loose material.

Appendix

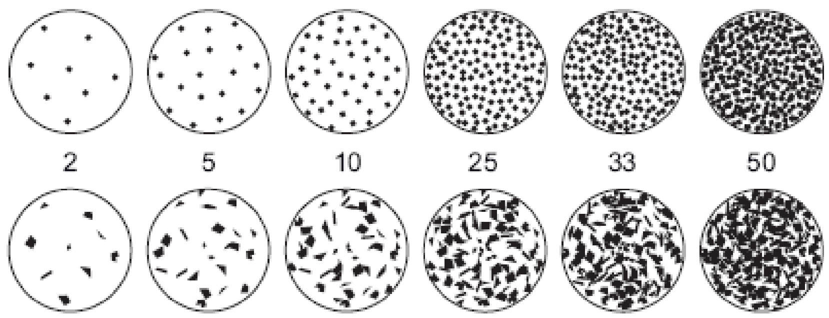


Figure A1.1 Chart to estimate percentage composition from area.

mm	grain term		sediment and sedimentary rock terms implying grain size	
	boulders		gravel, rudite, rudaceous sediments, conglomerates, breccias	
256	cobbles			
128				
64	pebbles			
32				
16				
8				
4	granules			
2	very coarse	sand	sand, sandstone, arenites, arenaceous sediments	
1	coarse			
0.5	medium			
0.25	fine			
0.125	very fine			
0.062	coarse	silt	silt, siltstone	mud, mudrocks
0.031	medium			
0.016	fine			
0.008	very fine			
0.004	clay		clay, claystone	

Figure A6.1 Grain-size descriptors.

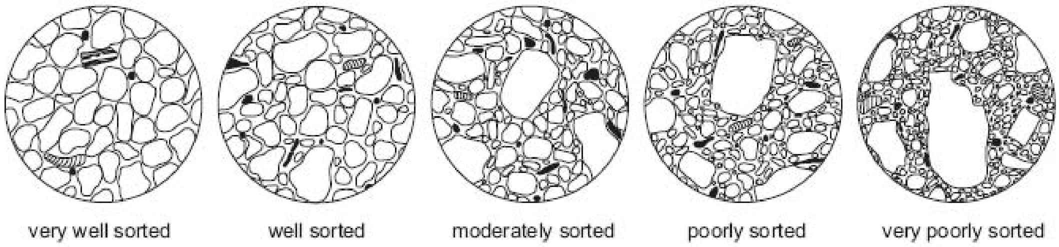


Figure A6.2 Comparison charts for particle sorting.

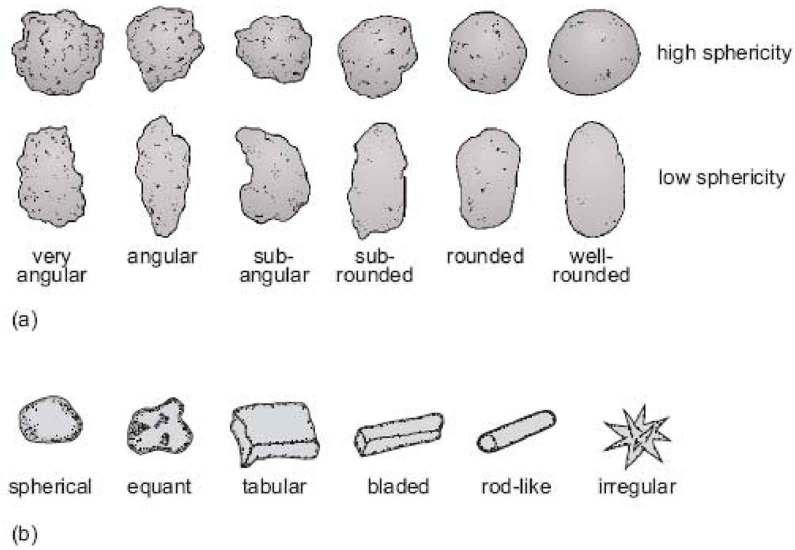


Figure A6.3 Comparison charts for grain morphology. (a) Rounding and sphericity. (b) Shape.

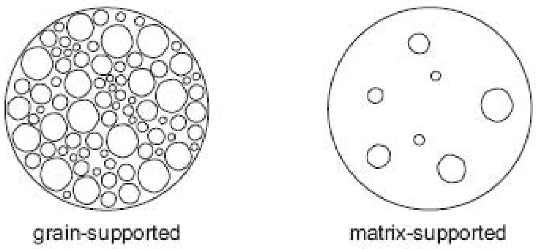


Figure A6.4 Comparison charts for grain fabric. It is also appropriate to note whether the grains are aligned if they are tabular of bladed.

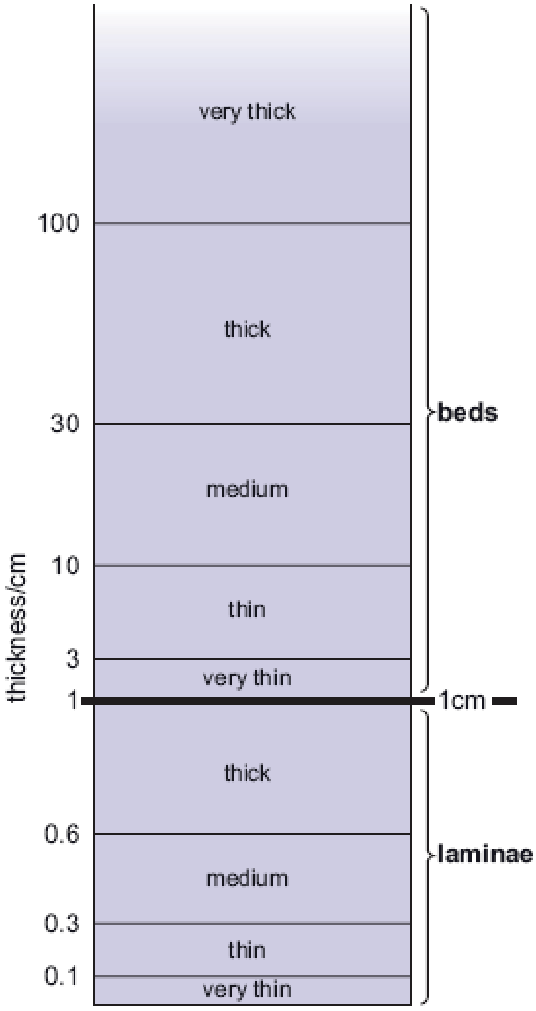


Figure A6.5 Terms for the description of lamination/bed thickness, etc.

