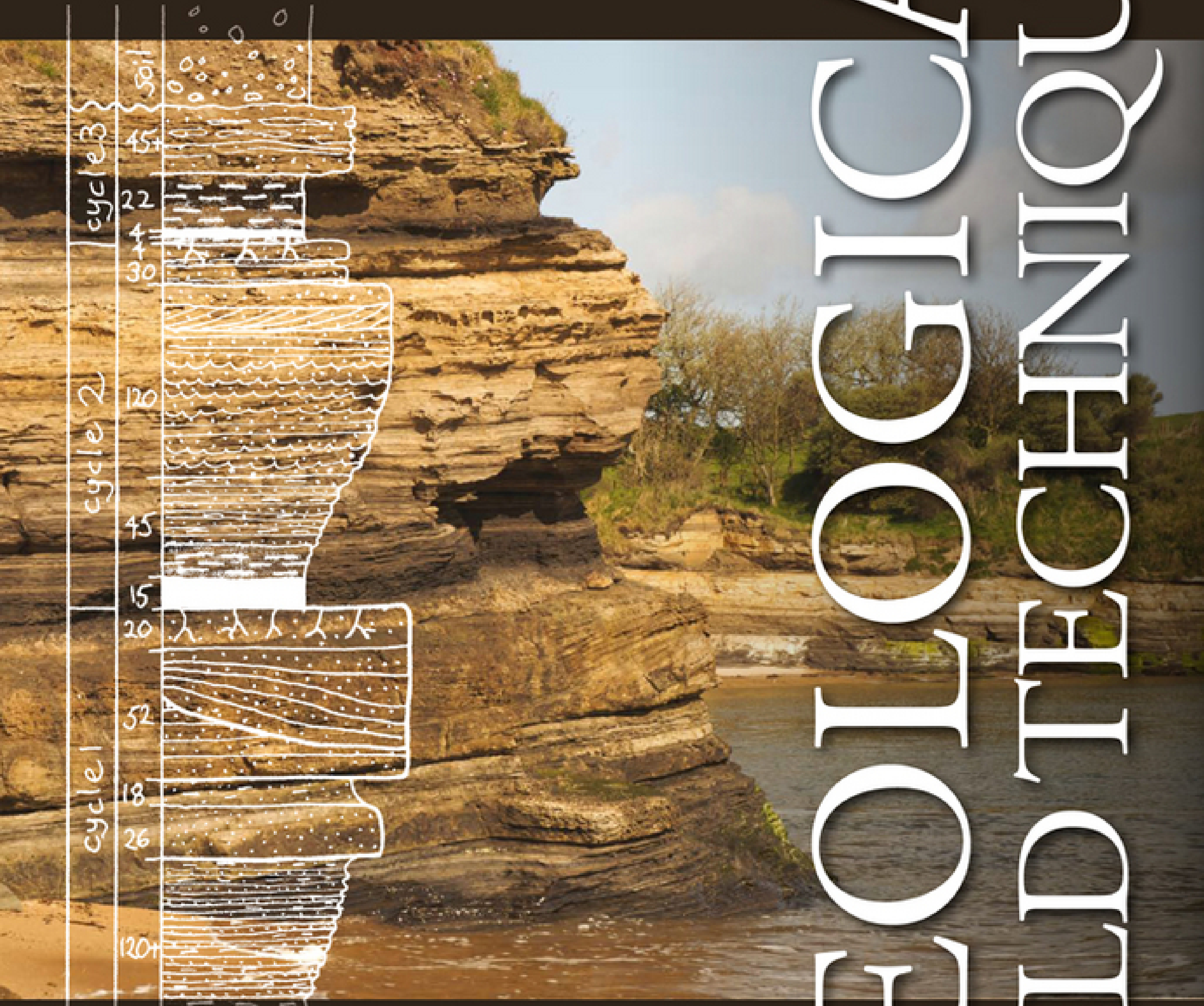
Edited by
ANGELA L. COE

GEOLOGICAL FIELD TECHNIQUES



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Cartoons by Ian Wightman

Front cover image: Carboniferous age (Namurian) rocks exposed at Sugar Sands Bay, near Alnwick, Northumberland, UK. These are part of a succession of rocks interpreted as infill of an interdistributary bay or lagoon along the shore of a delta. Superimposed on the photograph is part of a graphic log of the succession summarizing the thickness of the units, lithology, sedimentary structures and cycles. (Angela L. Coe, The Open University, UK.)

Back cover images (in descending order):

1. Walcott Quarry, Canadian Rockies during 1998 showing the exposure of the Burgess Shale (Cambrian) that is famous for the exceptional soft body preservation of some of the oldest fossils on Earth. (Angela L. Coe, The Open University, UK.)
2. Geologists working on the organic-rich mudrocks of the Monterey Formation (Miocene), Naples Beach, California, USA. (Anthony S. Cohen, The Open University, UK.)
3. Asymmetric folds in Proterozoic strata, Harvey's Return, Kangaroo Island, Australia. Lens cap is 5.5 cm across. (Tom W. Argles, The Open University, UK.)
4. A Silva compass-clinometer being used to measure the dip of a fault plane, Whitesands Bay, St David's, Wales, UK. (Tom W. Argles, The Open University, UK.)
5. The ammonite *Psiloceras planorbis* (J. de C. Sowerby) from the Lias Group, UK. This species defines the lowermost ammonite zone of the Jurassic. Ammonite is *c.* 4 cm across. (Peter R. Sheldon, The Open University, UK.)

Companion Website: A companion resources site for this book is available at www.wiley.com/go/coe/geology

With:

- All figures and tables from the book
- Additional excercises and answers
- Useful websites, selected by the authors

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Preface

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 unspoilt 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.

This book is aimed primarily at undergraduates studying geology and Earth sciences. It will also potentially be of use to engineers, archaeologists and environmental scientists who need to collect information on the bedrock. The increasingly multidisciplinary nature of science will make the text useful to masters, doctoral and professional scientists who do not have a background in practical geology or Earth science. The book is non-site specific and includes examples from around the world. There are chapters covering data collection from igneous, metamorphic and sedimentary rocks as well as specific chapters on palaeontological and structural data collection. It also deals with the basics of geological mapping.

The book assumes a basic understanding of the main concepts and theory in geology. It assumes that the reader is familiar with: the major rock-forming minerals, how to identify minerals in hand specimen, rock classification, geological processes and common geological terms. The further reading lists at the ends of the chapters provide a selection of introductory geological texts as well as more specialist ones. In addition there are appendices summarizing key geological features and classification schemes. There is also an accompanying website (www.wiley.com/go/coe/geology) with all of the figures, tables, links to other websites and other material. Reviews of the original book proposal suggested expansion of certain chapters and even the deletion of others, however, none of the reviewers agreed on which chapters these should be so clearly it is a matter of personal preference. We have therefore kept to the broad overview, and refer the reader to more specialist fieldwork texts that are available, and hope that this book inspires others to write textbooks on more specific fieldwork topics that are not available.

Writing a book on field techniques has long been an ambition of mine; the style and organization has had a lengthy gestation period during many months of fieldwork, both as a researcher and a university lecturer. I am delighted that when I was eventually able to spend some time completing this task I was joined by a number of colleagues who had expertise that complemented my own; it has been a pleasure to work with them. I would like to thank all the colleagues, PhD students and undergraduate students that I have worked with. My experience of being with them in the field has helped me to shape this book.

Wishing you both enjoyable and highly productive fieldwork.