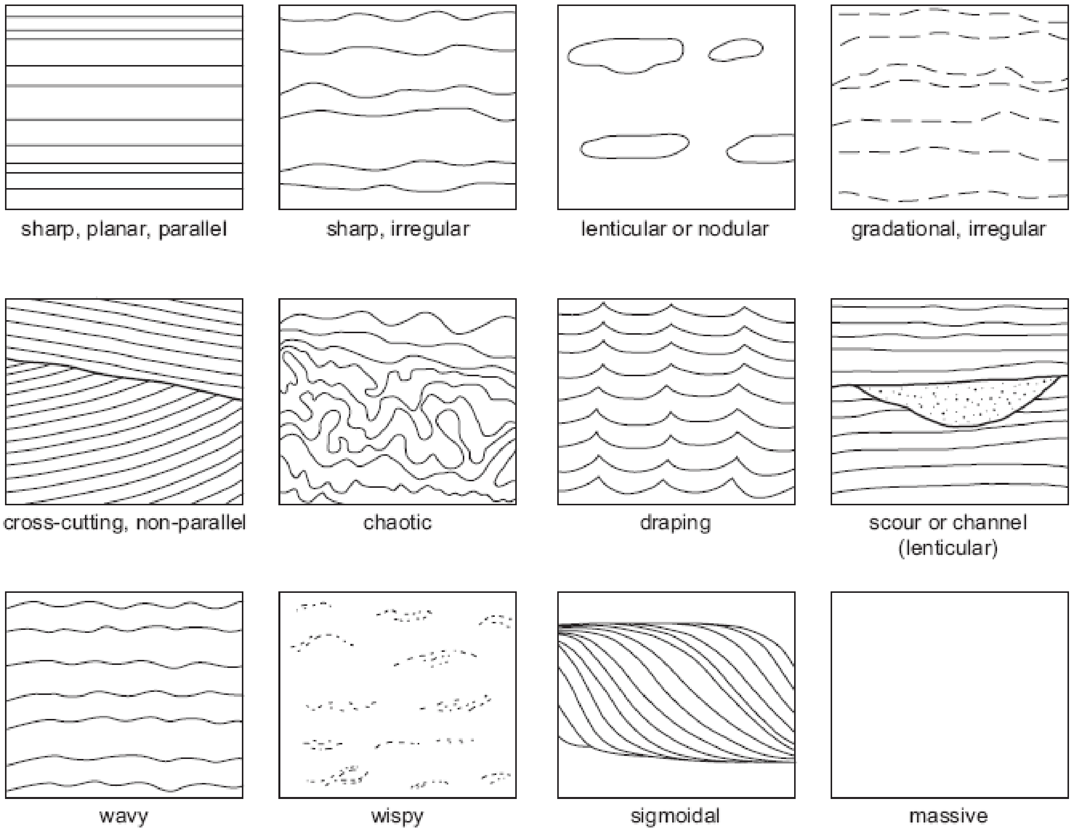


Figure A6.6 Terms for the description of bed character.

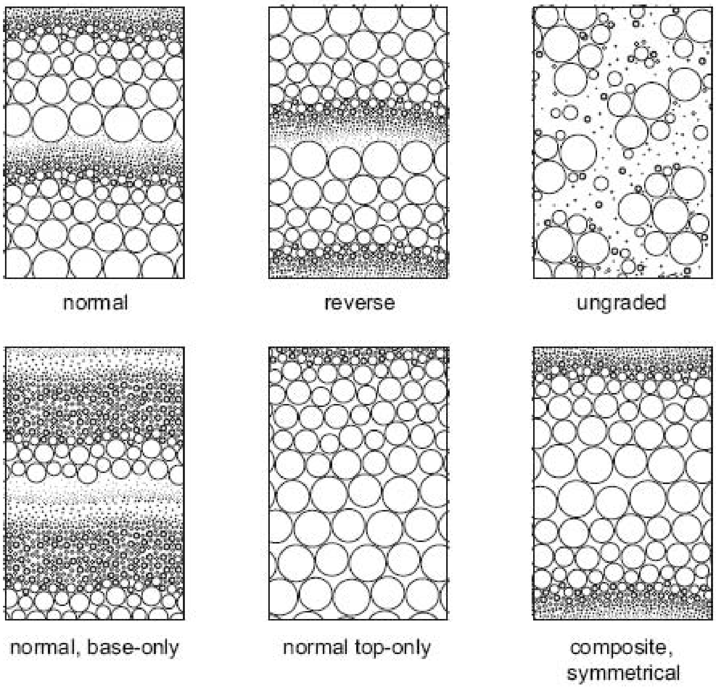


Figure A6.7 Different types of sedimentary grading.