Angela L.Coe
The Open University, November 2009

Acknowledgements

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We are very grateful to Tiffany Barry, Kate Bradshaw, Richard Brown, Brian McDonald, Susan Ramsay, Janet Sumner, Paul Temple and Clare Warren, all of whom were brave enough to lend us their field notebooks for reproduction in this book. We are also grateful to Kate Andrew and Susie Clarke who kindly allowed us to copy part of their geological field and fair copy maps. The unpublished field notes of these individuals are accredited in the figure captions.

Many thanks go to Ian Wightman whose inspiring and amusing cartoons have livened up this book. Andrew Tindle (The Open University) is thanked for his excellent photography of most of the hand specimens (particularly Chapters 8 and 9) and for providing a set-up for photographing specimens and field notebooks. Various colleagues have allowed us to reproduce their photographs in this book, for which we are grateful. These individuals are acknowledged in the figure captions. Andrew Whitehead and David DuPlessis with the help of Chris Hough and Jon Owen (The Open University) prepared the final version of the figures. Richard Howes is thanked for general assistance with the electronic files. We are grateful to Andrew Lloyd for help with scanning, image processing and also for contributing to the design and preparation of the cover image for this book.

We are grateful to all of the anonymous academic reviewers contacted by Wiley-Blackwell and Cambridge University Press who provided feedback and ideas on the book proposal. Susan Ramsay (University of Glasgow), Ian Parkinson (The Open University), Clare Warren (The Open University) and two anonymous reviewers contacted by Wiley-Blackwell are thanked for their comments on earlier versions of this manuscript.

Last, but not least, we would like to thank our field colleagues, and students, for interesting and stimulating discussion in the field.

Figure acknowledgements

Grateful acknowledgement is made to the following sources for previously published figures (for full references see pp. 261–262):

Map extracts in Figures 2.11, 2.12, 10.1a, 10.1b and 10.5. Reproduced with permission of the Ordnance Survey on behalf of Her Majesty's Stationary Office. © Crown Copyright 2010. All rights reserved; Figure 5.13: Spicer, R. A., and Hill, C. R. 1979. 'Principal components. …',Review of Palaeobotany and Palynology. Elsevier Inc; Figure 6.10: Coe, A. L. 1996. 'Unconformities within. …',in Special Publication No. 103, 1996. The Geological Society, London; Figures 6.13b and 6.14: Alexander, J. 1992. 'Nature and origin of. …', Journal of the Geological Society, Vol 149. Copyright © 1992 The Geological Society; Figure 7.16: Lippard, S. J. *et al*. 1986. The Ophiolite of Northern Oman. Copyright © 1986 The Geological Society; Figure 10.2b: Watts, D. R. *et al*. (2005) 'Mapping granite and. …', Geological Society of

1 Introduction

Angela L. Coe

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.

This book is divided into 14 chapters. Chapter 2 covers the most commonly used field equipment and outlines field safety procedures. Chapter 3 explores the general objectives of fieldwork and how to make a start. Chapter 4 is devoted to the production of a field notebook (hard copy or electronic), as this is the key record of geological field data. The bulk of the book comprises five chapters covering the necessary skills for the collection of palaeontological (Chapter 5), sedimentological (Chapter 6), igneous (Chapter 7), structural (Chapter 8) and metamorphic data (Chapter 9). Chapter 10 uses the field techniques covered in the previous five chapters to introduce geological mapping, where it is usually necessary to deal with a range of rock types and different kinds of exposure*. The book concludes with short chapters on recording numerical and geophysical data (Chapter 11), photography (Chapter 12) and sampling (Chapter 13).

Figure 1.1 (a) Geologists collecting data for a graphic log (Section 6.3) 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 (Section 2.12 and Chapter 13). (a and b: Angela L. Coe, The Open University, UK.)

(a)

(b)

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.