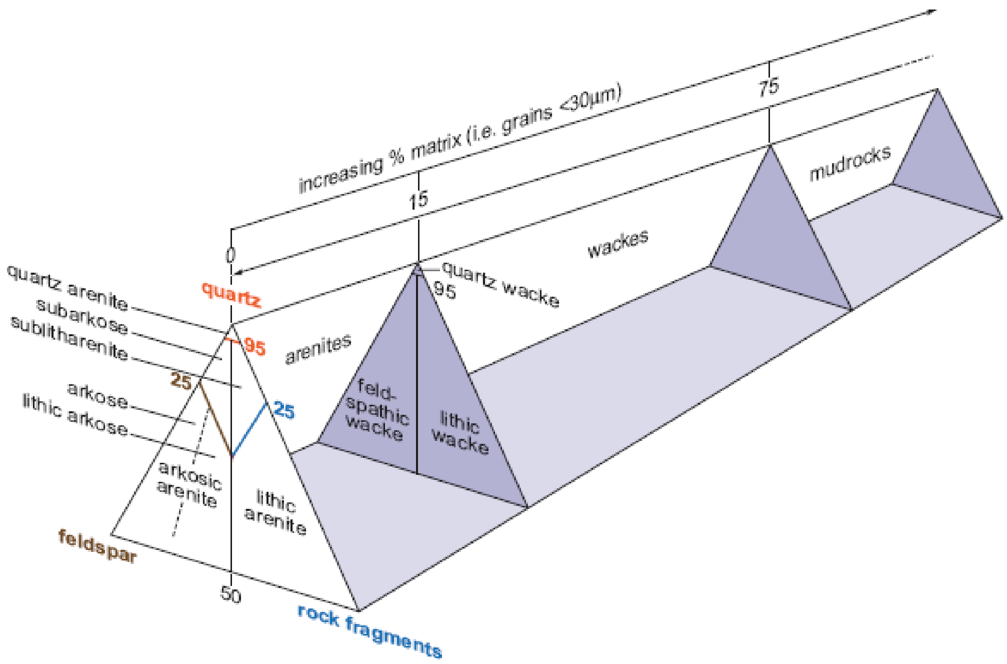
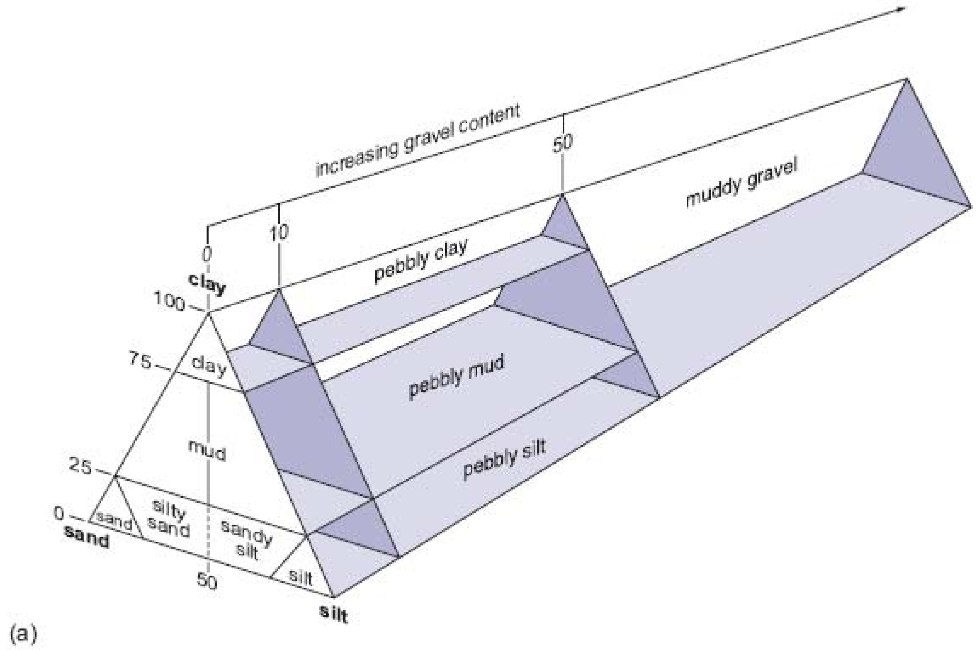


Figure A6.8 Classification of sandstones. (Modified after Pettijohn *et al.* 1973.)



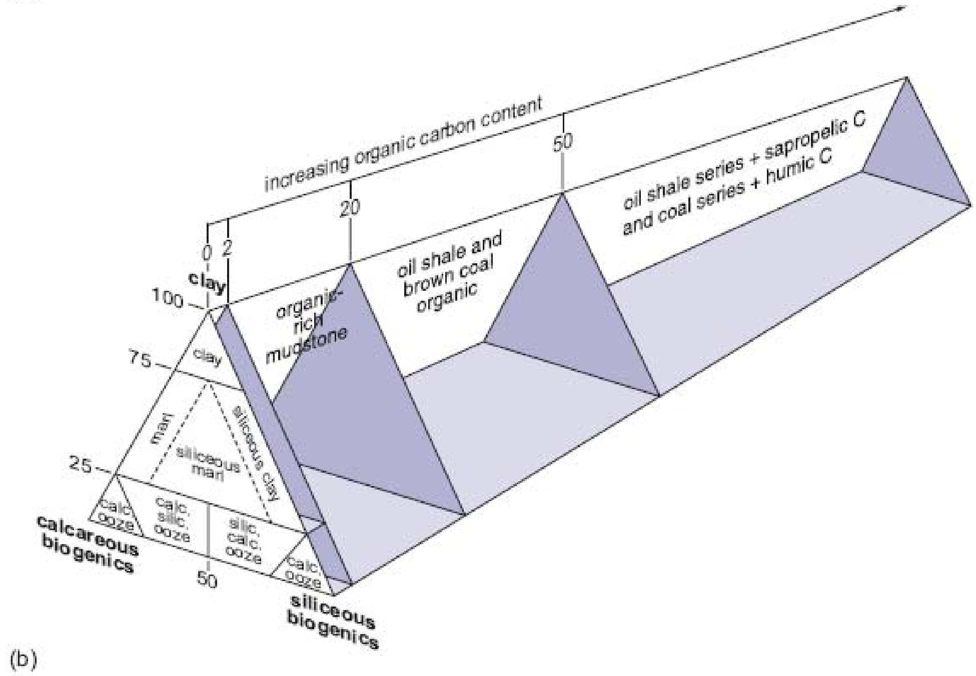


Figure A6.9 Classification of mudstones. (Modified after Stow 2005.)

(a) (b)

Figure 2.16 Use of a grain-size chart to determine the average grain size. (a) In this case the average grain size is 500 μm. The grain size varies between 375 and 750 μm. (b) Close up view of (a).

Table A6.1 Checklist for the description of sedimentary deposits.

Property		**Questions**
Composition	Grains	What is the composition of the most abundant grains?
	Matrix	Is there any fine-grained (clay-sized) fragmentary material infilling the spaces between larger grains? If so, what is it?
	Cement	Is there any crystalline material precipitated around the edges of grains, or in the spaces between grains? If so, what is it?
Texture	Grain size	What is the most abundant grain size present (use a grain-size card and Figure A6.1)?
	Grain sorting	Are the grains all more or less of the same size (i.e. well-sorted) or different sizes (i.e. poorly sorted) or somewhere in between (use the sorting scale; Figure A6.2)?
	Grain morphology:	See Figure A6.3
	shape or form	Are the grains long and thin or equidimensional?
	roundness	Do the grains have rounded or angular corners (use roundness scale)?
	sphericity	Are the grains like spheres (i.e. high sphericity) or are they elongate (low sphericity)?
	Grain surface texture	Are any quartz grains present smooth and glassy, or are they frosted?
	Grain fabric (packing)	Are the grains orientated in any preferred direction? Are the grains closely packed together? Are the grains matrix- or grain-supported? (See Figure A6.4)
Fossils		Can you see the remains of any body fossils or their movements (trace fossils)?
Sedimentary structures		Are there any obvious layers or other structures in the rocks? (See Figures A6.5–A6.7)

Table A6.2 Features of common minerals that constitute sedimentary deposits.