This book deals with challenges 1, 2 and 3. Challenge 4, interpreting the observations, is to a large extent a matter of experience and having a good theoretical understanding of geology and geological processes. There are many general geological and Earth science textbooks on the market, a selection of which are included in the further reading lists at the end of each chapter. Deciding what data to collect relates directly to the objective of the fieldwork (Chapter 3). Some typical overall objectives are: constructing the geological history of a region (Chapter 10), collecting data on a period of climate change (Chapter 6), gathering evidence for a mass extinction event (Chapter 5), understanding a phase of igneous activity (Chapter 7) or mountain building (Chapters 8 and 9), together with finding and evaluating mineral or water resources and understanding natural hazards (e.g. landslides, earthquakes and fl oods; Chapters 6 and 8). Within each of these major objectives the fieldwork should be broken down into achievable daily tasks. Locating the most suitable exposures is crucial if the objective of the fieldwork is anything other than detailed mapping where ideally all exposures need to be examined. The different types of exposure are dealt with in Chapters 3 and 10, and more specific examples are given in Chapters 5 – 9. Throughout the book, but particularly in Chapter 4, we have provided ideas and examples for constructing effective field notebooks. We have also added practical tips in the margin, and fl owcharts for deductive thinking processes and tasks. In Chapters 5 – 10 we have used worked examples to demonstrate both the method of reasoning and the way in which particular problems have been tackled.

1.1 A selection of general books and reference material on geology

Allerby, M. 2008. *A Dictionary of Earth Sciences*, Oxford University Press, 672 pp.

Bishop, A., Woolley, A. and Hamilton, W. 1999. *Minerals, Rocks and Fossils*, Cambridge University Press, 336 pp. [Small book with colour photos and brief, reliable descriptions of minerals, rocks and fossils.]

Cockell, C., Corfield, R., Edwards, N. E. and Harris, N. B. W. 2008. *An Introduction to the Earth - Life System*, Cambridge University Press and The Open University, 328 pp. [Full colour book covering Earth system science at the Earth ’ s surface with particular reference to life systems.]

Grotzinger, J., Jordan, T. H., Press, F. and Siever, R. 2006 .*Understanding Earth* (5th edition) W. H. Freeman & Co., 670 pp. [An outstanding, clearly written, widely used introduction to Earth sciences with many colour illustrations providing a global perspective.]

Keary, P. 2005. *Penguin Dictionary of Geology*, Penguin, 336 pp.

Murck, B. W. 2001. *Geology: A Self - teaching Guide*, John Wiley & Sons, 336 pp.

Rogers, N. W., Blake, S., Burton, K., Widdowson, M., Parkinson, I. and Harris N. B. W. 2008. *An Introduction to Our Dynamic Planet*, Cambridge University Press and The Open University, 398 pp. [Full colour book covering the solid Earth aspects of Earth system science, including planetary formation, the Earth ’ s structure, plate tectonics and volcanology.]

Rothery, D. A. 2010. *Teach Yourself Geology* (4th edition), Hodder and Stoughton, 288 pp. [Covers all of the basics and is useful as either a primer or a refresher.]

Stanley, S. 2005. *Earth System History*, W. H. Freeman & Co., 567 pp. [Accessible look at the Earth as a system. Extensively illustrated in full colour.]

1.2 Books on geological field techniques

Compton, R. A. 1985. *Geology in the Field*, John Wiley & Sons, 398 pp. [Comprehensive but dense black and white book on basic geology and field techniques. Replacement of Compton ’ s *Manual of Field Geology* (1962).]

Freeman, T. 1999. *Procedures in Field Geology*, Blackwell Science, 93 pp. [Pocket sized, black and white book covering mainly mapping techniques, with particular emphasis on compassclinometer and trigonometric solutions for recording the geometry of geological features.]

Maley, T. S. 2005. *Field Geology Illustrated*, Mineral Land

Publications, 704 pp. [Book illustrating geological features and terms through hundreds of clear black and white photographs and line drawings.]

See also: Barnes and Lisle 2003 (Section 10.7); Fry 1991 (Section 9.5); McClay 1991 (Section 8.4); Stow 2005, Tucker 2003 (Section 6.6); and Thorpe and Brown 1991 (Section 7.5).