Mineral	Chemical formula and name	Colour in hand specimen	Cleavage	Other features in hand specimen	Form and occurrence
Quartz	SiO_2 (silica)	Translucent	None	Will scratch steel	Common detrital grain, also a cement
Clay minerals	Various hydrous aluminosilicates	Typically grey, green or red	Planar or none	Fine-grained	
Calcite (sparite and micrite)*	$CaCO_3$ (calcium carbonate)	Translucent or white; variety of pale colours due to impurities	Rhombic	Scratched by steel; fresh surfaces fizz with acid	Forms grains, matrix and cement in limestones, dolomites and sandstones
Aragonite	$CaCO_3$ (calcium carbonate)	White with a pearly iridescence	Rectilinear	Original aragonitic bioclasts are often preserved in marine mudrocks	
Dolomite	$CaMg(CO_3)_2$ (calcium magnesium carbonate)	Buff, cream	Rhombic	Fizzes with warm acid and very weakly with cold acid	
Feldspar	Various including $K(Na)AlSi_3O_8$ (orthoclase) and $Na(Ca)\ AlSi_3O_8$ (albite)	Transluscent or pink or white	Present	Scratched by steel; weathers to white, powdery clay minerals	Detrital crystals
Glauconite	$KMg(Fe,Al)(SiO_3)_6.3H_2O$	Green	Planar	Soft; weathers to the iron oxide limonite	Ooids, mud and peloids; forms exclusively in marine environments
Iron oxide	Various including Fe_2O_3 (haematite) and $H_2Fe_2O_4(H_2O)_x$ (limonite)	Red (haematite) or yellow-brown (limonite) or green	None	Often more apparent on weathered surfaces	Crystals, grains, cements and as replacements

*See note on p. 276 about distinguishing between micrite and sparite.

Distinguishing between micrite and sparite

Micrite and sparite are both forms of calcite, the only physical difference between them being the grain or crystal size. Micrite refers to calcite that is less than 4 µm (0.004 mm) in size and sparite refers to calcite that is greater than 4 µm (0.004 mm) in size. They can be distinguished in hand specimen; sparite is translucent or semi-translucent because the large crystal size transmits the light through it, whereas micrite is opaque because of its small grain size. Micrite is often white or cream but it can also have pink, yellow or even green tinges depending on the other minerals present. You may find it useful to wet the rock specimen before you look at it through a hand lens to distinguish micrite from sparite.

The distinction between micrite and sparite is important because it yields information about the depositional process. Micrite is precipitated and settles out from suspension at the time of deposition as a matrix, and indicates low energy conditions. In contrast, sparite is a cement which is precipitated after deposition. Sparite can be subdivided into several different types; including poikilotopic (large crystals enclosing several grains); drusy (small- to medium-sized crystals which increase in size away from the edge of the grains into the centre of the cavity); isopachous (a thin fringe around the grains); and syntaxial overgrowth (crystal in optical continuity with the grain it has overgrown).

mm	grain term		sediment and sedimentary rock terms implying grain size	
	boulders		gravel, rudite, rudaceous sediments, conglomerates, breccias	
256				
128	cobbles			
64				
32				
16	pebbles			
8				
4				
	granules			
2	very coarse	sand	sand, sandstone, arenites, arenaceous sediments	
1	coarse			
0.5	medium			
0.25	fine			
0.125	very fine			
0.062	coarse	silt	silt, siltstone	mud, mudrocks
0.031	medium			
0.016	fine			
0.008	very fine			
0.004	clay		clay, claystone	

Figure A6.1 Grain-size descriptors.

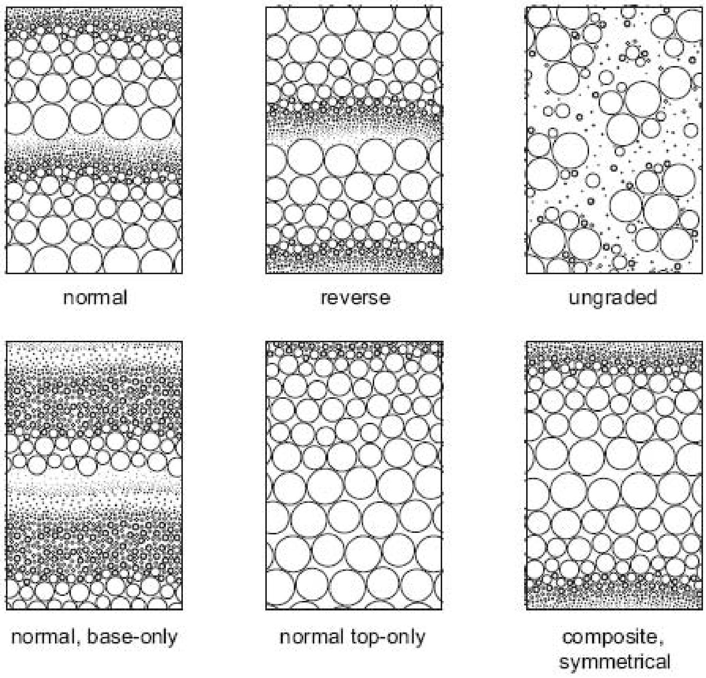


Figure A6.7 Different types of sedimentary grading.

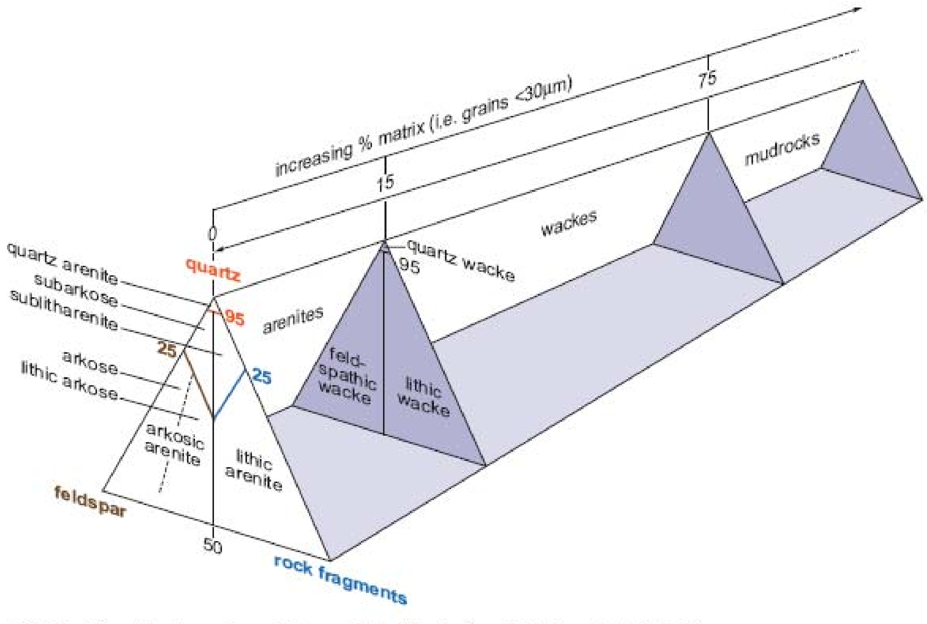


Figure A6.8 Classification of sandstones. (Modified after Pettijohn *et al.* 1973.)

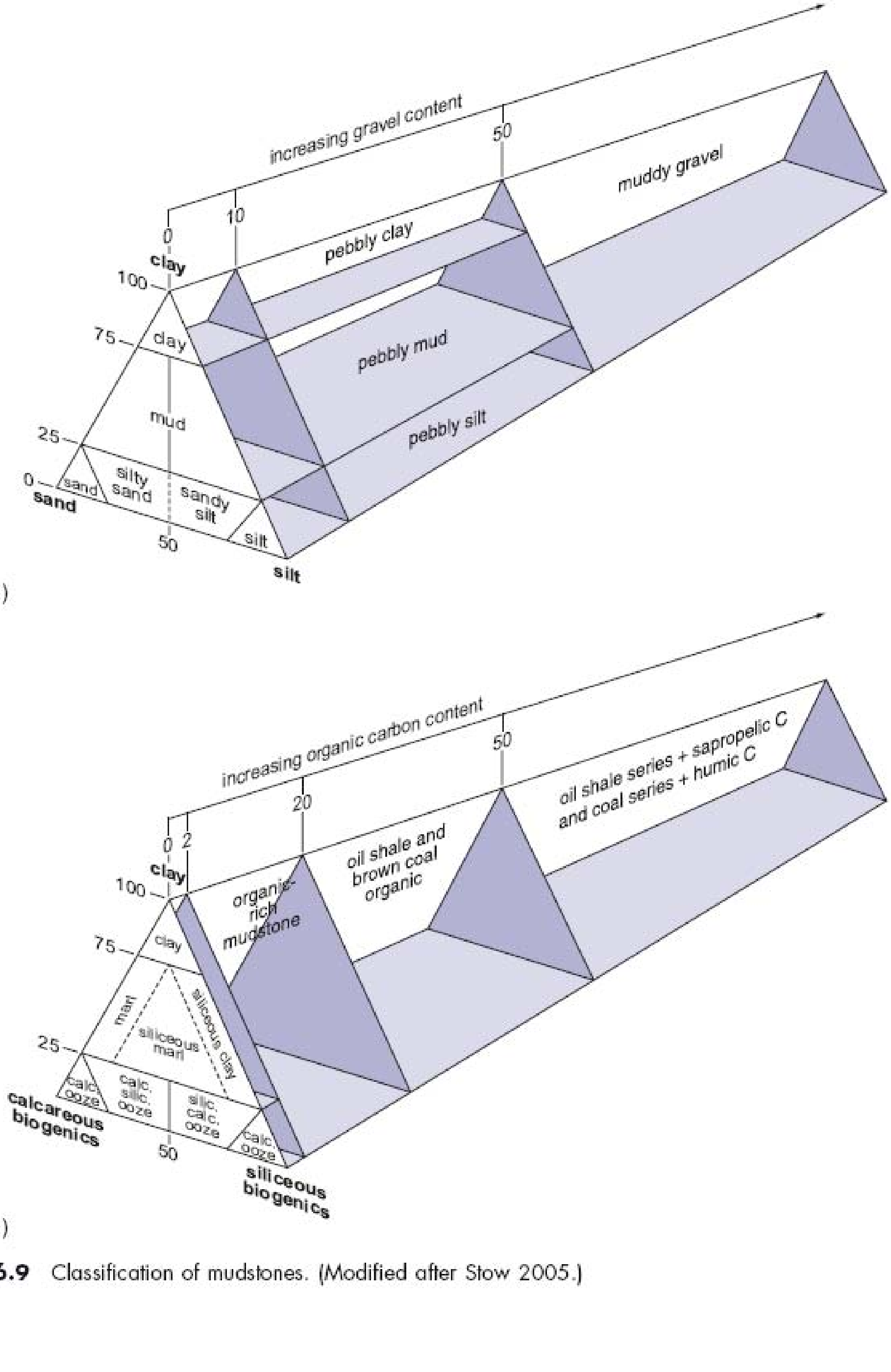


Figure A6.9 Classification of mudstones. (Modified after Stow 2005.)