* The term exposure is used to indicate areas where rocks are visible at the Earth ’ s surface. This is in contrast to the term outcrop which also encompasses those areas

where the rock is at the Earth ’ s surface but is covered by superficial deposits and soil.

2

Field equipment and safety

Angela L. Coe

This chapter 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 within Chapters 5 – 10 where appropriate. Sampling is covered as a separate topic in Chapter 13 and photographic equipment is briefly reviewed in Chapter 12. All the health and safety notes provided in this book are generic. Other sources and regulations will need to be consulted and followed depending on the field area, the country, the nature of the fieldwork and the regulations of your employer or educational institution.

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 on p. 6. Optional equipment and that needed for more specialist tasks is listed in Table 2.3 on p. 6.

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.

Table 2.1 Equipment required for most geological fieldwork. Clothing and safety equipment is discussed in Section 2.11 .

Essential field equipment
Field notebook
Pencils, eraser, pencil sharpener
A few coloured pencils
Tape measure, surveyor ’ s tape or folding ruler
Hand lens
Compass - clinometer
Comparison and identification charts appropriate to the task
Relevant topographical maps
First aid kit and any personal medical supplies that might be required
Backpack/rucksack
Food and water sufficient for the fieldwork period
Emergency food supplies
Suitable clothing and footwear
Spare clothing and/or sunblock as appropriate
Mobile phone, radio or satellite phone
Safety equipment as appropriate

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 a 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 × magnification and some contain both a 10 × and a 15 × or 20 × 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 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.

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.

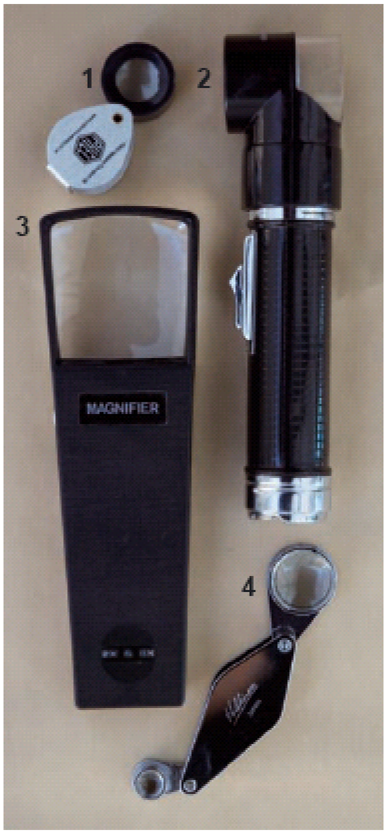

Figure 2.2 Photograph to show correct use of the hand lens. Note that the person is holding the lens close to his eye. The lens is fastened on a lanyard around his neck for ease of access and use.

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, pp. 8 – 9): 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 Brunton - type can also be used for more tasks (see below); however, it is bulkier, more expensive and for some functions more difficult to use. 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 (Section 2.3.3). 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 ° (= 360 °). 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). Note that because the azimuth scale is fixed in the Brunton - type and the needle moves relative to this the compass is numbered and labelled anticlockwise. The azimuth for the direction in which the long sight on the Brunton - type is pointing (Figure 2.3b) is the reading at the north end of the compass needle. Compass directions from north can either be reported approximately, e.g. northwest, east, etc., or to the nearest degree. The Brunton - type compass also has a built - in locking pin for the magnetic needle to temporarily hold the needle in place when a reading is taken (Figure 2.3 c).

Table 2.2 Typical sampling equipment. See also Chapter 13 .

Sampling equipment
Geological hammer
Sample bags
Paper, cling film or bubble wrap to wrap delicate samples
Marker pens/tile scribe/correction fluid for labelling
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 (Chapter 11)
Penknife
Weak hydrochloric acid (*c.* 10%)
Clipboard or mapping case
Rule and protractor