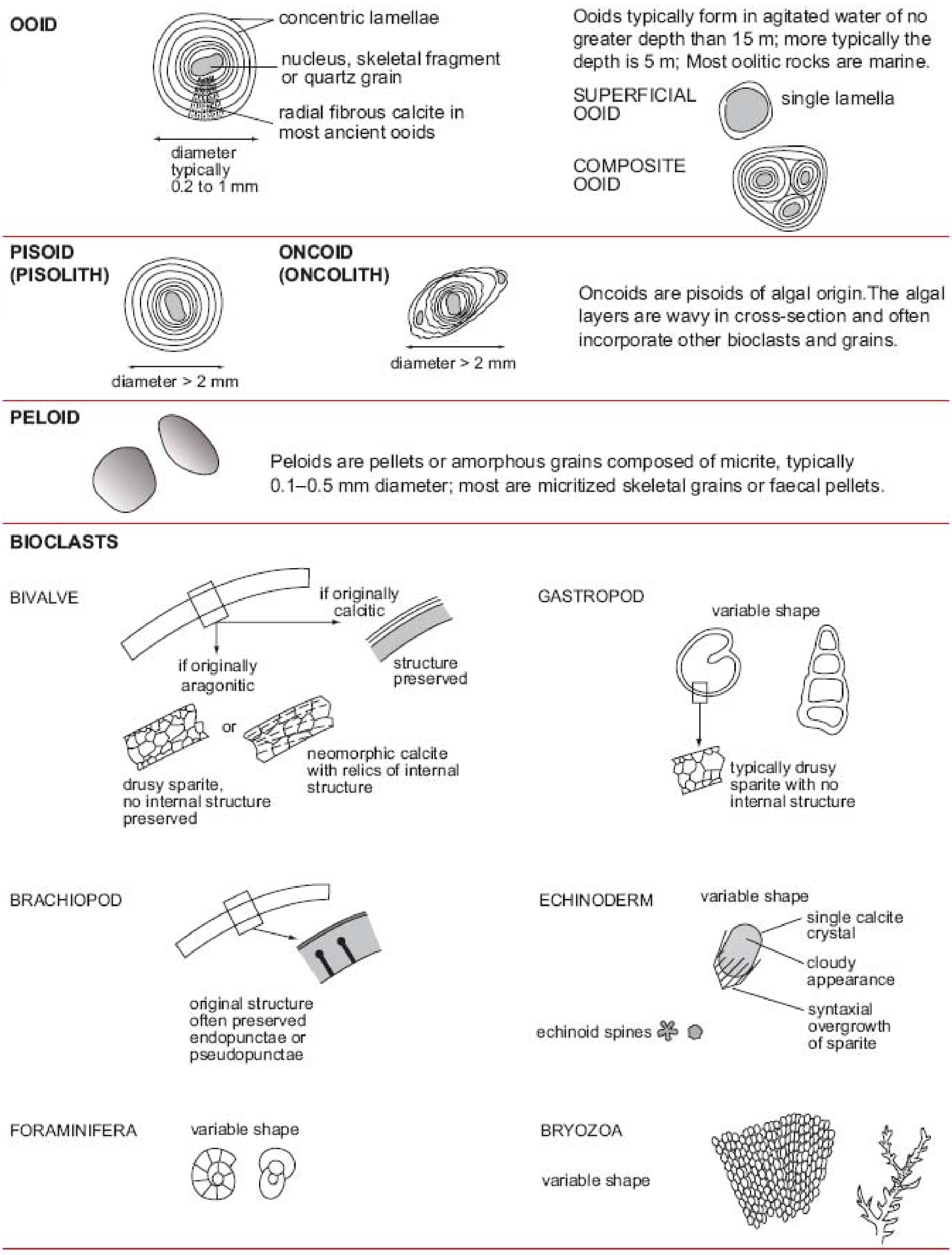


Figure A6.10 Main limestone-forming grains.

principal grain type	**limestone type**	
	cemented by sparite	micritic matrix
bioclasts	biosparite	biomicrite
ooids	oosparite	oomicrite
peloids	pelsparite	pelmicrite
intraclasts	intrasparite	intramicrite

limestone formed *in situ* (e.g. reef or stromatolite)= biolithite

fenestral limestone (micrite with cavities) = dismicrite

Figure A6.11 Folk scheme for the classification of limestones. (Modified after Folk 1962.)

original components not organically bound together during deposition						Boundstones: original components organically bound during deposition		
contains lime mud			lacks mud and is grain-supported	>10% grains >2 mm		organisms act as baffles	organisms encrust and bind	organisms build a rigid 3-D framework
mud-supported		grain-supported with muddy matrix		matrix-supported	supported by >2 mm component			
<10% grains	>10% grains							
mudstone	wackestone	packstone	grainstone	floatstone	rudstone	baffle-stone	bindstones	frame-stone

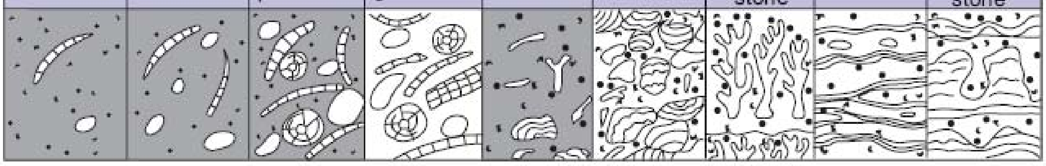


Figure A6.12 Dunham scheme for the classification of limestones. (Modified after Dunham 1962 with additions from Embry and Klovan 1971.)

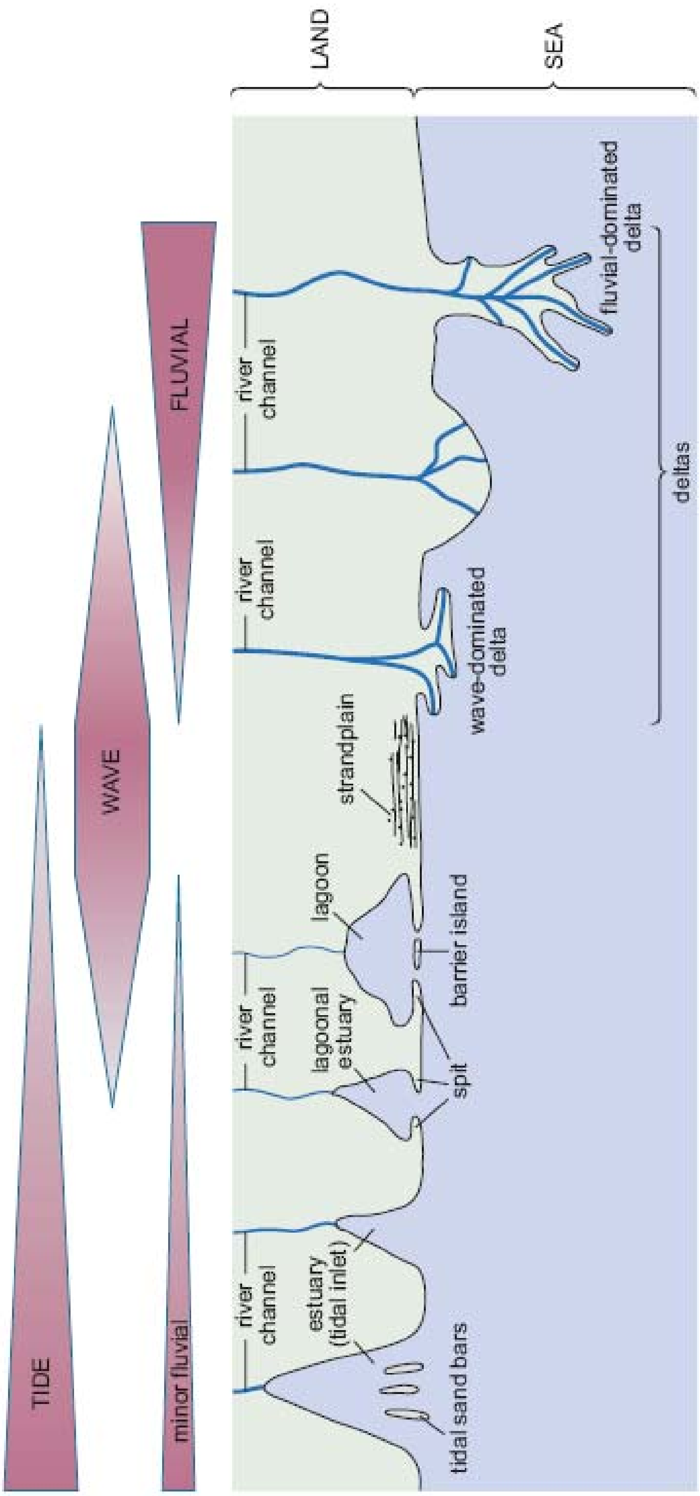


Figure A6.14 Sketch illustrating the spectrum of coastal morphological features and the processes dominant in each case. The importance of waves, tides and fluvial input is shown schematically by the boxes at the top of each figure; tapering of the box indicates less influence of that process.

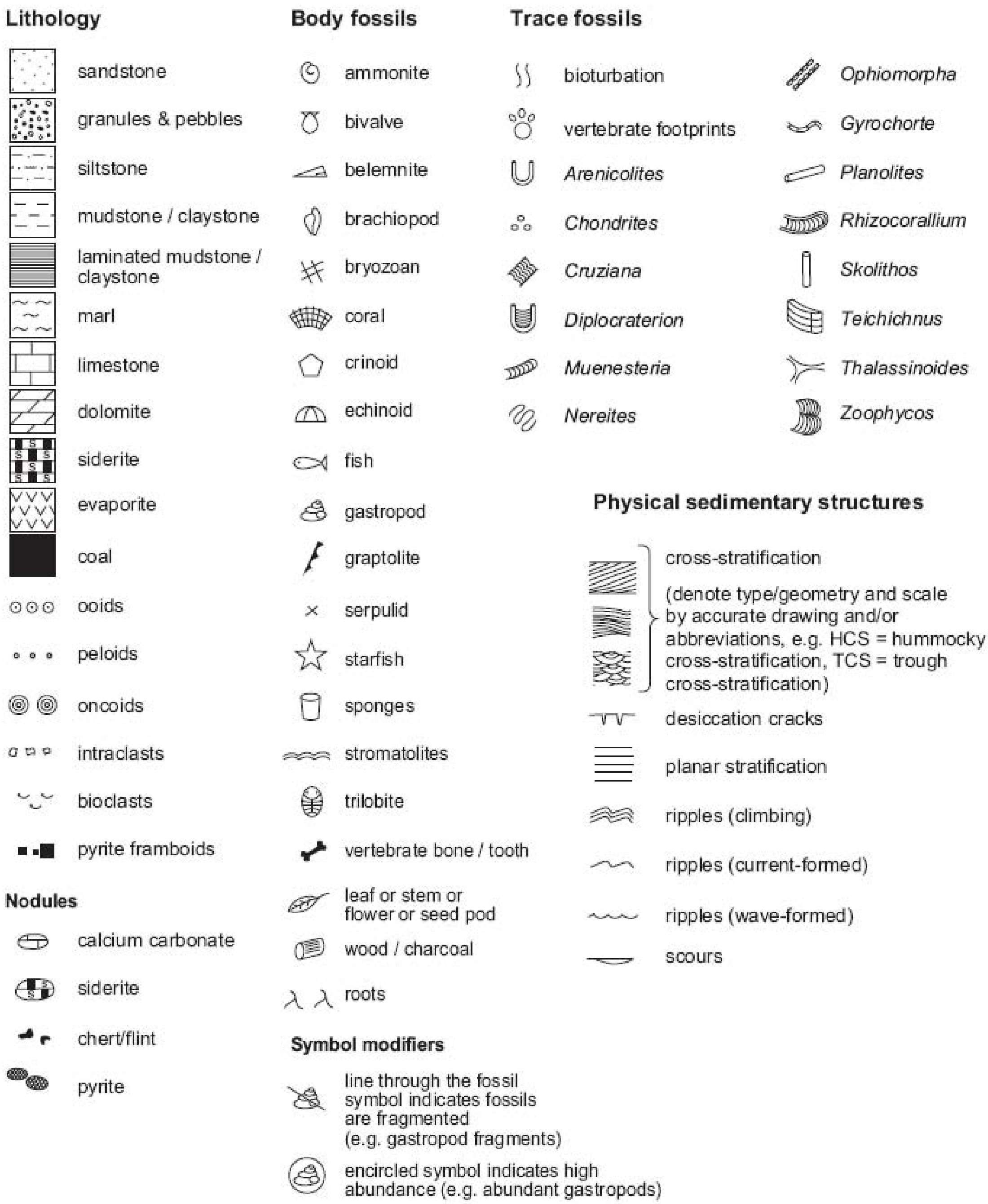
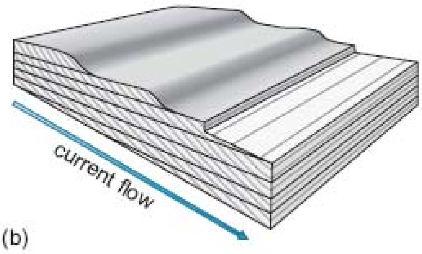


Figure A6.16 Some of the commonly used symbols for graphic logs and some ideas for other more specific features.

Planar cross-stratification

(a) plan view

Note: Structure needs to be examined in faces at right angles to confirm identification. Tabular beds and the horizontal lamination between the inclined beds as shown in (a) are consistent with planar cross-stratification.

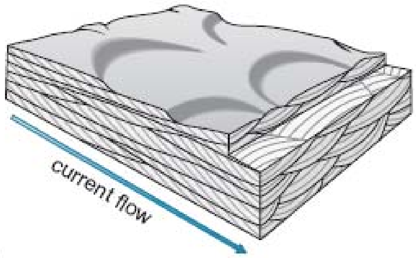


(b)

Trough cross-stratification

(c) cross-section

Note: Structure needs to be examined in faces at right angles to confirm identification. Lensoid shaped beds as shown in (c) are consistent with trough cross-stratification.



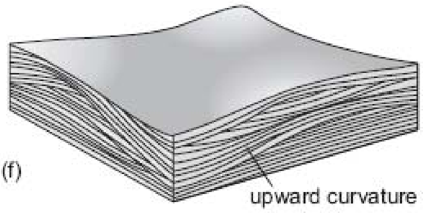
(d)

Hummocky and swaley cross-stratification

Hummocky cross-stratification (HCS)

(e) cross-section

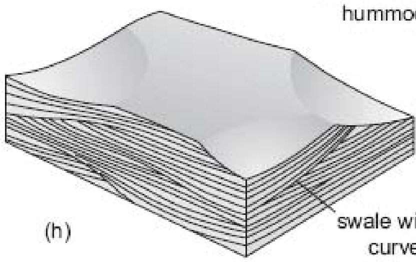
Note: Hummocky and swaley cross-stratification are part of a continuum. HCS has a 1:1 ratio of hummocks : swales whereas SCS is mainly swales as the hummocks have been eroded. For any location the wave length of the structure increases from HCS to SCS.



(f)

Swaley cross-stratification (SCS)

(g) cross-section

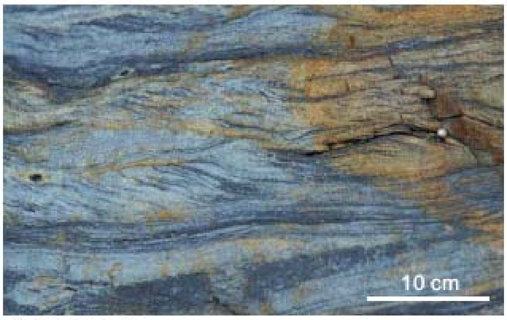


(h)

Figure A6.17 Common sedimentary structures. See also Tables 6.2–6.4. Red penknife is 9 cm long. (All Angela L. Coe, The Open University, UK, except (x) and (cc), R. Chris L. Wilson.)

Current-formed ripples

(i) plan view



(j) cross-section

Note: Asymmetric profile and relatively simple internal geometry of the inclined surfaces that build up as the ripple migrates.

Wave-formed ripples

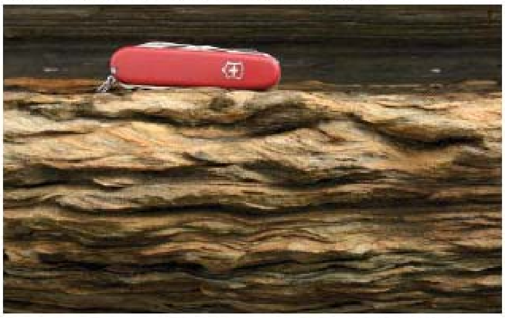
(k) plan view

Note: Asymmetric profile, bifurcating crests, complex internal geometry

(l) cross-section

(m) Cross-section of climbing wave-formed ripples

Wave-formed ripples with current



(n) cross-section

Complex wave-formed ripples formed within wave-base where there was also a dominant current. Note also the clay drapes.

Lenticular [l] and flaser [f] bedding

(o) cross-section

Tidal bundles

(p) cross-section

Note: Laminae are in multiples of seven and either widely spaced (spring tides) or closely spaced (neap tides).

Figure A6.17 *Continued*

Planar lamination

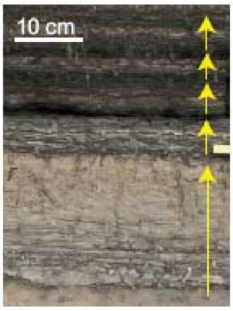
(q) cross-section

Current lineation

(r) plan view

Note: Looks like low amplitude ridges, best seen in low-angle lighting conditions

Grading



(s) cross-section

Coarsening-upward cycles with plant roots

(t) cross-section

Crudely fining-upward cycles

Evidence of desiccation

Desiccation cracks

(u) plan view

Pseudomorphs after halite

(v) plan view

Evidence for erosion

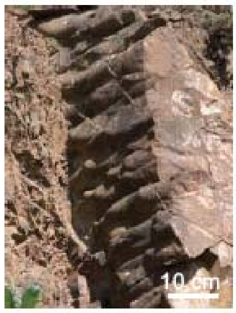
Scour

(w) cross-section

Groove casts

(x) underside

Flute casts



(y) underside

Figure A6.17 *Continued*

Nodules

(z) cross-section

Depositional evaporite nodules

(aa) cross-section

Early post-depositional siderite nodules (note ovoid shape)

(bb) cross-section

Late post-depositional calcium carbonate nodules (note spherical shape)

Evidence of dewatering

Load casts

(cc) plan view underside

Dish structures

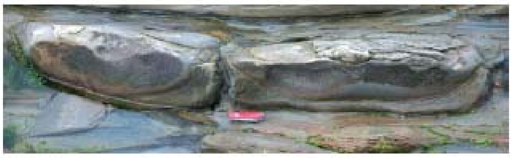
(ee) cross-section

Flame structures

(gg) cross-section

Note: Distinct flame shapes are flame structures. Otherwise this can be termed convolute bedding.

Ball and pillow structures



(dd) cross-section

(ff) cross-section

Leisgang rings and dendrites

(hh) plan view

Note: Both of these form during late diagenesis due to the precipitation of iron oxide (Leisgang rings) or manganese oxide (dendrites) in the rock.

Figure A6.17 *Continued*